An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy

WA-RD 765.1

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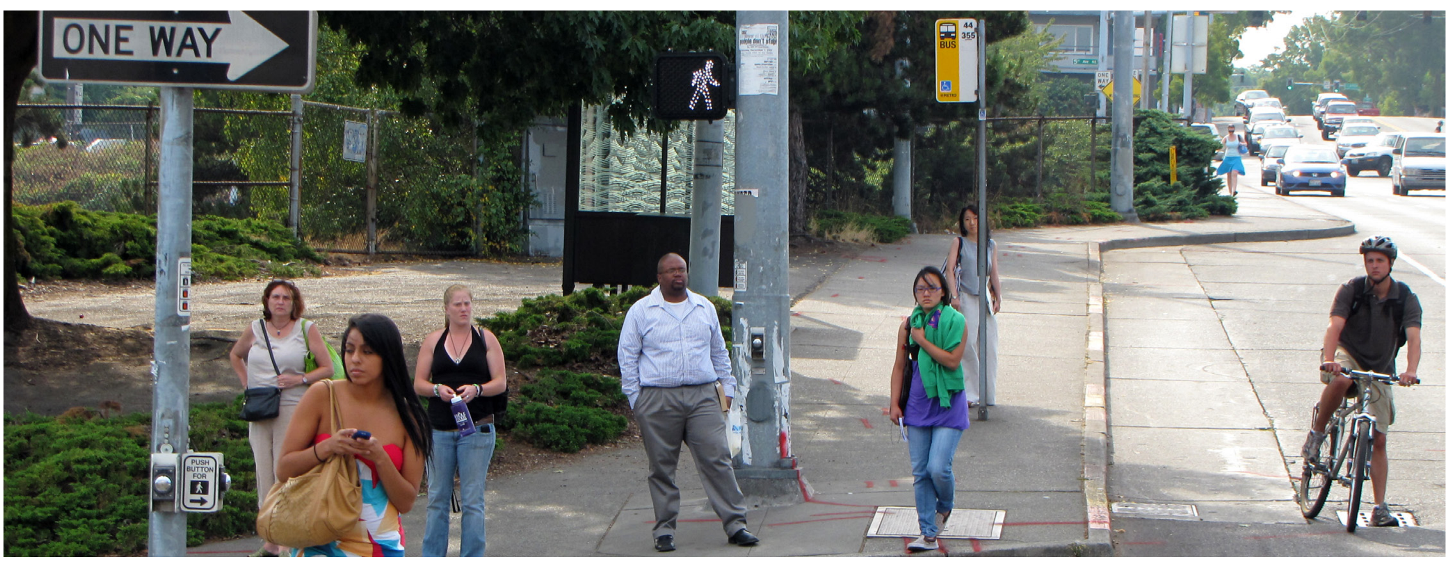
April 2011



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Impact Vehicle Miles Traveled through
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AN ASSESSMENT OF URBAN FORM AND PEDESTRIAN AND TRANSIT IMPROVEMENTS AS AN INTEGRATED GHG REDUCTION STRATEGY

by

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16. ABSTRACT:

This study is one of the first to test the effect of sidewalks on travel patterns and the first we know of to relate sidewalk availability with VMT and GHG emissions. Recently, several large jurisdictions in King County have developed local sidewalk data layers, creating a new opportunity to look at pedestrian infrastructure alongside other investment and policy strategies associated with reduced VMT and CO2. The study used travel outcome data from the 2006 PSRC Household Activity Survey. The household-level analysis was restricted to households in King County cities where sidewalk data was already available, and modeled the association of urban form, pedestrian infrastructure, transit service and travel costs on VMT and CO2, while controlling for household characteristics known to influence travel.

The results provide early evidence in the potential effectiveness of sidewalks to reduce CO2 and VMT, in addition to a mixed land use pattern, shorter transit travel and wait times, lower transit fares and higher parking costs. However, the lack of ability to collect sidewalk data from across all of King County limited the study results. The sample population was lacking in variation and skewed towards the more urban and walkable parts of King County. This contributed to difficulties with multicollinearity in the modeling process, which in turn may have limited the significance of other urban form variables that have been repeatedly associated with travel outcomes in other King County studies. This study is, however an important first step towards a more complete understanding of how pedestrian investment, urban form, transit service and demand management (pricing) policy can interact to meet the state's goals for VMT reduction. The inclusion of sidewalk data from across the entire county or region will provide further, and more conclusive insights.

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EXECUTIVE SUMMARY

In the last several years, Washington State has adopted a series of policy goals intended to reduce greenhouse gases (GHGs). Because transportation is one of the state's largest sources of GHG emissions, the Washington State Department of Transportation (WSDOT) has been asked to identify ways to reduce Vehicle Miles Traveled (VMT) statewide, and subject to a separate set of state-mandated goals for VMT reduction. Other local governments, such as King County and the City of Seattle, have established their own goals.

This study is one of the first studies to test the effect of sidewalks on travel patterns and the first we know of to relate sidewalk availability with VMT and GHG emissions. It has long been assumed that a more complete pedestrian network would be associated with more walking. Years of research have established the basic relationship that exist between the built environment and transportation behavior – a walkable, transit-oriented urban form is overall associated with less driving and more walking and transit use. However, few studies have looked at the potential effectiveness of objectively measured pedestrian infrastructure as a strategy to reduce VMT due the lack of consistently collected data on sidewalks and other pedestrian facilities. Recently, several large jurisdictions in King County have developed local sidewalk data layers, creating a new opportunity to look at pedestrian infrastructure alongside other investment and policy strategies associated with reduced VMT and CO_2: urban form, transit service and fares, and parking costs.

The study relied on travel outcome data from the 2006 PSRC Household Activity Survey, a recent two day travel survey of the 4-county Puget Sound Region. The household-level analysis was restricted to households in King County cities where sidewalk data was already available: over 70 percent of the King County Activity Survey participants drawn from 9 of the most populated cities in King County. The analysis modeled the association of urban form, pedestrian infrastructure, transit service and travel costs on VMT and CO_2, while controlling for household characteristics (such as household size, income and number of children) known to influence travel.

The results provide early evidence in the potential effectiveness of sidewalks to reduce CO_2 and VMT, in addition to a mixed land use pattern, shorter transit travel and wait times, lower transit fares and higher parking costs. Sidewalk completeness was found to be marginally significant (at the 10 percent level) in reducing CO_2, and insignificant in explaining VMT. Increasing sidewalk coverage from a ratio of .57 (the equivalent of sidewalk coverage on both sides of 30 percent of all streets) to 1.4 (coverage on both sides of 70 percent of all streets) was estimated to result in a 3.4 percent decrease in VMT and a 4.9 percent decrease in CO_2. Land use mix had a significant association with both CO_2 and VMT at the 5 percent level. Parking cost had the strongest associations with both VMT and CO_2. An increase in parking charges from approximately \$0.28 per hour to \$1.19 per hour (50^{th} to 75^{th} percentile), resulted in a 11.5 percent decrease in VMT and a 9.9 percent decrease in CO_2.

The lack of ability to collect sidewalk data from across all of King County limited the study results. The sample population that resulted was lacking in variation and skewed towards the more urban and walkable parts of King County. This contributed to difficulties with multicollinearity in the modeling process, and may have limited the significance of other urban form variables (such as residential density and intersection density) that have been repeatedly associated with travel outcomes in other King County studies. This study is an important first step towards a more complete understanding of how pedestrian investment, urban form, transit service and demand management (pricing) policy can interact to meet the state's goals for VMT reduction. The inclusion of sidewalk data from across the entire county or region will provide further, and more conclusive insights.

Based on the study results, the research team also developed and tested a simple spreadsheet tool that could be used in repeated applications to estimate the potential reduction in CO2 and VMT due to urban form, sidewalk coverage, transit service and travel cost changes. The spreadsheet could be used in a number of contexts where scenario analysis or impact assessment is appropriate – for example, comprehensive or neighborhood planning, transit-oriented development, or transit corridor planning. The tool was applied in three scenarios in two Seattle neighborhoods – Bitter Lake and Rainier Beach. Rainier Beach is the location of a new light rail (LRT) stop, while Bitter Lake is along a forthcoming bus rapid transit (BRT) service corridor, and both have a large degree of potential to transition into more walkable, transit supportive areas in the future. The results of the scenario testing indicates that current policy will produce small decreases in VMT and CO2: a nearly 8 percent decrease in VMT, and a 1.65 percent decrease in CO2 for Bitter Lake; and a 6.75 percent decrease in VMT and a 2.2 percent decrease in CO2 for Rainier Beach. These numbers indicate that more investment in pedestrian infrastructure and transit service will almost certainly be needed in order to meet stated goals for VMT and CO2 reduction. A scenario was developed that was focused on VM2 / CO2 reduction – complete sidewalk coverage, decreases in transit travel time and cost, and increases in parking costs, and slight adjustments to the mix of land uses. In total, these changes resulted in a 48 percent VMT reduction and a 27.5 percent CO2 reduction for Bitter Lake, and a 27 percent VMT reduction / 16.5 percent CO2 reduction for Rainier Beach – substantial departures from the trend that begin to illustrate what might have to happen in order to reach stated goals for VMT reduction.

1. INTRODUCTION & BACKGROUND

1. 1. Problem Statement

Land use and transportation research consistently identifies urban form, transit service, and pedestrian infrastructure as key factors associated with travel behavior characteristics, including vehicle miles traveled (VMT) and associated greenhouse gas emissions (GHG). In practice, planners and decision-makers look to a combination of all three strategies in order to create places that promote walkability and are less reliant on automobile transportation.

Generally, sufficiently complete data on neighborhood urban form characteristics like density and land use mix, and transit service and regional access are readily accessible or can be generated at an appropriate analytical scale for many urban regions. Complete city - or region-wide pedestrian infrastructure data (e.g. sidewalks), however, remains limited in many jurisdictions, since measurement is time-consuming, non-standardized, and difficult. This has restricted the available research on pedestrian facilities to ad hoc neighborhood comparisons, from which it is difficult to generalize broader policy implications. The lack of available pedestrian infrastructure data has also inhibited integrated analyses with urban form and transit service variables as related to vehicle use and emission generation.

New sidewalk inventories now available in a number of King County Washington cities, and the development of detailed estimates of carbon dioxide (CO_2) – a major contributor of greenhouse gas emissions – from transport, have enabled the ability to assess how combined investments and policy changes could impact non-auto mobility and reduce related GHG emissions.

1. 2. Project Objectives

The approved technical aims of this applied research effort were threefold:

1. **Develop** a method to assess the association between VMT and CO_2 emissions and three principal strategies: a) connectivity and completeness of pedestrian infrastructure; b) urban form strategies such as compactness of and proximity between complementary land uses, and levels of street network connectivity; and c) quality of transit service. The analysis will control for other influences on household VMT and CO_2 generation, such as household sociodemographic characteristics.
2. **Analyze** the association between the three principal strategies (sidewalk connectivity, urban form, and transit service) and CO_2/VMT. Multiple variables will be tested within each of the three principal strategies; the final model results will retain only the most important and effective strategies.
3. **Apply** the results of the statistical analysis in two neighborhood scale case study locations in Seattle and generate a comparison between base case or current conditions and one "smarter growth" alternative. The model will break out the impact of each particular independent variable on CO_2/VMT so that it is possible to see the separate, proportional impact in CO_2/VMT produced by the change in each input variable.

Specific products developed from this research effort include:

1. **Elasticity factors**, derived from project-specific statistical models, to express how much of a change in a given outcome (i.e. VMT or CO_2) is estimated to be associated with a change in an independent variable of interest (i.e. urban form, pedestrian facilities, transit service). Analytical results described in this format provide a readily clear and policy-relevant means of understanding how general land use decisions and transportation investments may support

or detract from VMT and CO_2 reduction targets.

2. **A predictive analytical tool**, developed using project-specific model results, to enable a flexible and robust evaluation of how alternative development approaches or transportation investments, particularly at the urban village, neighborhood, or station area scale, impact vehicle miles traveled and associated levels of carbon dioxide emissions.

1.3. Policy Context

Emissions from personal vehicle transport are a large and growing share of total GHG emissions in Washington. Statewide, the transportation sector currently accounts for approximately 45% of total GHG emissions, with 73% of these emissions resulting from passenger cars and trucks fueled by gasoline and diesel[1]. By 2020, statewide transportation emissions are anticipated to account for nearly 57% of total emissions[2], driven largely by population and employment growth in urban areas and associated increases in travel demand.

Aggressive GHG reduction targets have been established across many state sectors and agencies. The adopted 2008 State Climate Change Framework (E2SHB 2815) has set a total GHG emission reduction target of 50% below 1990 levels by 2050[3]. At the local level, the City of Seattle Climate Protection Initiative aims to reduce citywide greenhouse gases by 80% below 1990 levels by 2050[4]. Targeted initiatives to help achieve such goals are now central components of many current policy initiatives. In King County and the larger Puget Sound Region new transportation (i.e., PSRC Transportation 2040) and growth management plans (i.e., PSRC Vision 2040 and King County Comprehensive Plan, 2010 Update) are centered around the prioritization of investments in compact and walkable built environment services by efficient and accessible public transit and non-motorized networks.

Washington State has explicitly legislated the integration of GHG emission targets into the transportation planning process. Specifically, legislation directs the Washington State Department of Transportation (WSDOT) to adopt operational goals that reduce per capita VMT from a baseline of 75 billion annual vehicle miles by 50 percent by 2050, with interim targets of 18 percent by 2020 and 30 percent by 2035 (RCW 47.01.440). Local planning and transportation agencies are now required to have appropriate capacity to monitor and assess how specific investments and development initiatives like rail development, corridor planning, and neighborhood redevelopment may affect emission generation, adversely or otherwise.

WSDOT is in the process of developing the analytical tools and evaluative processes that will be necessary to address the emission reduction goals with which they are charged. This includes working together with other state agencies and MTPOs to develop plans and strategies to meet these goals, pursuant to the Governor's Executive Order on Climate Change 09-05. This situation suggests tools and methodologies are needed to help better position state DOTs, regional MPOs and local governments to assess and monitor the emission implications of transportation investment and land development decisions.

2. REVIEW OF PREVIOUS WORK

2.1. Relevant National and International Research

The land use and transportation literature consistently finds multiple urban form, regional accessibility, and transit service characteristics to be significantly associated with daily travel behavior outcomes, including VMT.[5] Generally, development patterns that 1) concentrate trip ends (e.g. origins and destinations) within walking and cycling distance to neighborhood destinations or to transit facilities for regional movement, 2) create a functional mix of land uses (e.g. live, work, play activities), and 3) have interconnected street networks are consistently and significantly associated with less driving[6], more walking[7] and transit use.[8] Elasticities between urban density and VMT on the order of -0.30 have been demonstrated in many studies.[9] Significant associations have been observed even after controlling for individual travel and residential location self-selection attributes and other attitude and preference metrics, suggesting a certain degree of causality in effect.[10,11, 12,13]

Travel-related GHG emission reductions associated with compact and walkable built environment characteristics are potentially significant.[14] Ewing et al's "Growing Cooler" study suggested that if 60-90 percent of new growth in the United States occurs in compact, walkable, transit-accessible form, VMT would decrease by 30 percent and nationwide transport-related CO_2 emissions will be reduced by 7-10 percent by 2050, relative to a trend line of continued low-density, single-use development.[15] Growth and development scenarios for 142 U.S. cities indicate that comprehensive compact development could reduce cumulative emissions by up to 3.2.GtCO_2e (or 15-20 percent of projected cumulative emissions) by 2020, in combination with more efficient vehicles and lower-GHG fuels.[16] However, a recent TRB research report found the nationwide GHG impacts of compact development to be much more moderate, with reductions in CO2 ranging from less than 1 percent to 11 percent in 2050.[17] Regional household location and accessibility measures (e.g. distance and travel times to major population and employment centers in a region) have been found to exhibit greater magnitudes of effect on travel-related GHG emissions,[18] suggesting that GHG reduction may be best achieved through a mixture of local and regional investments and actions.

Comprehensive research on the relationship between pedestrian infrastructure and travel-related outcomes remains limited, largely due to a lack of detailed and objectively measured data on sidewalk and other pedestrian supportive facilities, which inhibits citywide or region-wide analysis.[19,20] However, several region-wide scale studies that include pedestrian facilities have recently emerged. An 11-country study of physical activity and the built environment found that self-reported sidewalk presence was the single biggest factor in influencing physical activity. People located in urban neighborhoods who report they have sidewalks were between 15-50 percent more likely to get at least 30 minutes of moderate-to-vigorous activity at least five days a week.[21] An increased prevalence of sidewalks was demonstrated to yield the largest "return on investment" to reduce VMT and increase walking and cycling in Dane County, Wisconsin.[22]

Taken collectively, urban form, regional and transit accessibility, and pedestrian infrastructure characteristics all exhibit a significant degree of effect on VMT and CO_2 across a number of studies. These factors are often highly correlated with one another: where urban form is more pedestrian-friendly, there are often higher-quality pedestrian facilities and better transit service.[23,24] Because this multicollinearity between variables that are included in the same predictive model may produce large confidence intervals and inappropriately signed coefficients, composite measures of neighborhood "walkability"[25,26] or "accessibility"[27] that integrate multiple built environment factors into a single score or measure have been developed and applied in previous research. However, these strategies eliminate the possibility of analyzing the effects of individual components of an index (e.g. comparing the effectiveness of land use mix vs. the effectiveness of residential density), limiting the direct policy-relevance of many research findings.

2.2. Relevant Research in Washington State

The consultant team (Urban Design 4 Health, or UD4H) has been involved in several projects looking at VMT and CO_2 generation from household travel in the King County region. UD4H originally modeled CO_2 emissions from transport as part of the LUTAQH (Land Use, Transportation, Air Quality and Health) study, which examined the influence of urban form on CO_2 from transport. [28] HealthScape, the follow-up study to LUTAQH, updated these findings and integrated them into an existing scenario planning model called I-PLACE3S.[29] In June 2009, the consultant team, with support the Puget Sound Clean Air Agency and the Center for Clean Air Policy, completed a study under review by the Brookings Institution using King County as a case study. This study looked at the magnitude of changes in urban form and transit service that would be necessary to achieve targets for transportation related CO_2 emissions 2050, given improvements in vehicle and fuel technology. The study concluded that large changes in technology, land use patterns and transit service levels would all be necessary to achieve a high likelihood of meeting the targets; no single strategy provided enough leverage in itself. [30] Building on these ideas, King County funded the consultant team to develop a model to predict the mean amount of CO_2 emissions from transport per household for each block group in King County. The results of this work are being used by King County and the City of Seattle in its

GHG mitigation and development review process under the State Environmental Policy Act (SEPA). The research took into account household demographic factors, regional accessibility (measured by average travel time to 13 regional CBD areas by car and by transit), transit service (measured by number of bus door openings per block group), and local urban form measures (measured by residential density, mixture of uses, retail floor area ratio and intersection density within one kilometer along the travel network from the location of the household).

3. RESEARCH APPROACH & PROCEDURES

3.1. Project Approach

Figure 3.1 illustrates the process used to fulfill the project aims and objectives. Collection of all required data sets was based on availability and access from various sources. Advanced multivariate statistical models were developed and tested to determine the type and magnitude of associations between specified independent variables and VMT and CO_2 outcome measures. Data development and analysis phases were performed in an iterative manner, with model performance guiding the generation of informative, policy-relevant variables to be tested. A predictive spreadsheet tool was created for application in assessing VMT and CO_2 outcomes of different development scenarios in the King County region based on the final model results. Two sample case study areas in the City of Seattle, and associated future built environment scenarios for each, were developed to demonstrate and test the performance the predictive analytical tool.

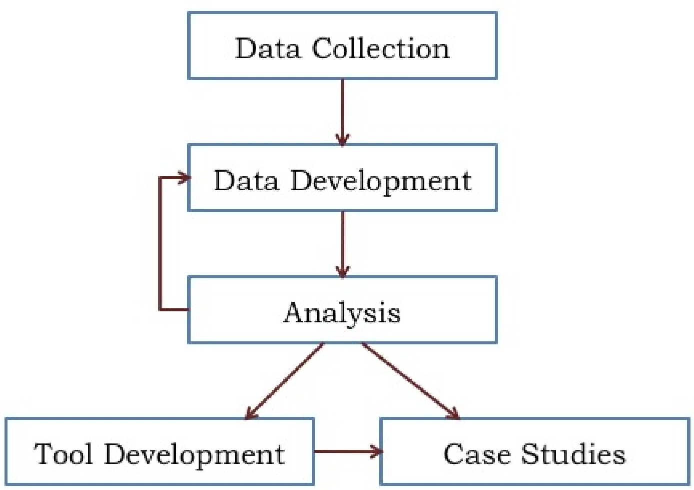


Figure 3.1: Research approach

3.2. Core Data Sources

The analysis utilized travel, emissions, and land use data from King County and the Puget Sound Regional Council. Most of these data sources had already been developed by the consultant team for the previous work in King County. Five primary data sources formed the basis of the analysis:

- The Puget Sound Regional Council (PSRC) 2006 Household Activity Survey, provided by PSRC. This survey was a two consecutive day travel diary of 4,746 households in the four-county region. The 2,699 King County households, and the 45,000+ trips associated with those households, provided the outcome data on CO_2 and VMT for the analysis. CO2 estimates were developed by the consultant team for previous King County projects and are summarized in Appendix A of this report.
- Network travel time matrices by bus and single occupancy vehicle (SOV) travel modes, imputed parking charges and imputed transit fares, for the 2006 four county regional travel network and transportation analysis zone (TAZ) structure. TAZ and network data was provided by PSRC and used to develop measures of travel time, transit service and travel costs used as independent variables in the analysis.
- To develop measures of local transit service, active transit stop and route locations within King County for the February 2006 and June 2006 time periods were used. These stops covered all bus routes by King County Metro, Community Transit and Pierce Transit servicing King County. Using both the February and June datasets accounts for any changes in transit system accessibility during the PSRC travel survey period. King County GIS Data Center and Sound Transit provided this transit data.

- Land use information for the 1-kilometer street network buffer surrounding each household location for participants in the PSRC 2006 Household Activity Survey residing within King County. The parcel data was developed for previous consultant team efforts using parcel-level land use data provided by the King County Tax Assessor. The parcel data, in combination with the County's GIS parcel level land use database, was the primary source of the urban form measures in the analysis. Data from 2006 were used to match the travel survey time period.
- Local sidewalk data represented the major new data collection effort for this study. Sidewalk files for nine municipalities within King County (Bellevue, Bothell, Federal Way, Kent, Redmond, SeaTac, Seattle, Shoreline and Tukwila), provided by the individual jurisdictions in response to requests by Washington State Department of Transportation staff. Figure 3.2 illustrates cities for which sidewalk data was provided (city borders are in black hashed lines; those cities for which sidewalk data was received have green lines within their borders). Specifics on these data sources and methods used to develop the project's master sidewalk database and independent variables to be tested are described in Appendix B of this report. The final household sample used for the project included only those households within King County cities for which we received sidewalk data.

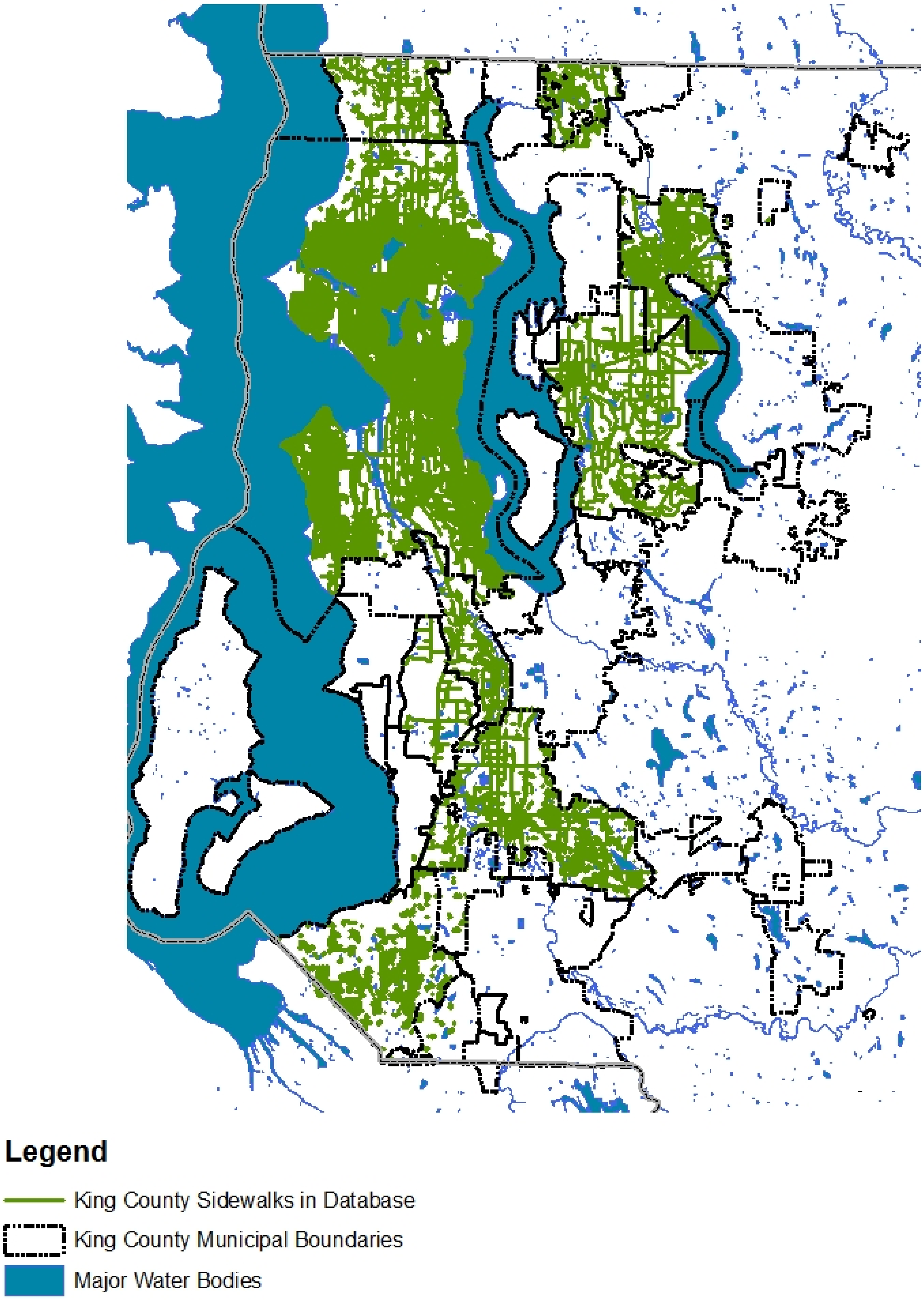


Figure 3.2: Location of King County sidewalks in project database

3.3. Dependent Variables Developed and Tested in Analysis

Estimated household vehicle miles traveled (VMT) and **carbon dioxide (CO_2) per day** – VMT and CO_2 emission estimates previously developed by UD4H for all King County participants in the 2006 PSRC Household Activity Survey were utilized. A detailed overview of the process used to estimate VMT and CO_2 is provided in Appendix A of this report. Briefly, each reported trip completed using a polluting vehicle mode (e.g. Car, Motorcycle, School Bus, Taxi and Public Bus) was assigned to the PSRC modeled road network assuming a shortest time path based on the travel time for the mode and time of day. Trips were then broken into multiple road segments, or "links", according to vehicle type. For each modeled road segment of each trip, CO_2 emission levels were assessed based on a vehicle's travel distance and speed (as determined by the PSRC travel demand model). Road facility type (arterial, freeway, etc), capacity, and estimated traffic volume based on the time of day are all taken into account using the method. Estimates also account for engine temperature (hot vs. cold start) and vehicle occupancy. Vehicle type and acceleration/deceleration data was unavailable for the estimation process. Final VMT and CO_2 variables were generated by calculating the weighted average daily VMT and CO_2 emissions per each household member, and then summing these averages per household.

3.4. Independent (Explanatory) Variables Developed and Tested in Analysis

Independent variables fall into four general categories: (1) neighborhood urban form measures, 2) pedestrian infrastructure variables; (3) transit and regional accessibility variables; (4) cost variables for parking and transit fares; and (5) socio-demographic and household characteristics variables. Each variable category has its own set of assumptions, constraints and methods that go into creating a usable data set on which to base a relevant model.

3.4.1. Neighborhood Urban Form Measures

Neighborhood urban form measures were calculated for the area within 1-kilometer (km) street network-based walk-sheds, or buffers, around each PSRC travel survey household location included in the final study sample. These neighborhood network buffers were developed by UD4H for previous projects and research. The buffer represents the area accessible to pedestrians on the street network within a 6-10 minute walking distance. Figure 3.3 below illustrates a one-kilometer network buffer around a hypothetical activity location. It also shows the difference between radial (crow-fly) and network approaches to establishing neighborhood buffers.

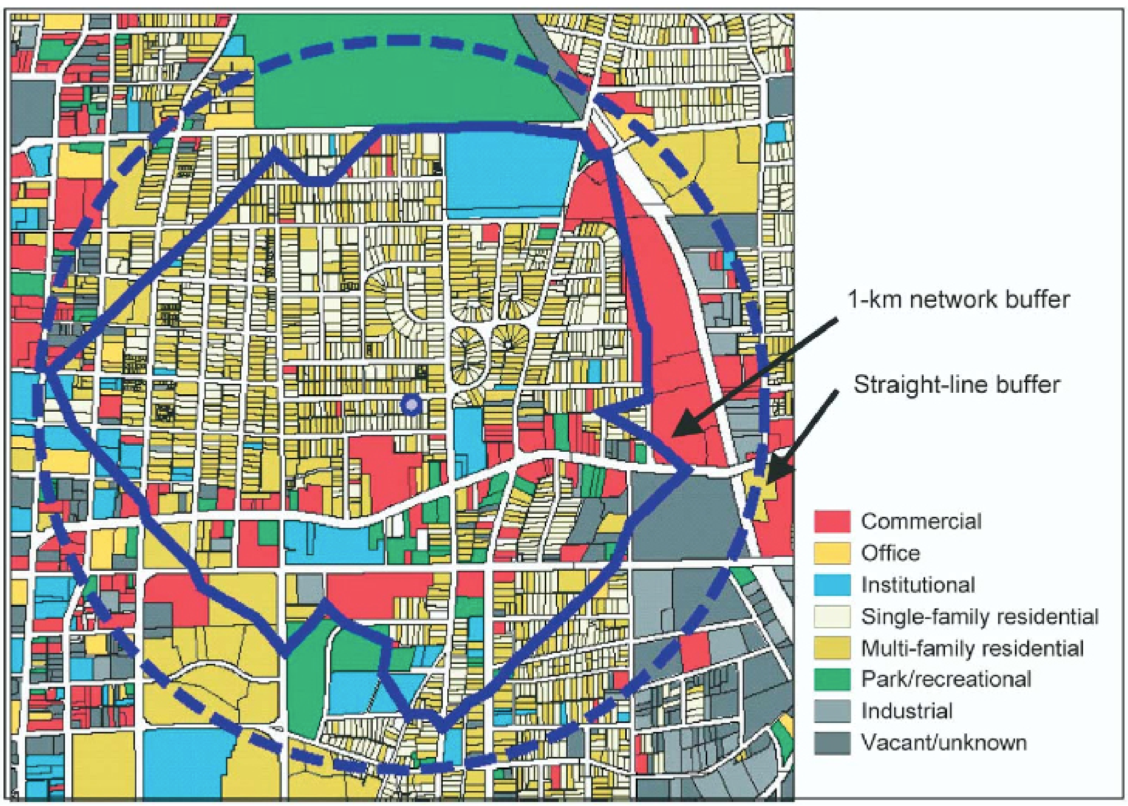


Figure 3.3: Measuring neighbourhood urban form.

The urban form measures developed were:

Net residential density – A measure of residential compactness measured by dividing the total number of dwelling units by the total number of acres designated residential within the 1km network buffer.

Intersection density – An approximation of network connectivity. Calculated by the total number of intersections divided by the total number of square kilometers within the 1km network buffer.

Land use mix – This variable represents a mixed-use index measure based on building square footage of specific land use types. The general formula for calculating the level of land use mix is:

Land Use Mix = -1*A/(ln(n))

where A=(b1/a)*ln(b1/a) + (b2/a)*ln(b2/a) +…+ (bn/a)*ln(bn/a)

a = total square feet of land for all five land uses
b1= square ft. of building floor area in land use type b1
b2= square ft. of building floor area in land use type b2
bn= square ft. of building floor area in land use type n

A value of zero indicates that all the land within the 1km buffer is dominated by a single land use; a value of one indicates equal distribution of square footage across all the land use categories. Two variations on the land use mix variable were generated to maximize statistical significance and meaningful coefficient values across statistical models.

Variation #1, Land Use Mix (including residential uses), represents a mixed-use index measure based on building square footage of civic & education, entertainment, office, residential, and retail uses for the 1km network buffer around household location.

Variation #2, Land Use Mix (excluding residential uses), represents a mixed-use index measure based on building square footage of civic & education, entertainment, office, and retail uses only for the 1km network buffer around household location. The working hypothesis was that a variety of non-residential destinations may be of more influence on household travel behavior than presence of other households.

Other measures of land use mix were also calculated based on 3 and 4 land use types.

Retail floor area ratio - Retail FAR is a ratio of retail building floor area to lot (parcel) area, and measures of the amount of shopping opportunity there is within walking distance of the household location. Multi-story buildings with no surface parking typically have FAR values higher than 1.0, so Retail FAR values higher than 1.0 would be expected in areas with multi-story commercial development (e.g. downtown central business districts). FAR can also be used as a suitable proxy measure of the pedestrian environment, because parcels with low FARs (0.1 – 0.3) tend to be single-story auto-oriented retail surrounded by parking. Retail FAR is calculated using the following formula:

$$\frac{\sum \text{Floor Area for all Retail buildings within 1km Buffer}}{\sum \text{Lot Area for all Retail buildings within 1km Buffer}}$$

3.4.2. Pedestrian infrastructure variables

Pedestrian infrastructure variables were also calculated for the area within pre-established 1-kilometer (km) street network-based buffers around each self-reported household location in the PSRC 2006 Household Activity Survey.

Sidewalk to street ratio - This variable shows the ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within the 1km network buffer. A minimum ratio of 0 means there is no sidewalk coverage in the buffer. The maximum ratio of

2.00 means there is total sidewalk coverage throughout the buffer. A ratio measure is employed to accurately capture the percentage of right-of-way that is traversable by pedestrians. A measure of total linear feet of sidewalk within the 1 km network buffer was considered but determined to be too gross a measure on which to identify any substantial magnitude of effect on the dependent variables.

Signalized intersection density – Calculated by counting the number of signalized intersection locations within each household buffer, then dividing the result of that count by the buffer area (square kilometers). In contrast to general intersection density as a measure of street connectivity, signalized intersection density can serve as a proxy indicator of the ease of street crossing for pedestrians, as traffic signals are generally positioned on larger, arterial streets.

3.4.3. Transit and regional accessibility measures

Number of different transit routes – This variable indicates the number of unique transit routes served by King County Metro, Sound Transit, Community Transit and/or Pierce Transit for the active stops within the 1km household buffer. In contrast to transit stops, this variable represents the variety of unique transit paths within walking distance of the household location.

Jobs / population balance - This variable is a ratio of jobs to population for the census block group where the household is located. This variable measures the balance between the number of residents and the number of employees in a census block group, relative to the average ratio of jobs/housing for all of King County. The formula for calculating the jobs/housing balance index is:

$$1 - [ABS (EMP - k*POP)/(jobs + k*POP)]$$

where ABS is the absolute value of the expression in parentheses, k is the regional ratio of jobs to residents for King County, and EMP and POP are the total block group employment and total block group population, respectively.

Weighted average of transit in-vehicle time – This variable shows the average transit travel time (in minutes) from the Traffic Analysis Zones (TAZ) where home is located to all accessible TAZs within King County, during peak period, by transit. Travel times are estimated from origin to destination TAZ travel time matrices based on the TAZ 2000 zone system, as provided by PSRC. A weighted measure is calculated using the following formula: 0.25 x AM Peak Period Transit In Vehicle Time (Mins) + 0.75 x Mid Day Period Transit In Vehicle Time (Mins). The weighting was established based on the number of daily peak (6) and off-peak (18) service hours as designated by King County Metro.

Weighted average of transit wait time – This variable calculates the average wait time (in minutes) for transit from TAZ where the home is located to all accessible TAZs within King County, during peak period, by transit. Wait times are estimated from origin to destination TAZ travel time matrices based on the TAZ 2000 zone system, as provided by PSRC. A weighted measure is calculated using the following formula: 0.25 x AM Peak Period Transit Wait Time (Mins) + 0.75 x Mid Day Period Transit Wait Time (Mins).

3.4.4. Cost variables for parking and transit fares

Imputed average per-trip household parking charge - An estimate of average per-trip parking charges (in dollars),for each household in the sample, based on imputed TAZ based charges for household trips from PSRC network estimates. Imputed charges are applied without regard to any actual charges paid by the travel respondent, or mode taken (e.g., for transit trips, parking charges are anticipated for what a traveler would have had to pay if the trip had been made as a single occupancy vehicle trip, based on PSRC estimates of hourly charges in the destination TAZ).

Imputed average per-trip household transit fare – An estimate of average per-trip transit fare box charges for each household in the sample, based on imputed TAZ based charges for household trips from PSRC network estimates. Imputed charges are applied without regard to any actual charges paid by the travel respondent, or mode taken (e.g., for private vehicle trips, transit charges are anticipated for what a traveler would have had to pay if the trip had been made as a transit trip, based on PSRC estimates of fare box charges in place in the destination TAZ, adjusting for the time period of the trip (i.e., peak or off peak period).

3.4.5. Socio-demographic and control variables

Total number of persons in the household – Taken directly from a component file of the PSRC 2006 Household Activity Survey.

Total number of workers in the household - Taken directly from a component file of the PSRC 2006 Household Activity Survey.

Total number of children age 16 years or younger in the household - The total number of persons by household identifier with age less than 16 from the PSRC 2006 Household Activity Survey. Since children cannot independently access a vehicle, serving transportation needs of children is a potential source of additional household trips, even when controlling for all other sociodemographic and urban form measures.

Number of vehicles per licensed drivers - This variable was calculated by dividing number of self-reported vehicles per number of licensed drivers in the household from the PSRC 2006 Household Activity Survey. A value of 0 means that there is at least one driver in the household, but no car associated with the household (e.g., someone who lives downtown, but chooses to use the bus or bike/walk).

Household income – Represented by a dummy variable (0 or 1) indicating if self-reported household income from the 2006 PSRC Household Activity Survey was higher than CPI adjusted King County median income (i.e., $64, 324.44; 1=Above Median, 0=At or Below Median.

3.5. Database Development

Households with complete data on all relevant variables were used in the analyses. Complete data across all vehicle use and emission outcome measures, neighborhood urban form measures (including sidewalks), transit and regional accessibility measures, socio-demographic and control variables were required to develop unbiased statistical models. The limiting factor in developing the project dataset was the availability of sidewalk data. The PSRC 2006 Household Travel Survey contains 2,699 King County households distributed across the entire region, reporting 39,297 trips made by a mode for which CO_2 emissions were estimated. For this project, complete sidewalk data was only available for 9 of the most populated cities within King County comprising 71 percent of survey households within King County. The total number of household buffers with valid sidewalk data was 2,006. Upon examination of those 2,006 cases, a source of potential error was identified. Some travel survey participants recorded home locations that which, when plotted, were not strictly within the municipal boundaries of the city that they identified as their home location. For these 77 records, assigning values of sidewalk length would be incorrect, because they were not within the municipality in the first place. Therefore, these 77 records were removed from the data set, leaving a final total of 1,929 eligible households.

3.6. Statistical Predictive Models

Advanced multivariate statistical models were developed and tested to determine the type and magnitude of associations between specified independent variables and VMT and CO_2 outcome measures described previously. Final predictive statistical models took the form of multivariate regression equations that produced both unstandardized and standardized coefficients, and statistical significance scores (i.e., T-scores) to indicate which variables were likely to have a substantial association with household level VMT and CO_2 emissions. Separate models were specified for VMT and CO_2 outcomes in order to determine if variation in type and magnitude of association and overall model performance was present.

3.7. Tool Development

Coefficients and parameters generated from the final statistical models were used to build a predictive, scenario assessment tool documented in an MS Excel spreadsheet. The spreadsheet tool contains all necessary information to estimate household-level vehicle use and related CO_2 emission outputs per unit of time (e.g. kg/day, metric tons/year, etc) and the 95 percent confidence interval around each baseline and forecasted estimate.

3.8. Case Study Testing

Case study neighborhoods were selected by the project's Technical Advisory Committee, in collaboration with the consultant team in order to test and demonstrate the application of a VMT-CO_2 predictive analytical tool. A number of potential sites were considered for the case studies. Priority focus was on identifying locations that met some or all of the following criteria in order to leverage the most policy utility from application of the predictive tool:

1. Capacity to test changes in the independent variables that are the focus of the study, including:
    - Sidewalk coverage. Since most areas of the City have complete sidewalk coverage, there were only a few areas where we were able to test significant increases in sidewalk coverage.
    - Transit service. The case study areas identified by WSDOT and the City had either experienced significant increases in transit service since the 2006 travel survey due to the addition of light rail transit (LRT), or are expecting increases in transit service due to forthcoming bus rapid transit (BRT) service.
    - Urban form (land use mix, residential density, retail FAR, amount of retail, street connectivity).
2. Relevance in terms of timing and ability to shed light on a forthcoming policy / planning decision. The City of Seattle has recently begun the process of updating neighborhood plans for the urban villages. It is therefore possible for the case study results to inform neighborhood planning processes.

4. STATISTICAL MODEL RESULTS

4.1. Sample Descriptives

Summary statistics for the neighborhood urban form measures, pedestrian infrastructure variables, transit and regional accessibility variables, cost variables for parking and transit fares, and sociodemographic characteristics measured for the sample population (n=1,929 households) are presented in Table 4.1. These statistics are assessed relative to the entire set of King County households within the PSRC Household Activity Survey. The distribution of means and one-sample T-tests indicate that household respondents in the project sample population are located in generally more compact, walkable, and centrally situated areas, and travel fewer vehicle miles than the larger King County sample population.

4.2. Final VMT and CO2 Model Results

The final statistical models are Ordinary Least Squares linear regressions, measuring the influence of household socio-demographic traits, urban form measures, transit accessibility and monetary costs of travel (i.e., transit fares and parking charges) on daily household travel related CO_2 and VMT. Table 4.2 presents the final, best-fitted models of household-level VMT and CO_2 for the sample population.

4.2.1. Model Performance

The specified models explain approximately 35.19 percent of the variation in daily household travel related CO_2 generation and 32.23 percent of the variation in daily household VMT generation, respectively, after accounting for the influence of statistically insignificant variables in the model. This share of variation is common to most planning and transportation research aimed at assessing travel behavior.

Table 4.1: Descriptive statistics

	WSDOT Observations Subset					PSRC 2006 Household Activity Survey King County Sample			One Sample T-Test		Indep
	N	Min	Max	Mean	Standard Error	N	Mean	Standard Error	T	Prob.	T
Socio-demographic and control variables											
Total number of persons in the household	1929	1	6	2.09	.026	2699	2.21	.023	**-4.42**	**1.0532E-05**	**-3.31**
Total number of workers in the household	1929	0	5	1.1467	.01926	2699	1.1649	.01636	-0.94	0.3456	-.72
Number of children under age 16 in the household	1929	0	4	.36	.017	2699	.42	.016	**-3.74**	**0.0002**	**-2.73**
Number of vehicles per licensed driver (blank for households with no vehicle)	1857	0	6	1.0501	.01216	2617	1.0976	.01037	**-3.90**	**9.7630E-05**	**-2.97**
Household total income, as reported in PSRC 2006 survey	1693	1	99	7.78	.101	2365	7.92	.085	-1.38	0.1683	-1.06
Neighborhood urban form variables											
Net residential density within 1km network buffer around household location	1928	0.72	269.03	18.7568	.83320	2697	14.6720	.61095	**4.90**	**1.0254E-06**	**3.95**
Intersection density within 1km network buffer around household location	1928	6.11	144.56	66.2696	.54519	2697	57.7676	.50103	**15.59**	**1.0022E-51**	**11.48**
Retail FAR for 1km network buffer around household location	1929	0.00	1.24	.2698	.00400	2699	.2120	.00350	**14.47**	**3.8232E-45**	**10.88**
Mixed use index (based on building sq. ft. of civic & education, entertainment, office, residential, and retail uses) for 1km network buffer around household location	1929	0.00	0.88	0.2781	0.00392	2699	0.2424	0.00351	**9.11**	**2.0558E-19**	**6.78**
Mixed use index (based on building sq. ft. of civic & education, entertainment, office, and retail uses; no residential square footage) for 1km network buffer around household location	1929	0.00	0.75	0.2394	0.00317	2699	0.2084	0.00288	**9.78**	**4.4665E-22**	**7.24**
Pedestrian infrastructure variables											
Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	1929	0.00	2.71	1.1557	0.01294	2012	1.1125	0.01326	**3.34**	**8.5840E-04**	**2.33**
Signalized intersection density within 1km network buffer around household location	1929	0.00	79.67	5.4509	.22572	2699	4.2764	.16667	**5.20**	**2.1671E-07**	**4.19**
Transit and regional accessibility variables											
Number of different bus routes for the active stops within the 1km buffer for the household	1929	0	140	11.86	.492	2699	9.12	.363	**5.57**	**2.8952E-08**	**4.48**
Jobs/housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	1929	0.01	1.00	.3853	.00608	2699	.3775	.00510	1.27	0.2031	.98
Weighted average of bus in-vehicle time	1929	75.25	153.46	99.6090	.41447	2683	108.0355	.49998	**-20.33**	**2.0693E-83**	**-12.98**
Weighted average of bus wait time	1929	5.07	49.78	11.2074	.11609	2683	15.1023	.21153	**-33.55**	**9.1754E-195**	**-16.14**
Travel cost variables											
Imputed average per-trip household transit fare	1871	0.38	5.03	1.5602	0.00617	2612	1.5761	0.00548	**-2.58**	**1.0043E-02**	**-1.93**
Imputed average per-trip household parking charge	1871	0.00	7.79	0.7934	0.02645	2612	0.6560	0.02053	**5.19**	**2.2740E-07**	**4.10**
Outcome variables											
Estimated VMT per day for the household (VMT/day/household)	1929	0.00	190.54	30.1114	.59929	2699	35.3510	.60116	**-8.74**	**4.8385E-18**	**-6.17**
Estimated CO2 per day for the household (gCO2e/day/household)	1929	0.00	74750.81	12821.5805	233.71907	2699	14960.7306	235.94787	**-9.15**	**1.3740E-19**	**-6.44**

Note: T-statistics and associated probabilities in **bold** are significant at the 5% level

Table 4.2. Final VMT and CO_2 model results

Independent (Input) Variables	Household Daily VMT Model (Outliers removed)				Household Daily CO2 Model (Outliers removed)			
	Coefficient	T	Beta	VIF	Coefficient	T	Beta	VIF
1. Total number of workers in the household	**8.8157**	**13.56**	**0.3070**	1.25	**3670.4220**	**14.72**	**0.3258**	1.25
2. Total number of children age 16 or younger in the household	**4.6306**	**6.64**	**0.1440**	1.15	**2148.0400**	**8.03**	**0.1702**	1.15
3. Number of vehicles per licensed drivers (blank for households with no licensed drivers)	**5.2573**	**4.84**	**0.1103**	1.27	**2068.4330**	**4.97**	**0.1106**	1.26
4. Dummy variable indicating household reported higher income than CPI adjusted King County median (i.e., $64,324.44; 1 = Above Median, 0 = At or Below Median)	**3.2460**	**3.50**	**0.0735**	1.08	***624.5501***	***1.75***	***0.0360***	1.08
5. Signalized intersection density within 1km network buffer around household location	0.1900	1.20	0.0769	**10.09**	71.7513	1.18	0.0740	**10.10**
6. Mixed use index (based on building sq. ft. of civic & education, entertainment, office residential, and retail uses) for 1km network buffer around household location	--	--	--	--	**-3890.2870**	**-2.53**	**-0.0702**	1.96
6a. Mixed use index (based on building sq. ft. of civic & education, entertainment, office, and retail uses; no residential square footage) for 1km network buffer around household location	**-10.1157**	**-2.05**	**-0.0579**	1.95	--	--	--	--
7. Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	-1.2152	-1.15	-0.0290	1.56	***-734.6875***	***-1.81***	***-0.0447***	1.55
8. Number of different bus routes served by King County, Community Transit and/or Pierce Transit for the active stops within the 1km buffer for the household	-0.0812	-1.18	-0.0720	**9.06**	-30.8855	-1.17	-0.0697	**9.03**
9. Jobs/housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	-2.9433	-1.53	-0.0332	1.16	-880.9328	-1.19	-0.0253	1.15
10. Weighted average of bus in-vehicle time	***0.0836***	***1.92***	***0.0597***	2.34	**32.6198**	**1.96**	**0.0593**	2.35
11. Weighted average of bus wait time	**0.3130**	**2.40**	**0.0683**	1.98	**130.0958**	**2.64**	**0.0733**	1.97
12. Imputed average per trip household parking charge	**-3.6693**	**-7.74**	**-0.1758**	1.26	**-1360.8620**	**-7.49**	**-0.1661**	1.26
13. Imputed average per-trip household transit fare	**10.3679**	**5.51**	**0.1163**	1.09	**4163.8020**	**5.83**	**0.1202**	1.08
Regression Constant	-7.9403	-1.34	NA	NA	-1717.5720	-0.76	NA	NA
R^2				0.3277				0.357
Adj. R^2				0.3223				0.3519
Root MSE (aka Std. Error of the Estimate)				19.594				7518.4
N				1654				1655

Note: Coefficients in **bold** are significant at the 5% level
Coefficients in ***bold italic*** are significant at the 10% level
Coefficients with **bold underlined** VIF values are likely co-linear

4.2.2. Socio-demographic and control variables

All individual and household-level control variables performed as expected. Households with more workers, more kids, higher incomes and greater vehicle accessibility all are significantly associated with greater average daily VMT and CO_2 generation. This observation suggests the models are correctly specified and that included measures are internally valid.

4.2.3. Urban form, sidewalk coverage and transit accessibility variables

Model coefficients suggest that more pedestrian-oriented urban form characterized by increased sidewalk availability and land use mix (greater accessibility to destinations) was associated with lower daily household CO_2 levels and VMT generation. Higher values of land use mix within a 1 km network distance of a person's home is the only consistently significant urban form variable associated with reduced VMT and CO_2, at the 5 percent threshold of statistical significance. The VMT and CO_2 models included different land use mix variables in order to maximize the inclusion of statistically significant and policy relevant meaningful coefficients. Sidewalk coverage reached the 10 percent threshold of significance in the CO2 model, but not the VMT model. Signalized intersection density and number of transit routes did not reach statistical significance, but because the retain expected direction of effect on both outcomes and have high policy relevance, they remain in the final model. Sidewalk coverage was also retained in the VMT model for the same reasons. These estimated coefficients are the best available approximation available and any statistical insignificance may be caused by a lack of sufficiently varied data and/or co-linearity among other variables.

4.2.4. Travel time and cost variables

The two travel cost variables – imputed daily parking and transit fares per person – were highly significant at the 5 percent level in both models. Higher daily parking fees at trip destinations was negatively associated with VMT and CO_2 emission levels. Conversely, higher daily transit fares may discourage transit use as evident through a positive association with VMT and CO_2 emission levels. Longer transit wait and travel times may also lead to increased vehicle use and related CO_2 emission levels, as observed by the significantly positive coefficients of these variables.

4.3. Elasticities

Point elasticities express the marginal degree of change in a dependent variable Y that is anticipated from a change in a pre-specified value of a particular input variable X, holding all other inputs constant. The main model results provide an absolute estimate of the existing per household VMT and CO2 levels in King County, and what these levels are expected to be after a specific change (or combination of changes) to urban form, pedestrian infrastructure, transit service, and travel pricing are put in place. The elasticity values provide insight into the anticipated change in VMT and CO2 levels at particular "cut-points" in each independent variable. Elasticities, employed in this context, also help to understand the return-on-investment (ROI) or cost-effectiveness of development decisions relative to VMT and CO_2 levels.

The magnitude of effective change associated with a given point elasticity is not constant. The exact pattern of how the value of point elasticities change is dependent in large part on the distribution of the input variable X for which the point elasticity is being calculated. Generally, for normally distributed input data, the rate of change between point elasticities is towards progressively smaller values. Every input variable X has a low and high end to its distribution in the project sample population. As one gets closer to these extremes, it becomes progressively more difficult to achieve the same percentage change in outcome variable Y by increasing (or decreasing) the input variable X of interest. This effect is commonly referred to as "diminishing marginal returns". A situation where the rate of change between point elasticities does not get progressively smaller (e.g. increasing returns) may occur when the distribution of the input variable is skewed.

Table 4.3 provides the quartile percentage values (25^{th}, 50^{th} and 75^{th} percentile) for all input variables from the project sample population. Table 4.4 and 4.5 illustrates the marginal change results for the VMT and CO2 models, respectively, obtained through the point elasticity calculations using the percentile values.

Table 4.3: Data Input Percentiles (n=1,654)

Independent (Input) Variables	**For Cases Used in VMT Model (N = 1,654)**			**For Cases Used in CO2 Model (N = 1,655)**		
	25th Percentile	50th Percentile	75th Percentile	25th Percentile	50th Percentile	75th Percentile
1. Total number of workers in the household	1	1	2	1	1	2
2. Total number of children age 16 or younger in the household	0	0	0	0	0	0
3. Number of vehicles per licensed driver (blank for households with no licensed drivers)	0	0	1	0	0	1
4. Dummy variable indicating household reported higher income than CPI adjusted King County median (i.e., $64,324.44; 1 = Above Median, 0 = At or Below Median)	1	1	1	1	1	1
5. Signalized Intersection Density within 1km network buffer around household location	1.525553	3.169908	5.150846	1.529052	3.181336	5.194805
6. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office residential, and retail uses) for 1km network buffer around household location	0.1409029	0.2207922	0.3245175	--	--	--
6a. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office, and retail uses; no residential square footage) for 1km network buffer around household location	--	--	--	0.1534338	0.2489309	0.3790097
7. Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	0.57467	1.425099	1.637994	0.5766436	1.425494	1.639568
8. Number of different bus routes served by King County, Community Transit and/or Pierce Transit for the active stops within the 1km buffer for the household	4	6	11	4	6	11
9. Jobs/housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	0.1538799	0.3318325	0.5813934	0.1538799	0.3328581	0.5813934
10. Weighted average of bus in-vehicle time	87.31959	97.84916	107.7664	87.31959	97.84916	107.7664
11. Weighted average of bus wait time	9.05975	11.85986	14.64465	9.05975	11.85986	14.64465
12. Imputed average per trip household parking charge	0	0.2875135	1.187902	0	0.2861907	1.187902
13. Imputed average per-trip household transit fare	1.43	1.508571	1.65	1.43	1.508571	1.65

Note: T-statistic and associated probability values in **bold** are significant at the 5% level

Table 4.4: Point elasticities based on households in final VMT model

Independent (Input) Variables	25th Percentile	50th Percentile	75th Percentile	Elasticity Change from 25th to 50th Percentile	Elasticity Change from 50th to 75th Percentile
5. Signalized Intersection Density within 1km network buffer around household location	0.96%	1.97%	3.15%	1.01%	1.19%
6a. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office, and retail uses; no residential square footage) for 1km network buffer around household location	4.45%	7.16%	10.88%	2.70%	3.73%
7. Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	2.20%	5.64%	6.53%	3.44%	0.90%
8. Number of different bus routes served by King County, Community Transit and/or Pierce Transit for the active stops within the 1km buffer for the household	1.03%	1.55%	2.87%	0.52%	1.33%
9. Jobs/housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	1.43%	3.13%	5.62%	1.70%	2.49%
10. Weighted average of bus in-vehicle time	24.35%	26.50%	28.43%	2.16%	1.92%
11. Weighted average of bus wait time	9.47%	12.05%	14.47%	2.58%	2.42%
12. Imputed average per trip household parking charge	0.00%	3.21%	14.72%	3.21%	11.52%
13. Imputed average per-trip household transit fare	49.96%	51.29%	53.53%	1.34%	2.23%

Table 4.5: Point elasticities based on households in final CO_2 model (n=1,655)

Independent (Input) Variables	25th Percentile	50th Percentile	75th Percentile	Elasticity Change from 25th to 50th Percentile	Elasticity Change from 50th to 75th Percentile
5. Signalized Intersection Density within 1km network buffer around household location	0.85%	1.74%	2.82%	0.90%	1.07%
6. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office residential, and retail uses) for 1km network buffer around household location	4.35%	7.25%	11.48%	2.90%	4.23%
7. Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	3.10%	8.03%	9.34%	4.93%	1.32%
8. Number of different bus routes served by King County, Community Transit and/or Pierce Transit for the active stops within the 1km buffer for the household	0.92%	1.38%	2.56%	0.46%	1.18%
9. Jobs/housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	1.01%	2.21%	3.92%	1.20%	1.71%
10. Weighted average of bus in-vehicle time	22.18%	24.21%	26.02%	2.03%	1.82%
11. Weighted average of bus wait time	9.22%	11.74%	14.10%	2.52%	2.37%
12. Imputed average per trip household parking charge	0.00%	2.79%	12.72%	2.79%	9.92%
13. Imputed average per-trip household transit fare	46.92%	48.25%	50.49%	1.33%	2.24%

The following observations are noteworthy:

- Parking charges have the highest magnitudes of marginal changes between percentiles in both the VMT and CO_2 models. The greatest degree of marginal change occurs when parking charges are increased from approximately \$0.28 per hour to \$1.19 per hour (50^{th} to 75^{th} percentile, which results in a 11.52 percent decrease in VMT and a 9.92 percent decrease in CO2). This suggests that parking charge rates generate a substantial influence on VMT and CO_2 only when they reach higher-end rates.
- Transit fares, land use mix and signalized intersection density have similar but less dramatic effects, as evidenced by their overall lower magnitudes (e.g., 1.34 percent to 2.23 percent elasticities on VMT for transit fare, 2.70 to 3.73 percent for mixed use; 1.01 and 1.19 percent for signalized intersection density). These results highlight that urban form, while difficult to change in the immediate term, may be an effective complementary strategy to pricing and transit service when trying to reduce VMT / CO_2.
- Diminishing marginal returns are evident in the sidewalk ratio variable. Investments in sidewalk infrastructure are likely to exceed relative cost effectiveness in terms of VMT and CO_2 outcomes when investment exceeds sidewalk coverage in the 50^{th} percentile. For the project sample, the 50^{th} percentile is a sidewalk ratio of 1.42, equivalent to full sidewalk coverage on both sides of 71 percent of the street network. In any project area where that threshold is not yet met, there may be a cost effective benefit in adding sidewalks.

4.4. Model and Data Limitations

4.4.1. Sample distribution

The final model was limited by an inability to generate a complete countywide sidewalk layer. Cases from the 2006 PSRC Household Activity Survey sampled for this research were constrained to those respondent households with valid sidewalk data to ensure complete built environment and accessibility measures across all participants. The project scope of work and timeframe precluded any primary sidewalk data collection efforts by WSDOT or the consultant team – it was necessary to rely on local jurisdiction sidewalk data, where it existed. Local sidewalk data was only available for 9 of 39 incorporated areas within King County, or 71 percent of the King County households in the PSRC travel survey. Summary statistics provided in Section 4.1. indicated a greater prevalence of more compact, walkable, centrally located, less auto-dependent areas in the project sample households relative to the entire 2006 PSRC Household Activity Survey. The development of a regional sidewalk layer – either for King County or the 4-county Puget Sound Region – would benefit future analyses and planning efforts that seek to understand potential VMT / GHG impacts of sidewalk investment and other pedestrian infrastructure. This project provides important early evidence that sidewalks may be a part of such a VMT / GHG reduction strategy.

4.4.2. Multicollinearity

Because it limited the variation in urban form across the study sample, the lack of sidewalk data also contributed to problems with multicollinearity. Multicollinearity (e.g. co-association) between variables is already common in research on urban form and travel related outcomes. In this case, it limited the ability to include many generated variables known to relate with VMT and CO_2 emissions in the academic and applied literature. Including variables that exhibit high degrees of multicollinearity in the same model may result in Type II error, or "false-negative", situations where meaningful and statistically significant associations are masked and the null hypothesis (e.g. no meaningful relationship) is accepted when in fact it should be rejected. The modeling process entailed multiple iterations of testing different combinations of variables to determine an informative but well-fitted and appropriately performing final model. Interactive terms (two-way, co-dependent or synergistic effects of groups of variables) and non-linear transformation of variables (including logarithm and linear input variables) were tested in an attempt to improve specific variable and overall performance of VMT and CO_2 models. Interactive terms provided no additional or "value-added" results to the findings. Non-linear transformations resulted in either substantial losses in explanatory power, reductions/complete losses of statistical significance of urban form variables, or both. The variables retained in all final models are considered the "best available" and will enable meaningful and policy-relevant scenarios to be tested by planners and decision-makers. Nevertheless, future work would do well to improve on the models submitted here.

The following notable independent variables were dropped from the final statistical models:

- **Net Residential Density**: Highly co-linear with many other urban form variables, making them insignificant or wrongly signed, along with a slight loss in model power.
- **Intersection Density**: This variable was found to be statistically insignificant across all model iterations. Several variants of intersection density were also tested (non-signalized intersection density, non-signalized/overall intersection density ratio, signalized/overall intersection density ratio, signalized/non-signalized intersection density). Results were either

statistically insignificant, or confirmed the underlying conclusion that signalized intersection density increased CO_2/VMT output.

- **Household Size**: Larger household sizes (e.g. number of individuals residing in a dwelling unit) are generally associated with increased vehicle travel and related CO_2 emissions. This variable was removed from final VMT and CO_2 models because co-linearity with Number of Workers in Household was resulting in "wrong" direction for this variable. Removing Household Size resulted in less loss of model power than removing Number of Workers in Household.

4.4.3. Travel cost charge variables

Imputed per-trip household parking charges were generated based on PSRC estimates of an average hourly charge in the destination TAZ. It is possible, however, that parking charge rates may vary by street or business area within a given TAZ. The PSRC data did not account for such variation, and was the only regionally consistent information available.

5. APPLICATION OF FINDINGS: SCENARIO ASSESSMENT TOOL AND CASE STUDIES

5.1. Development of Scenario Assessment Tool

A predictive scenario assessment tool was generated from the statistical model coefficients and parameters, and provides a basic platform for King County planning agencies to evaluate how different combinations of investment and policy strategies may impact household-level VMT and travel-related CO2 generation. In its current state, the tool can help to inform planning, zoning, development review, and transportation investment strategies at the neighborhood, urban village, or station planning areas. Tool equations are calibrated specifically for the King County area. The tool is documented in a simple Microsoft Excel spreadsheet that contains all necessary information to estimate household-level vehicle use and related CO_2 emission outputs per unit of time (e.g. kg/day, metric tons/year, etc) and the 95 percent confidence interval around each baseline and forecasted scenario estimates. Tool instructions are included in Appendix C of this report. Results from an assessment of tool performance in two case study planning areas are presented here.

5.2. Study Area Descriptions

Criteria used by the consultant team and project Technical Advisory Committee to select case study areas to test and demonstrate the performance of the scenario assessment tool are summarized in Section 3.8. Bitter Lake Village (130th Avenue and Aurora in Seattle, WA) and Rainier Beach were determined to best meet all identified criteria. Case study areas are illustrated in Figures 5.1 and 5.2, respectively. Turquoise lines signify the case study boundaries;

the red and blue circles signify ¼ and ½ mile distance from the transit station.

Figure 5.1. Bitter Lake Village case study

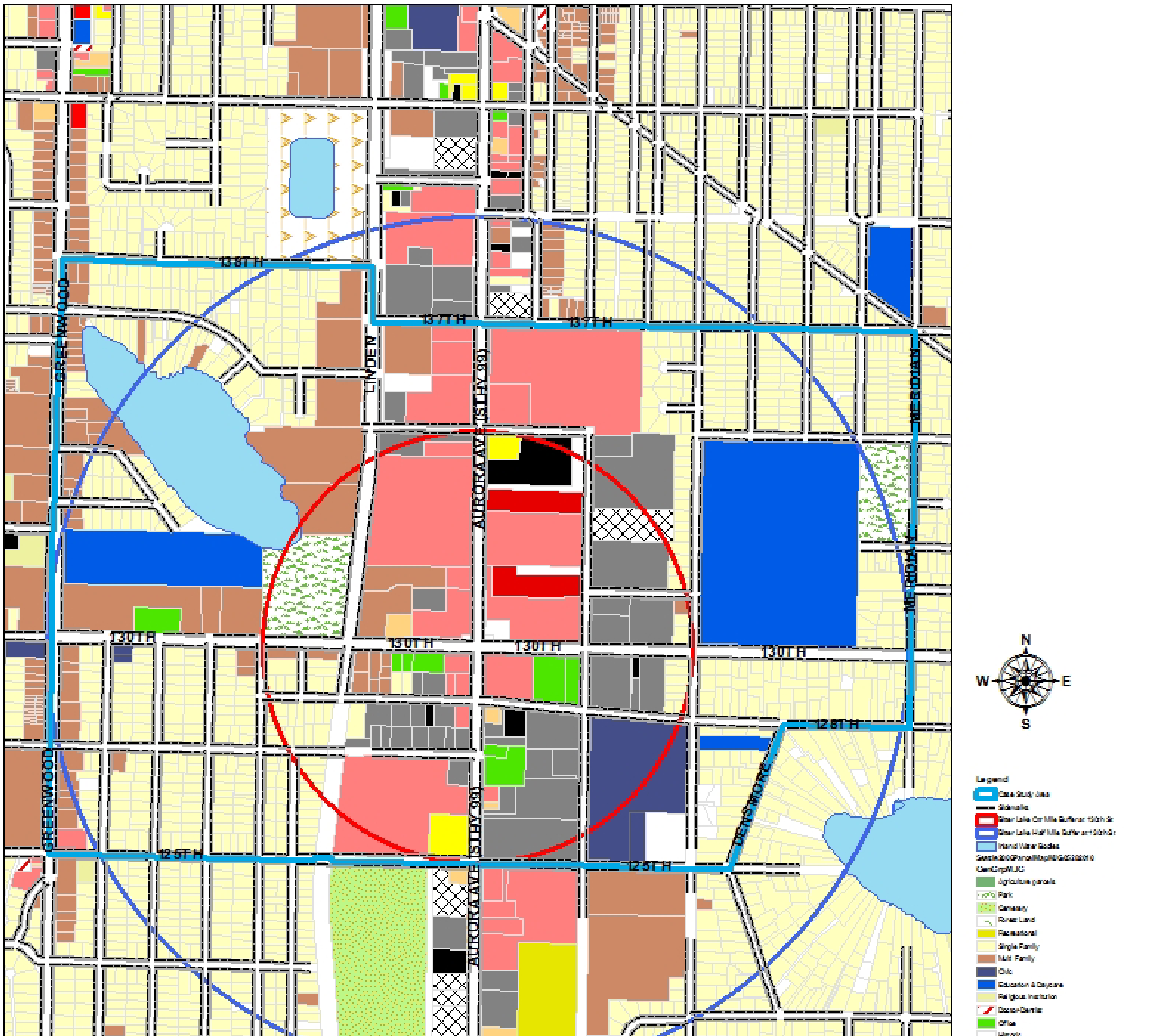
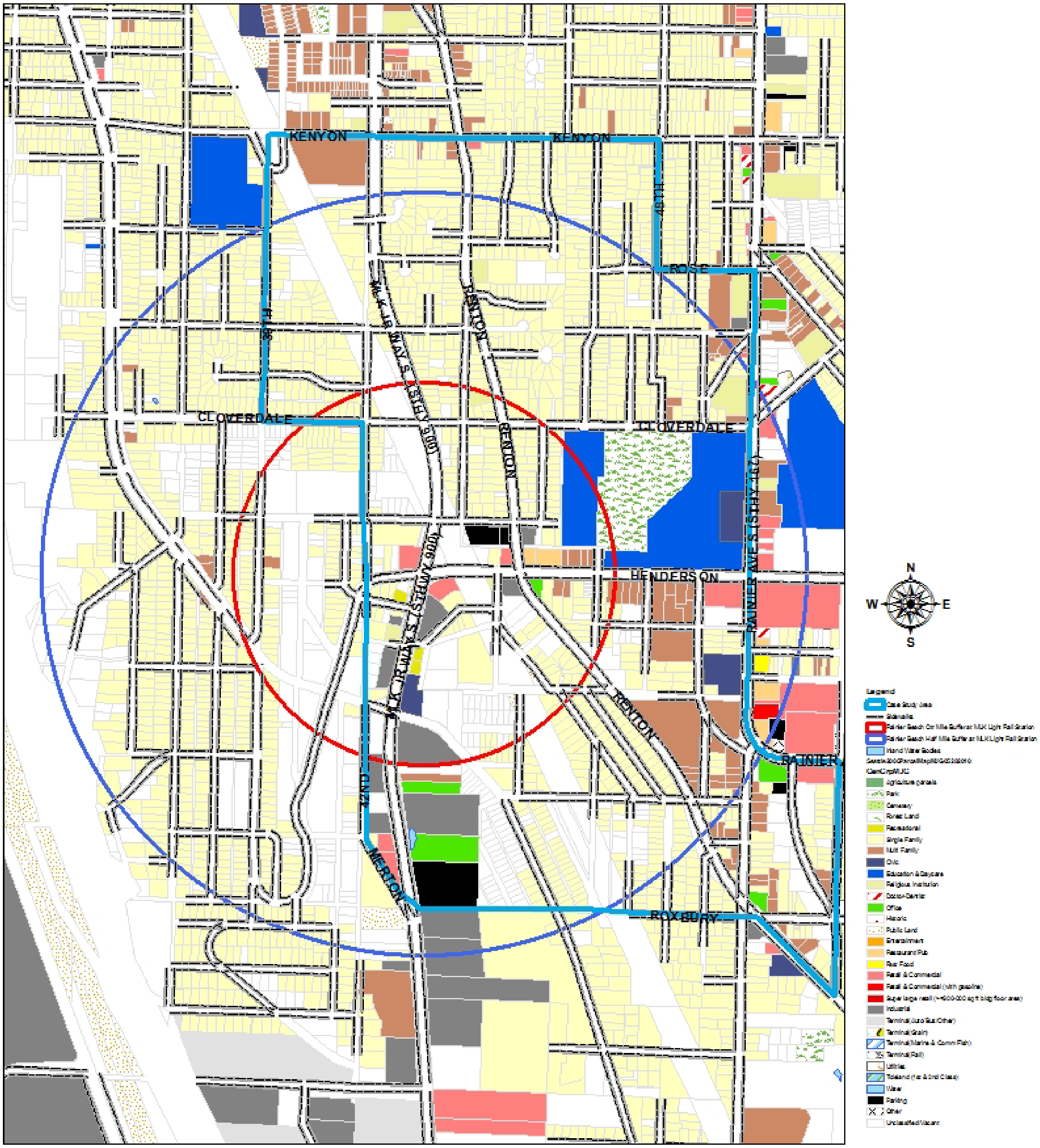


Figure 5.2. Rainier Beach case study



Bitter Lake Village (130th Avenue and Aurora)

Bitter Lake Urban Village is one of the City of Seattle neighborhood plans being updated in 2010 – 2011, which makes the timing of this case study quite relevant and potentially informative from a policy perspective. There is a significant amount of potential for change in the urban form and transit service provision around the 130th BRT station. The street network is quite disconnected, with a sidewalk network that is largely limited to the major arterial streets. The area is dominated by auto oriented "strip" retail. The presence of large vacant parcels within the 130th station area creates further opportunities to transition to a more pedestrian friendly transit hub. Bitter Lake Park and Ingraham High School, both within the catchment areas of the 130th station area, offer an opportunity to connect residential, commercial recreational and educational facilities with a more complete sidewalk and / or trail network. The boundary includes single family residential areas outside the urban village boundary in order to properly represent the character of the neighborhood and generate reasonable results from testing changes in the area.

Rainier Beach

Similar to Bitter Lake, Seattle is initiating a neighborhood plan update process in 2010-2011 for the Rainier Beach area. The sidewalk network to west of LRT station is quite fragmented, and low density / auto oriented commercial / warehouse / industrial development along Martin Luther King, Jr. Way S. close to the Rainier & Henderson LRT station creates the opportunity to transition to a more compact, mixed and pedestrian friendly station area. With Dunlap Elementary and Rainier Beach High School to the east of the station area and Rainier Beach pool and the Chief Sealth Trail nearby, this study area also contains a wide array of land use types and destinations. The study area boundary is focused on the potential light rail catchment area to the east of the station, avoiding a steep hill to the west which is likely to inhibit potential pedestrian movement and introduce a factor into the analysis for which we were unable to control (topography). The proposed boundary includes some of the single family areas that surround the designated urban village and also extends partially into industrial / auto-oriented commercial areas south of the station - therefore capturing the most complete picture of the light rail station catchment area as possible.

5.3. Case Study Scenarios

Three scenarios were developed to test the performance of the spreadsheet tool. City of Seattle staff, with input from WSDOT and the consultant team, provided one "existing conditions" (current population, urban form, infrastructure, pricing and transit service conditions) scenario and one "current policy" (anticipated population and employment, and planned urban form, infrastructure, pricing and transit service characteristics based on current policy and investment plans) scenario for each neighborhood. The consultant team also developed an additional "VMT-CO2 reduction" scenario to test the tool's robustness and to determine the magnitude of development strategies that might be required to yield substantial reductions in transportation-related VMT and CO_2 emissions. Detailed scenario assumptions are described in Appendix D of this report.

The Existing Conditions scenario assumed 2006 socioeconomic, built environment, transit service, and travel cost conditions for both the Bitter Lake and Rainier Beach planning areas, in order to match the time period of the VMT / CO2 data (the 2006 household survey). Socioeconomic and demographic characteristics were calculated at the block level using U.S. Census (2000) with the exception of the "average number of licensed vehicles per driver in the household" which utilized comparable data from the PSRC 2006 Household Activity and Travel Diary survey. Sociodemographics - household size, number of kids and cars per household, and income - was assumed to remain constant throughout all three scenarios in order to highlight the "pure" effects of the policy strategies. Built environment, transit service, and travel pricing assumptions were provided by City of Seattle for the Existing Conditions and Current Policy scenarios. UD4H then made adjustments to those assumptions for the VMT / CO2 Reduction scenario while maintaining employment, population and square footage totals.

Apportioning of information between various geographies was required to develop assumptions for transit service and cost variables that precisely matched the study area boundaries. The apportioning process used in these circumstances is described in Appendix E of this report. It is anticipated that scenario results will be an accurate estimate for the actual population as scenario development utilized actual observed or reported data for the planning areas.

The assumptions used in each of the scenarios are summarized in the tables below. Numbers in italics were used in other calculations (for example, the square footage numbers were used to calculate measures of land use mix).

Table 5.1: Bitter Lake Case Study Assumptions

BITTER LAKE			
INPUT FACTORS	**Existing Conditions**	**Current Policy**	**VMT / CO2**
Signalized Intersection Density	6.86	6.86	6.86
Land Use Mix			
Civic & Educational Sq. Footage	337,813	337,813	384,069
Entertainment Square Footage	0	10,000	50,000
Office Square Footage	130,424	153,351	250,000
Residential Square Footage	2,587,623	4,887,623	4,887,623
Retail Square Footage	802,506	943,579	760,673

Sidewalk Ratio	0.60	0.99	2
Number of Transit Routes	6	6	6
Jobs/Population Balance			
Total Employment	2548.20	3748.20	3748.20
Total Population	4062.00	7513.94	7513.94
Average Transit Travel Time	105.68	105.68	100.00
Average Transit Wait Time	12.59	10.07	9
Average hourly parking charge	4.36	4.36	5.00
Average transit trip fare	2.04	2.04	2.00
Number of Households in Planning Area	2236.05	4,136.27	4,136.27

Table 5.2: Rainier Beach case study assumptions

INPUT FACTORS	**RAINIER BEACH** **Existing Conditions**	**Current Policy**	**VMT / CO2 Reduction**
Signalized Intersection Density	4.10	4.10	4.10
Land Use Mix			
Civic & Educational Sq. Footage	280,193	280,193	260,000
Entertainment Square Footage	0	5,000	11,774
Office Square Footage	20,504	24,876	33,000
Residential Square Footage	1,875,473	2,450,473	2,450,473
Retail Square Footage	61,577	74,705	80,000
Sidewalk Ratio	0.96	1.24	2
Number of Transit Routes	12	10	10
Jobs/Population Balance			
Total Employment	402.24	552.24	552.24
Total Population	4614.36	6216.59	6216.59
Average Transit Travel Time	92.27	92.26	90.00
Average Transit Wait Time	8.91	7.128662946	6.5
Average hourly parking charge	4.36	4.36	5.00
Average transit trip fare	2.04	2.04	2.00
Number of Households in Planning	1370.20	1,845.97	1,845.97

5.4. Testing and Calibration

Assessment of tool performance and case study results were based on the produced nature and magnitudes of effect. VMT and CO2 output estimates were required to generally conform to the nature of effects observed in the statistical modeling process for tool performance to be considered methodological sound and fit for practical application. For example, tested scenarios developed around the largest changes in urban form, transit service and accessibility, and travel pricing variables relative to the Existing Conditions scenario would be expected to yield the lowest per household VMT and CO2 estimates relative to other scenarios with less dramatic variation in variables.

5.5. Interpretation of Results

The spreadsheet tool performed as expected in both the Bitter Lake Village and Rainier Beach case study planning areas. Results are summarized in Tables 5.3 and 5.4 below. The contribution of each strategy (input factor) to the total average household VMT and CO2 is shown in the table, to give an idea of relative strategy effectiveness. All told, the Current Policy scenario resulted in a nearly 8 percent decrease in VMT, and a 1.65 percent decrease in CO2 for Bitter Lake. Rainier Beach's Current Policy scenario decreased VMT by 6.75 percent and CO2 by 2.2 percent. These numbers indicate that more investment in pedestrian infrastructure and transit service will almost certainly be needed in order to meet future goals for VMT and CO2 reduction. However, because residential density was necessarily eliminated from the model, the City may realize small additional decreases in CO2 and VMT due to substantial planned increases in residential density in these study areas. Although the evidence in this study does not support such a conclusion, past research in this region does indicate that residential density is an important factor in attempting to reduce auto use. Additionally, the analysis only compares two different growth scenarios within the same neighborhood of the city. Comparing the population / employment growth predicted for these study areas against that growth in a more exurban area less well-served by transit would likely provide more contrast in results. The particular approach to scenario planning will depend on the particular planning process or decision being made – for example, where to locate growth in a city or a region (in the context of comprehensive or regional planning) or how a segment of predicted growth should be accommodated (in the context of neighborhood planning, which was the approach taken here).

The VMT / CO2 Reduction scenarios were able to get much larger reductions in VMT and CO2, primarily by adjusting transit service and cost variables and assuming complete sidewalk coverage in both study areas. Although the adjustments are small in total, because they are large-area averages, they would require large amounts of change in a single area or transit route – or smaller amounts of change to many areas / routes. However, in the judgment of the consultant team, they are not unrealistic. Small adjustments were also made to the distribution of land uses within the planned total square footage estimated by the City of Seattle. In total, these changes resulted in a 48 percent VMT reduction and a 27.5 percent CO2 reduction for Bitter Lake, and a 27 percent VMT reduction and 16.5 percent CO2 reduction for Rainier Beach – substantial departures from the trend that begin to illustrate what might have to happen in order to reach stated goals for VMT reduction.

Table 5.3: Bitter Lake case study results

BITTER LAKE STUDY AREA RESULTS INPUT FACTORS	Existing Conditions		Current Policy		VMT/ CO2 Reduction	
	Estimated VMT	**Estimated CO2 (g)**	**Estimated VMT**	**Estimated CO2 (g)**	**Estimated VMT**	**Estimated CO2 (g)**
Signalized Intersection Density	1.30	492.46	1.30	492.46	1.30	492.46
Land Use Mix	-6.39	-2229.27	-6.50	-1,789.21	-8.10	-1,910.20
Sidewalk Ratio	-0.73	-441.92	-1.20	-727.05	-2.43	-1,469.38
Number of Transit Routes servicing the area	-0.49	-185.31	-0.49	-185.31	-0.49	-185.31
Jobs/Population Balance	-2.81	-840.83	-2.71	-809.77	-2.74	-820.21
Average Transit Travel Time	8.84	3447.15	8.84	3,447.15	8.36	3,261.98
Average Transit Wait Time	3.94	1637.57	3.15	1,310.05	2.82	1,170.86
Average hourly parking charge	-16.01	-5937.50	-16.01	-5,937.50	-18.35	-6,804.31
Average transit trip fare	21.17	8500.40	21.17	8,500.40	20.74	8,327.60
Household Constant (assuming all other impact factors balance to zero)	-7.94	-1717.57	-7.94	-1,717.57	-7.94	-1,717.57
Estimated Daily Average HH	**15.80**	**8648.32**	**14.54**	**8,506.78**	**8.10**	**6,269.06**
95% Confidence Interval						
Lower Bound	-	-	-	-	-	-
Upper Bound	54.31	23,421.97	53.05	23,280.44	46.60	21,042.72
Estimated Daily Total Area	**35,338.95**	**19,338,077.35**	**60,155.05**	**35,186,374.56**	**33,514.22**	**25,930,547.88**
95% Confidence Interval						
Lower Bound	-	-	-	-	-	-
Upper Bound	121,431.84	52,372,720.75	219,410.72	96,294,258.86	192,769.90	87,038,432.18

Table 5.4: Rainier Beach case study results

RAINIER BEACH STUDY AREA RESULTS INPUT FACTORS	Existing Conditions Estimated VMT	 Estimated CO2 (g)	Current Policy Estimated VMT	 Estimated CO2 (g)	VMT / CO2 Reduction Estimated VMT	 Estimated CO2 (g)
Signalized Intersection Density	0.78	294.44	0.78	294.44	0.78	294.44
Land Use Mix	-4.83	-1,329.54	-5.71	-1,216.62	-6.63	-1,257.97
Sidewalk Ratio	-1.17	-705.36	-1.51	-912.05	-2.43	-1,469.38
Number of Transit Routes servicing the area	-0.97	-370.63	-0.81	-308.85	-0.81	-308.85
Jobs/Population Balance	-0.78	-232.75	-0.78	-233.94	-0.79	-236.59
Average Transit Travel Time	7.72	3,009.67	7.72	3,009.52	7.53	2,935.78
Average Transit Wait Time	2.79	1,159.26	2.23	927.41	2.03	845.62
Average hourly parking charge	-16.01	-5,937.50	-16.01	-5,937.50	-18.35	-6,804.31
Average transit trip fare	21.16	8,497.95	21.16	8,497.95	20.74	8,327.60
Household Constant (assuming all other impact factors balance to zero)	-7.94	-1,717.57	-7.94	-1,717.57	-7.94	-1,717.57
Estimated Daily Average HH	**23.9663**	**12,128.55**	**22.35**	**11,863.38**	**17.35**	**10,069.36**
95% Confidence Interval						
Lower Bound	-	-	-	-	-	-
Upper Bound	62.47	26,902.21	60.85	26,637.03	55.85	24,843.01
Estimated Daily Total Area	**32,838.71**	**16,618,552.72**	**41,252.56**	**21,899,460.74**	**32,026.79**	**18,587,750.44**
95% Confidence Interval						
Lower Bound	-	-	-	-	-	-
Upper Bound	85,594.48	36,861,431.68	112,326.56	49,171,214.74	103,100.79	45,859,504.44

5.6. Tool Benefits

The spreadsheet tool is considered a "first attempt" at developing a comprehensive VMT and CO_2 assessment tool for King County planning agencies. For a short set of instructions on how to use the tool, see Appendices C and E; for more details on how data and assumptions were applied to the tool in the case studies, see Appendix D. Practical advantages of this initial tool include:

Evidence-based

The spreadsheet tool is able to replicate the methodology of the research upon which the travel and environmental outcomes are based. The tool applies the same built environment characteristics used in the base analysis, and it can incorporate demographic information that is important to predicting CO_2 and VMT. Data required for scenario inputs are readily available to and calculable for most planning agencies within King County. This situation better enables application of the tool county-wide.

Interface and ease of use

The MS Excel spreadsheet interface is a standard computing program used within the United States and is familiar and available to most planning practitioners and decision-makers. Baseline and future scenario characteristics are inputted within the same MS excel spreadsheet tab, with associated percentage changes provided for all input and outputs variables. This enables the clear and transparent display of data and information for tool users and stakeholders. Data input and any adjustments for future planning scenarios can be completed relatively quickly. This enables an adaptable range of applications from in-house policy assessments to larger neighborhood or community workshops where participants are able to revise input values as needed or desired.

The tool can help to inform planning, zoning, development review, and transportation investment strategies at the neighborhood, urban village, or station planning areas.

5.7. Tool Limitations

The base data and statistical approaches employed to develop the spreadsheet tool restrict its application in several ways:

Limitations of base research

The tool is limited by the lack of sidewalk data for the less-walkable areas of King County. This resulted in a lack of variation in the sample and to an extent impacts the generalizability of the results. Past studies (without sidewalk data) using the same travel and urban form datasets but for the whole county showed significant relationships for a broader array of urban form variables than we found in this "truncated" dataset.[31] These studies consistently found multiple urban form variables such as intersection density, residential density, and retail density / presence, to be associated with VMT and CO2. The tool, while able to test a number of different policy strategies, is therefore limited in the *urban form* strategies that are able to be tested.

Input variable range

VMT and CO2 coefficients obtained from statistical models specified using multiple regression analysis methods are based on a range of variable values drawn from the project sample of households. These are listed in Table 4.1. King County planning agencies interested in applying the spreadsheet tool should not test the effect of input variable values that fall beyond the minimum and maximum range of variables in the project sample of households.

Reduced number of urban form variables

An optimally specified model and scenario assessment tool would have included all pertinent urban form variables known to relate with VMT, CO_2 active transportation and transit use described in Section 3.4.1. These include net residential density, intersection density, and retail floor area ratio – all characteristics of the built environment that are subject to local planning policy and regulations. Issues with multicollinearity between the various urban form variables, as discussed previously, limited the number and type of urban variables retained in the final model and assessment tool. The tool would benefit from additional work to include a wider variety of urban forms within the sample – for example, including more rural King County households.

6. CONCLUSIONS

6.1. Summary of Research

This project provides new empirical evidence associating multi-scale urban form, pedestrian infrastructure, transit service and travel cost characteristics to household level VMT and CO_2 emissions in the King County area of Washington State. The integration of pedestrian infrastructure data, specifically sidewalk coverage, is a unique contribution to the field of study and helped to advance a more complete assessment of these relationships. Statistical model results demonstrate that travel pricing and demand management strategies yield consistently large and significant influence on VMT and CO_2 generation. Nevertheless, the significance of variables such as land use mix and sidewalk availability suggest that the success of these strategies may largely depend on having a local land use and transportation system to promote alternative mobility options.

Marginal analysis results obtained through elasticity development allowed for the determination of which urban form, transit service and pedestrian infrastructure elements may be most effective in reducing household VMT and related CO2. As with any policy intended to meet an objectively measurable outcome, urban form interventions to address CO2 (either directly or indirectly) are subject to diminishing marginal returns. Understanding whether the change (and presumed benefit) is worth the cost in public investment, and what degree of public acceptance exists for the proposal is crucial for developing sound and rational policy and investment choices. Elasticities and marginal change analyses demonstrated that only moderate increases in sidewalk infrastructure may be needed to yield significant decreases in VMT and associated CO2. Conversely, more aggressive and substantial increases in land use mix may be required before a greater return on investment is realized.

Model results were imported into a scenario assessment tool developed in a Microsoft Excel spreadsheet interface. Model performance was tested on two case study neighborhoods. The case study assessments were an informative test. The scenarios tested here are a good "first step" upon which to build additional planning and evaluative efforts.

6.2. Technical Refinements and Adjustments

Several improvements could be made in future work to refine the data, statistical models and scenario assessment tool utilized and produced as part of this effort:

Additional sidewalk and pedestrian infrastructure data

Sidewalk data was only available from nine of the 39 King County jurisdictions for the analysis. This reduced the total number of households that we were able to include in the analysis (73 percent of the King County travel survey households were able to be included in the analysis), limited the variability of urban form measures, and hampered the study results. The study team strongly recommends collecting additional sidewalk data and re-running the CO2 analysis. This would help to address the problems with limited variation in the sample and enhance applicability of the analysis. It will be crucial to measure CO2 from travel as an outcome in addition to VMT because the relationship between CO2 and VMT is not 1:1, as is often assumed. There are, in fact, substantive differences between CO2 and VMT due to speed and hot vs. cold starts. The research team already has in-hand detailed measures of CO2 from travel (described in Appendix A), urban form and transit service measures for all of the King County travel survey households in the PSRC survey, giving such a project a head start in terms of timing and budget.

Emission Adjustments

Refinements could be made to increase the precision of the emission estimates. California Air Resources Board (CARB) speed-based emission factors are readily available and would make it possible for future work to create speed-sensitive CO2 emissions estimates, as opposed to the flat rate applied in this analysis. CO2 emission estimates could be made sensitive to vehicle model year and type. Currently the emission rate applied to every trip (regardless of the vehicle type used) is based on a regional fleet distribution of 55.4% auto and 44.6 light duty truck. Emission estimates that were sensitive to vehicle model year and type were not available for this effort. To provide such estimates would require producing the five times of day look-up tables used in this analysis for each model year of each vehicle type. Even if only two vehicle types were used (auto, and light duty truck) then 250 (2 vehicle types*25 model years*5 time of day periods) tables would need to be produced and applied to the survey data.

Distance Adjustments

Additional adjustments could increase the accuracy of the travel distance estimates. This analysis is based on TAZ to TAZ centroid emission amounts, which may not be the actual distance traveled on the road network or the actual trip path (in the case of trips which would otherwise bypass the TAZ centroid). In particular, TAZ-based estimates for bus trips (both school and public buses) and short (intra-TAZ) trips would benefit from a more refined approach to determining trip distance. In the future, these estimates could be refined by using the point on the PSRC model road network that is nearest the trip end to calculate distance, rather than the TAZ centroid, as the base from which to estimate the trip distance in the PSRC model. Network-based offset distances could also be used, which would not only allow a more accurate approximation of the travel path, but would allow the further refinement of speeds for each link of that travel path. This is especially important for intrazonal trips; for those trips, it was necessary to assume the entire offset distance was traveled at 20mph.

6.3. Opportunities for Future Work and Applications

The statistical models and scenario assessment tool developed here are considered a "first step" towards understanding and measuring the effect of different built environment characteristics and transportation system investments on household level VMT and CO2 emissions. Future work would do well to build off this effort through any of the following means:

"Focal points" of change

To be most instructive, additional scenarios should be specified to test different focal points of urban form, pedestrian infrastructure, and transit service and accessibility changes. For example, a scenario should be specified that is focused on increasing planning area sidewalk coverage and another focused on increasing transit service availability, while holding all additional variables constant.

Creating a more robust planning tool

A more detailed planning tool could be developed based on the results of this work. This might include more detailed estimation of urban form elasticities and/or diminishing marginal effect of urban form on VMT/CO2 mitigation. However, it is recommended that the underlying shortcomings of the analysis (the inclusion of a full set of sidewalk data) are addressed before further tool development commences.

Build additional street design / pedestrian environment variables

Future work could benefit from data collection and development and testing of other more detailed street design variables. For example, this could include an integrated nonmotorized and street network, which will better capture the connectivity of the pedestrian environment and allow the creation of variables that compare pedestrian and vehicle connectivity.

Assess multiple health and environmental outcomes

New research suggests that urban form strategies that promote lower rates of VMT yield "win-win" strategies across environmental and human health outcomes.[32,33] Although informative, many of the studies fail to include micro-scale pedestrian infrastructure variables into their analyses. Models developed for this research project that include detailed pedestrian infrastructure information could be re-specified to assess their synergistic effects on both emission and physical activity or obesity outcomes.

7. RECOMMENDATIONS

With a projected population increase of nearly half a million additional residents by 2030 (about a quarter of the current population) there exists significant opportunity to ensure new development in King County, the Puget Sound Region and statewide supports vehicle use reductions and lower carbon footprints. Findings from this research provide additional, evidence-based information to assist the Washington State DOT, King County, and other regional, state and local planning agencies develop reasonable and defensible climate reduction plans, goals, and objectives. Moreover, as these entities move forward with implementation of these strategies, the scenario assessment tool will help to identify and monitor neighborhood growth and redevelopment initiatives that will result in tangible VMT and CO_2 emission reductions.

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APPENDIX A

Development of VMT/CO2 Outcome Measures

APPENDIX A: DEVELOPMENT OF VMT/CO_2 OUTCOME MEASURES

Measuring CO_2 Emissions

Methods used to estimate CO_2 emissions evolved out of methodologies developed for detailed assessments of criteria air pollutants[34]. The process relied on information about each vehicle trip taken by King County households in the 2006 PSRC travel survey, supplemented by information from the PSRC travel demand model. Each reported trip was assigned to PSRC's modeled road network assuming a shortest time path based on the travel time for that mode and time of day. Trips were then broken into multiple road segments, or "links" according to facility type.

For each modeled road segment of each vehicle trip, CO_2 emissions levels were assessed based upon a vehicle's travel distance and speed. The travel speed on any given segment was determined by PSRC using its travel demand model. The model takes into account road facility type (arterial, freeway, etc), capacity and estimated traffic volume based on the time of day. This approach is a much more detailed measurement than the standard methodology, which uses a simple average speed for each trip and relies on self reported travel time and resulting speed.

The PSRC travel survey includes 45,606 trips from King County households. Of that total, 39,297 trips were made by a mode for which CO_2 emissions were estimated (car, public bus, school bus, motorcycle and taxi/shuttle. Our emissions estimation used the following main steps, each of which will be discussed in more detail in the sections that follow:

1. Determine travel modes for which emissions estimates will be created, and assign a primary travel mode to each trip.
2. Determine travel path, speed and distance.
3. Calculate CO_2 emissions for all modes, and adjust for cold starts and vehicle occupancy.

1. Determining Travel Mode.
PSRC travel survey participants were able to report up to five different modes used to complete their trip. For example, a person could report they went from home to work by driving their car to the ferry terminal, riding the ferry, walking from the ferry terminal to a bus stop and after arriving near their destination by bus walking the rest of the way to their work location. Of the 45,605 trips in the analysis set (trips made by King County households), 96.4% of them reported using a single mode, 2.5% of trips used two modes, 1% of trips used three modes, and 0.1% of trips used four modes. No trips listed 5 or more types of transportation.

For this analysis we only estimated CO_2 emissions for a single mode per trip – the 'primary' mode. For trips where survey respondents reported more than one mode, the following rules were used to determine which mode was the 'primary' mode for each trip:

- If a trip used a public bus for any segment of a trip (regardless of other modes used) that trip was categorized as having public bus as its primary mode.
- If a trip used a school bus for any segment of a trip (regardless of other modes used) that trip was categorized as having school bus as its primary mode.

- If a trip used a car/van/truck for any segment of a trip (regardless of other modes used, unless a public bus or school bus is used) that trip was categorized as having car/van/truck as its primary mode.
- If a trip used a taxi/shuttle for any segment of a trip (regardless of other modes used) that trip was categorized as having taxi/shuttle as its primary mode[1].

2. Determining Travel Path, Speed and Distance.
The actual trip path followed for each travel survey trip was not recorded in the PSRC travel survey. In order to estimate the trip path, PSRC, using its modeled road network and travel demand model's equilibrium assignment process, modeled the shortest time-path for the travel survey trips. Traffic volume and flow (congestion levels) were used to determine the shortest time path (from a loaded assignment at equilibrium) depending on the reported time of the trip.

In order to determine trip distance, trip origins and destinations were assigned to the centroid (centerpoint) of the TAZ which contained them. For intra-TAZ trips, the TAZ to TAZ centroid distance method was not used, as it would result in a trip distance of zero. Instead, the PSRC model estimates an average intrazonal trip length based on the area of the TAZ[2]. For the distances associated with intra-zonal trips, we assumed the travel speed was 20 mph for their entire length, and applied the corresponding emission value for that speed.

Distance Adjustments. The TAZ-based estimates used in this analysis for vehicle trips provided by PSRC do not account for the distance between the actual trip end point and the TAZ centroid. Most trips do not start or end at the TAZ centroid, but at some other location within the TAZ. However, the centroid is a central location where the major roadway network is located and is designated by the PSRC as the surrogate geographic terminus for trips within a zone because of its ability to provide an "average" approximation of origins and destinations within that zone. Figure A-1 below conveys the origin (O) and destination (D) of a hypothetical trip in relation to the TAZ centroid. It is important to also note that TAZ-based estimates for bus trips (both school and public buses) are quite unlikely to accurately represent the actual path (route) of the bus, since the bus route is unlikely to be the shortest time path between the origin and destination TAZ.

Figure A-1. Trip Path Based on TAZ Centroids and Actual Trip Ends (O and D)

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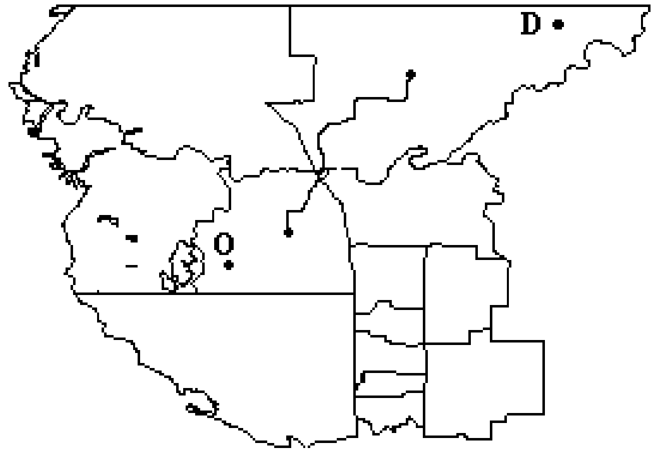
[1] Only one taxi trip used another mode (bicycle).
[2] http://wwwpsrc.org/data/tdmodel/model_doc(final).pdf (pg. 147: Average-intrazonal-trip-length (in miles) = 0.75 * SQRT (area (in sqmi)). "For a square TAZ, the square root of the area gives the length of one side. For a non-square TAZ, the square root of the area is the side of an equivalent square. The average length of a straight line with both ends randomly chosen in the unit square is 0.52665 if the distance is Pythagorean, 0.67333 if the distance is rectilinear. The coefficient of 0.75 is a higher than it would be for a unit square, but is a reasonable number to use for the wide mix of TAZ shapes."



We attempted to adjust the centroid-based trip distances estimates in order to account for distance between the actual trip end point and the TAZ centroid. Using X/Y coordinates of the TAZ centroids and actual trip end locations, it is possible to calculate the crow-fly (straight line) distance between the trip end point and TAZ centroid. This adjustment added, on average, just over a half-mile to the beginning and end of each trip (about 1.1 miles per trip, on average). However, this approach would only have added the distance between the TAZ centroid and the trip end, regardless of the direction of the trip.

The hypothetical trip shown in the figure above (between points O and D) is longer than the distance between TAZ centroids. However, the opposite circumstance also exists where the distance between points O and D is shorter than the distance between the TAZ centroids. Therefore, while adding the calculated distances from the actual trip origins to the centroid would work in the case shown, it would artificially bias the results by always increasing distances and not accounting for the opposite condition, where trip ends are closer than centroids. Because of this we chose to use the centroids and not add in the additional distances between trip ends and centroids. Due to averaging from trips that are longer or shorter than the centroid locations, it is not anticipated that this approach will bias the results. A distinct advantage of the centroid-based approach is that it is consistent with the methods employed by the PSRC for travel demand modeling -- and it is an acceptable industry standard.

Concurrent with this process of determining speeds and distances, PSRC applied California Air Resources Board (CARB) provided speed-based CO_2 emissions rates to determine a CO_2 emissions amount for each link of each trip based on the estimated travel speed and distance. The amount from all links in the modeled path were summed to give a trip total between TAZ centroids.

1. Calculating Distance and CO2 Emissions.

It was not possible to estimate CO_2 emissions for all travel modes reported in the PSRC travel survey. In the case of motorcycle trips, there was no ability to use a common emission factor ratio (across all speeds) to adjust the auto/truck emissions provided by PSRC. For public bus and school bus modes emissions were estimated based on the trip distance provided by PSRC in the travel survey data, estimated fuel mileage, and the US Environmental Protection Agency's

(EPA) ratio of pounds of CO_2 emissions per gallon of diesel fuel (22.2)[3]. This single conversion factor does not account for speed or acceleration. For auto-bus combination trips it was not possible to proportion the trip distance between the different modes given available survey data. Nonmotorized modes were assigned zero emissions. The remainder of the modes (ferry, golf cart, wheelchair, train) generated emissions, but had very small trip totals and no clear methodology to estimate emissions.

Emissions factors provided by CARB were used to generate CO_2 emissions for car/van/truck and taxi/shuttle trips – the vast majority of the trips. These emissions factors account for vehicle acceleration and deceleration, a refinement over factors used in the past. For each time period, the emissions per mile for each link of each trip were calculated and aggregated up to total per-vehicle, per-trip emissions.

Vehicle Occupancy. Emissions and distance were divided among vehicle occupants to create a per-person, per-trip total. For auto/van/truck trips we used the vehicle occupancy reported by travel survey participants. The maximum number of people a survey participant could indicate were in the vehicle with them is "6 or more." When this amount is indicated the number of people in addition to the survey participant that are assumed to be in the vehicle is 6. Ridership data provided by King County Metro Transit was used to apply average weekday ridership assumptions of 11.29 passengers for off peak (midday, night and evening) periods, and 12.59 passengers for peak periods (AM and PM). For school buses we assumed an occupancy of 35, and in the case of taxis vehicle occupancy was assumed to be 1 for the purpose of allocating emissions. Although taxis will have at least 2 people in them, but as in the case of driving alone, the sole reason the trip is occurring is due to a single person, and therefore all the emissions generated were assigned to that person.

Household Level Estimates. Once the emissions and distance estimates were apportioned as described above, the per capita values were aggregated to the individual household level, for each day of the two travel diary. These daily aggregated totals were then averaged to create a daily household VMT and GHG emissions estimate, which serve as the dependent variables (i.e., output measures) for this project. The relevant formulae are:

Equation 1 Personal Daily Average CO_2 Emissions from Travel

$$\sum_{d=1}^{D} \mathit{Total\ Daily\ Per\ Capita\ CO2}\ \mathbf{x}\ \mathit{Proportion\ of\ All\ Survey\ Trips\ Made\ on\ Day}(d)$$

where d = Index (the count) of survey days for a specific individual within a household

Equation 2 Estimated Household Daily CO_2 Emissions from Travel

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[3] U.S. Environmental Protection Agency. Emissions Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. Accessed February 23, 2011 at <http://www.epa.gov/otaq///////////climate/420f05001.htm>

$$\sum_{p=1}^{P} Results\ from\ Equation\ 1$$

where p = Index (the count) of survey participants within a particular household

APPENDIX B

Sidewalk Data Assembly

APPENDIX B: SIDEWALK DATA ASSEMBLY

1. Data Generation and Assembly Procedures

1.1. Initial Data Cleaning and Development

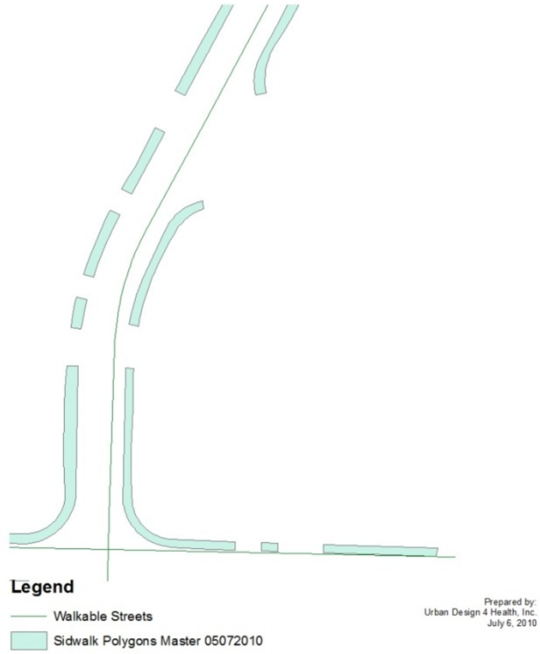
Preliminary estimates of total sidewalk distance within each household's 1 km network buffer were calculated by intersecting network buffer polygons around household locations with a master sidewalk line file created for this project. The master sidewalk line file was created by merging together the individual sidewalk files for the nine municipalities in UD4H possession:

- Bellevue
- Bothell
- Federal Way
- Kent
- Redmond
- SeaTac
- Seattle
- Shoreline
- Tukwila

In order to successfully execute the merge of the line files for the separate municipalities, several initial data cleaning steps had to be performed. The specific tasks with regards to selecting, modifying and validating the data for each municipality varied, but generally involved at least one of the following tasks:

1. Because the sidewalk archives were organized according to the administrative requirements of each jurisdiction, the first step was to identify which common elements could be combined. For example, one jurisdiction (SeaTac) provided only centerlines of streets with sidewalks, with notation within the underlying data table as to which street segments had only one side of the street covered by sidewalks. In two other jurisdictions (Bothell and Federal Way), sidewalk segments were provided as polygons. In this case, including the length of more than one edge of the polygon would grossly overestimate the length of sidewalk surface (see Figure B-1, below).

Figure 1: Sidewalk Polygon Example in Federal Way



2. The sidewalk elements needed to be selected out from any other elements in the municipal source record which were not immediately relevant to the analysis (e.g., crosswalks, railroad crossings, impervious surfaces, etc.). Details for each municipality is presented in Section 3 of this appendix.
3. The individual sidewalk files had to be reconciled with the date of the travel survey (2006). This was done either by using the existing metadata, or contact with relevant staff members within each municipality (as identified by WSDOT staff).
4. The individual sidewalk files had to share a common geography type (i.e., line or polyline), in order to be consolidated into a single master shapefile.
5. The definition of what constitutes a sidewalk segment (paved, raised right of way, as opposed to simply striped asphalt or gravel) should be consistent across the jurisdictions included in the analysis.

In the final assessment, only the length of sidewalk and geographic location were provided in sufficient detail to be combined across all data sets. Once the individual municipal files were standardized according to these cleaning steps described above, they were consolidated using the Merge tool in ArcGIS 9.3.1 (found under the General directory in Data Management Tools). The specific properties of this consolidated master file can be found in Section 4 of this appendix.

The master sidewalk file was then overlaid onto the polygons for the 1 km network buffer around each household location in King County contained in the PSRC 2006 Household Travel Survey (N=2,699). Using the Intersect tool in ArcGIS 9.3.1, the polygons were used to create a subset of the master sidewalk file which calculated the length of each segment of sidewalk intersecting a specific 1 km buffer. These results were then exported to Microsoft Access, and an aggregation query was performed to estimate the total length of all sidewalk segments within 1 km of each household. A similar application of the Intersect tool, and aggregation query was performed on an archived version of the walkable street network for King County, to generate the total distance of pedestrian accessible street right of way within 1 km of each household. The total number of buffers with non-zero total sidewalk distance was 2,006.

1.2. Validity Check

Once the total sidewalk and street distances were calculated for the buffers, the last task was a validity check for the cases where no sidewalk distance was returned. Upon examination of the cases, a source of potential error was addressed. Some travel survey participants recorded home locations that which, when plotted, were not strictly within the municipal boundaries of the city that they identified as their home location. For these 77 records, assigning values of zero sidewalk length would be incorrect, because they were not within the municipality in the first place. These records were removed from the data set. Total number of viable cases with sidewalk data: 2,006 – 77= 1,929

Initial Sidewalk Dataset: Summary Statistics and Variable Definitions

The current data set contains sidewalk information on the 1 kilometer network buffer area around 1,929 King County household locations that participated in the 2006 Puget Sound Transportation Survey. The variables collected include the total linear feet of sidewalk within each network buffer (accounting for sidewalks on both sides of the street), the total length of walkable streets within each buffer, and the ratio between the two. Except in cases of measurement error, the upper limit of the ratio between total sidewalk distance and total street distance is 2.00; a street segment cannot have more than twice the length of the right of way covered by sidewalks. Of the 1,929 participants currently under consideration, there are 4 cases where the ratio grossly exceeds this 2.00 upper limit; upon closer inspection, the overages appear to be paved paths which extend beyond existing road right of ways for the walkable street subset. Further inspection of these cases will be performed to determine if the observations should be cleaned or removed from consideration.

Table B-1 – Sidewalk Data Summary, All Cases

		Total linear feet of sidewalk estimated within the participant network buffer (accounting for both sides of street)	Total linear feet of walkable street surface (e.g.,excluding interstate highways and non pedestrian bridges) estimated within the participant network buffer	Ratio of sidewalk surface to street surface for walkable streets
N	Valid	1929	1929	1929
	Mean	100655.9237	77657.7754	1.1557

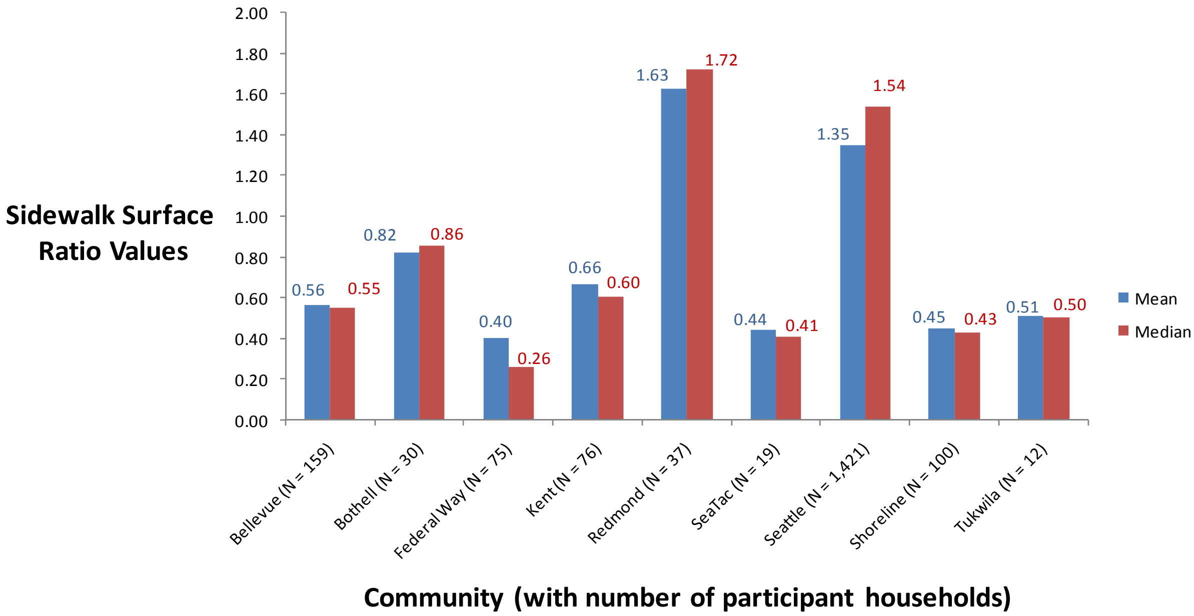
	Std. Deviation	72028.98115	31500.42945	.56829
	Minimum	.00	857.10	.00
	Maximum	251184.06	151562.44	2.71
	10 (N = 192)	13712.0311	32972.1592	.3119
Percentiles	30 (N = 386)	35610.6205	58743.7347	.7000
	50 (N = 386)	96435.7854	80329.5141	1.4238
	70 (N = 387)	154412.4903	99168.5355	1.6026
	90 (N =386)	201768.1323	116300.4673	1.7525

Table B-1 provides the mean, median and values at specific percentile cut points for each of these variables, for all cases in the dataset. The average of the total linear sidewalk distance within each 1 km buffer is to 100,655.9 feet (19.06 miles); for total length of walkable street surface, the corresponding values is 77,657.8 feet (18.32 miles), and the ratio average is 1.1557 (i.e., there is, on average, an 15.57% greater amount of total sidewalk distance than street surface within a participant's 1 km home location network buffer. Put another way, if total sidewalk coverage would is a ratio of 2.00, 1.1557 represents about 60% sidewalk coverage.

Figure B-2 charts the mean and median sidewalk ratio values for participant households, grouped by their individual municipalities; more detailed analyses for the individual municipalities can be found in Appendix C.[4] These results are included for demonstration purposes only.

Figure B-2: Mean and Median Sidewalk Ratio Values for Participants, by Individual Municipality

[4] The number of observations in each percentile grouping are not reported in Appendix C, due to limited sample sizes in most municipalities.



The results in Table 2, while informative, illustrate the potential limitation of trying to analyze individual cities with the PSRC 2006 Household Activity and Travel Diary Survey. While the City of Seattle has sufficient sample size to indicate their values are representative for the entire city, smaller cities may not have sufficient sample size. If, for some unknown reason, the observations in Redmond were not representative of the City of Redmond as a whole (e.g., survey participants more prone to pedestrian behaviors in Redmond were more likely to locate in areas which support that travel mode, so they have better sidewalk connectivity within their buffer), then the values would not be representative for City of Redmond as a whole. In contrast, City of Seattle, with a much larger sample size, is more likely to be representative of the city as a whole.

2. Directions for Future Data Assembly Steps

While these assessments represent a useful first step, their primary role is to serve as the basis for further data development. Total linear feet of sidewalk is too gross a measure on which to identify a substantial magnitude of effect, and is also highly collinear with total street right of way within the 1 km buffer (R=+0.881 in the sample). Additionally, the ratio is an imperfect measure of the effects of sidewalks on VMT/CO_2 generation because the effect on inspiring pedestrian behavior is anticipated to be non-linear (i.e., going from 0 to 1 full side of the street covered with sidewalk surface is expected to be more effective than the additional gain of going from 1 to both sides of the street being covered).

In order to account for these effects, we would need to build more refined measures of sidewalk surface within the 1 km buffer area. Specifically, we would have to develop the percentage of walkable street surface within the 1 km buffer which has no sidewalks, sidewalks on one side of the street, and sidewalks on both sides of the street. Measures could also include the percentage of sidewalk coverage along routes to specific destinations (e.g., schools, parks, retail outlets, etc.).

3. Sidewalk Data Assembly Metadata Criteria Selection Notes

Bellevue—Data structure made it difficult to discern different types of non-motorized infrastructure (i.e., sidewalks vs. trails) and status (i.e., completed vs. scheduled vs. cancelled projects). Selected features where COMPLETEDA = <Null> and STATUS = ('I' or 'N'), then reversed selection to get viable sidewalk right of ways.

Bothell— Sidewalks recorded as polygons. Confirmed with Bothell staff (Ms. Wolfe), entire file is based on paved pedestrian right of way; no need to further subset the data.

Federal Way—Sidewalks were generated as part of impervious surface polygons, provided by Federal Way and Tacoma Fire Services District, by way of WSDOT. Selected only those polygons identified as "SIDEWALK" in the impervious surface file.

Kent—Entire file is based only on paved sidewalks (i.e., concrete or pavers, no asphalt sidings or unpaved gravel); no need to further subset the data. Removed from consideration all segments that were classified as CODE=3 (Crosswalks) or CODE=4 (Railroad Crossing)

Redmond—Sidewalk file did not contain information on date of construction, but did contain index related to street centerlines. Using street centerline as date of construction for the sidewalk, removed all sidewalk segments which were constructed during or after 2007.

Seattle—Removed from consideration all pedestrian segment which met any of the following conditions:

> <u>SurfType</u> LIKE "UImpv" OR;
> <u>SurfType</u> LIKE "Other" OR;
> <u>SurfType</u> LIKE "AC" AND (<u>CurbType</u> LIKE "None" OR <u>CurbType</u> LIKE "Rollcb" OR <u>CurbType</u> LIKE "TEAC" OR <u>CurbType</u> LIKE "TEPCC"

SeaTac—Entire file is based on paved pedestrian right of way; no need to further subset the data, but only covers centerlines. Manually inspected sidewalks vs. Google Streetviews (6/23/2010), identified which segments had viable sidewalks on only one side of street.

Shoreline—Selected features except those where FCODE = "Crosswalk"

Tukwila— Confirmed with City of Tukwilla staff contact, entire file is based on paved pedestrian right of way; no need to further subset the data.

4. Structure of UD4H Master File

Name: **UD4HKingCountySidewalkMasterLineArchive06242010.shp**
Projection: NAD 1983 HARN State Plane Washington—North
Map Units: Feet
N = 53,905 sidewalk segments, covering 9 municipalities from Appendix A.

<u>FID</u> – The line segment record ID automatically generated by ArcGIS

Shape - The geometry type for the line segment record. Fixed as "Polyline M" for all records. No analytic value for this project, although may be necessary for anyone doing additional geospatial data management.

TotPedLen – The total number of linear feet (on both sides of the street right of way) dedicated to viable pedestrian paths (i.e., grade separated, paved surface, regardless of pavement type (i.e., paving stone vs. concrete vs. asphalt, etc.)).
In general, TotPedLen is equivalent to the length of the line segment for a particular sidewalk in the municipal source file (see SourceCity, defined below). However, there are two notable exceptions to this rule:

1.) For SeaTac, whose source file only contained information on street centerlines where sidewalks existed, TotPedLen is calculated by doubling the length of the line segment in situations where sidewalks exist on both sides of the street (see notes on the municipal source file above).
2.) For Bothell and Federal Way, whose sidewalk source files were provided as polygons, the first step was to convert the polygons into polylines. These polylines could then have the length of their perimeter calculated. Using the perimeter as a starting point, and assuming a 4 ft. width of sidewalk surface, the length of each sidewalk element was calculated as:
    ([Length of Polyline] – 8)/2
    The reduction of the perimeter by 8 ft. accounts for the expected width of the sidewalk right of way; dividing the result in half returns the linear feet of sidewalk in the segment.

SourceCity – The municipal file from which the sidewalk source data was collected

APPENDIX C

Spreadsheet Tool Instructions

APPENDIX C: SPREADSHEET TOOL INSTRUCTIONS

The CO2 / VMT Spreadsheet Calculator can be used to estimate changes in transportation-related CO2 and Vehicle Miles Traveled (VMT) based on changes in urban form, sidewalks, transit service, and transit and parking pricing. The tool is, however, based on an incomplete, skewed dataset and therefore, in the opinion of the research team, may create results that are biased or incomplete.

Contents of the CO2 / VMT Calculator

The Calculator contains the following 6 tabs in an Excel workbook:

1. The correlation matrix of input variables
2. The final model results
3. The spreadsheet calculator
4. A lookup table for average AM Peak and Mid Day off peak for transit in-vehicle time, transit wait time, and transit fares (in 2006 constant dollars) from any zone in King County to any destination zone within King County.
5. The spreadsheet calculator results for Rainier Beach.
6. The spreadsheet calculator results for Bitter Lake.

Instructions for using the CO2 / VMT Calculator

- Green cells are intended for inputting raw data on existing/baseline conditions
- Blue cells are for inputting raw data on planned/change conditions
- Orange cells are values for model variables that are calculated from the input data. These cells are password-protected in order to prevent them from being accidentally altered. To change the password, use the menu tools > protection > unprotect sheet and enter the password co2vmt (case-sensitive). However, it is NOT recommended that the base formulas be changed. Changing the formulas should only be done in the case of updated research.
- Column A shows the input factors used for the estimates. The users will need to generate data on these factors in order to use the calculator.
- Column B has supplementary direction about data sources for the input factors, how they should be used /entered in the spreadsheet, and how they should be developed.

APPENDIX D

Working Assumptions Used in Case Study Analysis

APPENDIX D: WORKING ASSUMPTIONS USED IN CASE STUDY ANALYSIS

This memo summarizes the assumptions used for the City of Seattle case studies as part of the CO_2 / VMT analysis. Based on these assumptions, "existing conditions" and "change" scenarios were developed for two case studies in Seattle: Rainier Beach and Bitter Lake. Both neighborhoods are existing or planned station areas for high-speed transit (light rail in the case of Rainier Beach; BRT in the case of Bitter Lake).

1. Unless otherwise stated, all household characteristics discussed below are taken from PSRC population block group level estimates and projections for 2006.

2. All household / demographic values were held constant for the change scenarios in order to test the "pure" effect of policy / service / infrastructural changes in the area. To get average household size, total existing study area population was divided by existing number of households. Average household size was assumed to remain constant between the "existing conditions" and the "change" scenario.

3. The number of housing units and/or households for the baseline scenarios was used to calculate other input variables and to estimate the total daily CO_2 / VMT output for the study area. The number of housing units / households was estimated based on PSRC block group level population data. The block group level data was apportioned to the case study area based on the proportion of block group residential building floor area (in square ft) within each case study area. The formulae used were:

$$\sum_{b=1}^{B} \textit{Number of Housing Units per Block Group x } (\% \textit{ Block Group Residential Sq.Ft. Within Study Area})$$

$$\sum_{b=1}^{B} \textit{Number of Households per Block Group x } (\% \textit{ Block Group Residential Sq.Ft. Within Study Area})$$

where b = Index of all block groups intersecting the boundaries of a case study area

4. **Average number of workers** and **average number of children per household** were calculated using U.S. Census 2000 data, provided by PSRC. The percentages were calculated by multiplying the total number of households (U.S. Census 2000 SF3, Table P010), aggregate number of workers (U.S. Census 2000 SF3, Table P026), and aggregate number of children under age 16 (U.S. Census 2000 SF3, Table P008) by the percentage of residential square footage for each block group intersecting the study area,

and then summing to get weighted totals for number of workers, kids and households within each case study area. The weighted totals were then divided to get the average number of workers and children under 16 per household within each case study area.

5. **Average number of licensed vehicles per driver in household** was calculated using King County data from the PSRC 2006 Household Activity and Travel Diary survey. The number is based only on King County survey participant households with at least one licensed driver in the household (N = 2,617; $N_{\text{King County survey households}}$ = 2,699). No comparable block group level data exists to generate more refined estimates for the case study areas.

6. The **percentage of households above the county median income** was determined using population data for King County from U.S. Census 2000. The formula used was:

$$\sum_{b=1}^{B} \# \, Hh \text{ per Block Group} \times (\% \text{ Block Group Residential Sq.Ft. in Study Area}) \times (\% \, Hh \text{ Above County Median Income}$$

where b = Index of all block groups intersecting the boundaries of a case study area

7. The **signalized intersection density** values for the baseline scenarios were calculated using a 50 ft. buffer around the exterior of the study area border. This was done to ensure that intersections on boundary streets were included in the calculation of this variable. There was no change between the baseline and change scenarios for this measure.

8. Building square footage for the land use types used in the **land use mix** factor were calculated by crosstab of all parcels within the boundaries of the study area for the baseline scenarios. The totals for the change scenarios added square footage based on assumptions and totals sent to UD4H by the City of Seattle on 12/13/2010 and shown in the table below. The new non-residential floor area was divided among non-residential uses in proportion to existing area of each non-residential use.

Change Scenario Square Footage Assumptions	**Bitter Lake**	**Rainier Beach**
New non-residential floor area (sq ft)	174,000	22500

9. **Sidewalk ratios** for the baseline scenarios were calculated using a 50 ft. buffer around the exterior of the neighborhood border. This was done to ensure that sidewalks on both sides of boundary streets were included in the calculation of this variable for the case study areas. The value of 2.00 – equivalent of complete sidewalk coverage on both sides of all case study streets - for the

change scenarios is based on the specification of 100% sidewalk coverage.

10. **The number of transit routes servicing the case study area** in the baseline scenarios was determined by aggregating by route the active bus stops within a 50 ft. buffer around the case study area. The 50 ft. buffer was used to ensure that bus stops on boundary streets were included in the calculation of this variable for the case study areas. The number of bus routes used in the change scenarios was provided by the City of Seattle. The only change from the baseline was in the Rainier Beach area, where the number of bus routes was reduced from 12 routes to 10 routes through the case study area.

11. The baseline scenario values for **jobs/population balance** were calculated based on proportions of residential and employment related building floor area (in square ft) within the census block groups intersecting the case study areas. To apportion the block group level population and employment to the case study area, for each block group that intersected the case study area, the proportion of block group residential / employment building floor area (in square ft) within each case study area was multiplied by the population / jobs estimate for that block group. The block group level totals were then summed. The formula below illustrates this procedure:

$$\sum_{b=1}^{B} PSRC\ 2006\ Block\ Group\ Population\ Estimates\ \ x\ (\%\ Block\ Group\ Residential\ Sq.Ft.\ in\ Study\ Area)$$

$$\sum_{b=1}^{B} PSRC\ 2006\ Block\ Group\ Employment\ Estimates\ \ x\ (\%\ Block\ Group\ Employment\ Sq.Ft.\ in\ Study\ Area)$$

where b = Index of all block groups intersecting the boundaries of a case study area

To create the final jobs / population balance ratio, the estimated case study employment was divided by estimated case study population.

The change scenario numbers were the sum of the baseline values, plus the additional households (multiplied by average household size to get total additional population) and jobs for each case study area as sent from the City of Seattle to UD4H on 12/13/2010, shown in the table below:

Change Scenario Job / Housing Assumptions	**Bitter Lake**	**Rainier Beach**
New Residential Housing Units	2000	500
New Jobs	1200	150

12. **Average transit travel and wait times** from the case study area were calculated according to the following formulae:

$$\sum_{t=1}^{T}\left(\begin{matrix}(25\%\ Avg.\ AM\ Peak\ Bus\ Travel\ Time\ from\ TAZ\ throughout\ King\ County) +\\ (75\%\ Avg.\ MidDayBus\ Travel\ Time\ from\ TAZ\ througout\ King\ County)\end{matrix}\right) \times \frac{(Area\ of\ TAZ\ Segment\ intersecting\ Case\ Study\ Area)}{(Total\ Area\ within\ Case\ Study\ Boundaries)}$$

$$\sum_{t=1}^{T}\left(\begin{matrix}(25\%\ Avg.\ AM\ Peak\ Bus\ Travel\ Time\ from\ TAZ\ to\ all\ TAZs\ within\ King\ County) +\\ (75\%\ Avg.\ MidDayBus\ Travel\ Time\ from\ TAZ\ to\ all\ TAZs\ within\ King\ County)\end{matrix}\right) \times \frac{(Area\ of\ TAZ\ Segment\ intersecting\ Case\ Study\ Area)}{(Total\ Area\ within\ Case\ Study\ Boundaries)}$$

$$\sum_{t=1}^{T}\left(\begin{matrix}(25\%\ Avg.\ AM\ Peak\ Bus\ Wait\ Time\ from\ TAZ\ throughout\ King\ County) +\\ (75\%\ Avg.\ MidDayBus\ Wait\ Time\ from\ TAZ\ througout\ King\ County)\end{matrix}\right) \times \frac{(Area\ of\ TAZ\ Segment\ intersecting\ Case\ Study\ Area)}{(Total\ Area\ within\ Case\ Study\ Boundaries)}$$

where t = Index of all originating TAZs intersecting the boundaries of a case study area

The 25% peak/75% off peak split is consistent with the average travel time variable created for the final model, based on the premise that 25% of PSRC's estimated network travel times fall within peak (i.e., rush hour) conditions. Because all PSRC travel and wait time estimates are TAZ based, a weighting factor is applied to apportion the TAZ-level estimate to the case study area. As per instructions from the City of Seattle on 11/24/2010, the case study area future conditions leaves average travel time the same, but reduces wait time by 20%.

13. **Average hourly parking charges** were calculated based on the average of all King County TAZs that have non-zero parking charges, using PSRC data on parking costs. All costs are in 2006 constant dollars.

14. For **average transit trip fares**, the baseline estimate of average fares per trip originating from the case study area was calculated according to the following formula:

$$\sum_{t=1}^{T}\left(\begin{matrix}\mathbf{(25\%\ Avg.\ AM\ Peak\ Bus\ Fare\ from\ TAZ\ throughout\ King\ County) +}\\ \mathbf{(75\%\ Avg.\ MidDayBus\ Fare\ from\ TAZ\ througout\ King\ County)}\end{matrix}\right) \mathbf{x} \frac{\mathbf{(Area\ of\ TAZ\ Segment\ intersecting\ Case\ Study\ Area)}}{\mathbf{(Total\ Area\ within\ Case\ Study\ Boundaries)}}$$

where t = Index of all originating TAZs intersecting the boundaries of a case study area

As directed by the City of Seattle in discussions with UD4H on 11/24/2010, there were no changes from the baseline applied for this factor, because any future fare increases are expected only to be adjustments for inflation.

15. Lastly, it was necessary to calculate a total number of households in the “change” scenarios in order to calculate the total CO_2 and VMT for each study area. Arriving at a total number of households meant converting the number of housing units provided by the City, because households are by definition occupied housing units. Using the existing number of households and the existing number of housing units, a vacancy rate was derived. The vacancy rate was applied to the number of housing units provided by the City for the change scenarios.

APPENDIX E

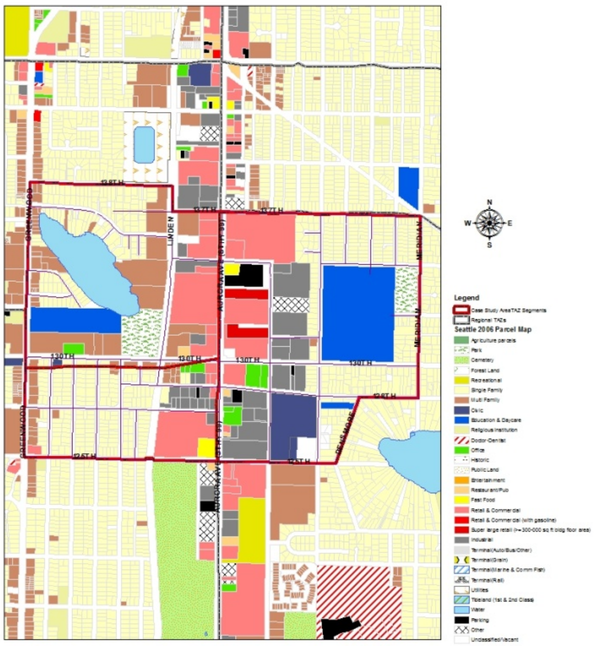
Apportioning Information Between Different Geographies

APPENDIX E: APPORTIONING INFORMATION BETWEEN DIFFERENT GEOGRAPHIES

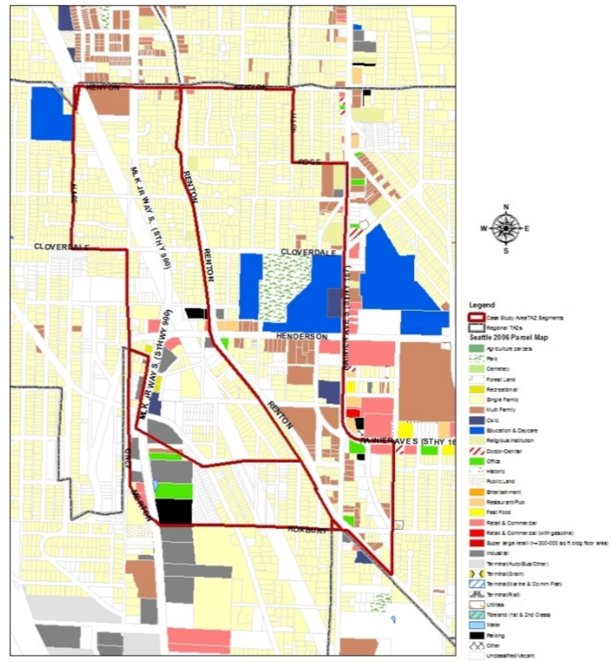
Overview

In the course of completing the case studies for this project, it became necessary to assign information from one spatial boundary to another. As an example, determining average bus travel and wait time for the case study areas required the information on these measures, provided by PSRC and stored at the TAZ level, applied to the neighborhood areas within the case study boundaries. Upon closer inspection, it became apparent that the case study area and TAZ boundaries did not overlap in such a way that one completely circumscribed the other. The study area maps below illustrate the point: the gray areas are the boundaries of the TAZs which intersect the case study areas, while the red areas are the proportions of those TAZs which actually fall within the case study area boundaries.

Bitter Lake



Rainier Beach



These inconsistencies in boundary areas raise the question of how to properly apportion the information in the TAZs to the case study areas. After careful consideration, it was determined that each TAZ should have its travel and wait time data assigned to the case study area based on the proportion of area that lay within the neighborhood boundary. Estimating the proportion of a TAZ within each case study neighborhood was achieved by using the Intersect Tool in ArcGIS 9.3.1 to "cut" the relevant areas of each TAZ for each case study neighborhood. With that information in hand, the only remaining issue was a simple percentage apportionment and summing.

As an example, since TAZ #8 in the PSRC database covers 46.76% of the area in Bitter Lake, the average values of AM Peak and Mid Day Bus Travel and Wait Time from TAZ #8 to all other TAZs within King County, were multiplied by 0.4676 to get the contribution of that TAZ to the bus and wait times for the Bitter Lake neighborhood. The process was then repeated for TAZ #4, #6 and #8, (making up 0.02%, 34.69% and 18.53% of the Bitter Lake area, respectively).

The proportional times from each TAZ were then summed, in order to estimate the full estimate of AM Peak and Mid Day Bus Travel and Wait Time from the Bitter Lake area. Finally, these full estimates were weighted according to the 25%/75% split for peak vs. off peak operations, then added together to calculate a weighted average of bus travel and wait times from Bitter Lake to any destination within King County. The same process was followed for the TAZs covering the Rainier Beach neighborhood.

Generalizability, Assumptions and Limitations

One benefit of this procedure is it can be easily replicated with other administrative geographies (e.g., assigning information from a Census Tract, Block Group, or ZIP code to a neighborhood or TAZ). To facilitate that end, the spreadsheet tool includes a table of average wait time, travel time, imputed parking charge and imputed transit fares, for both AM and Mid Day travel conditions, from each TAZ in King County to all other destination TAZs within King County. These estimates are based on the PSRC 2006 network skims. With that information already summarized, all that would be necessary to replicate the wait time, travel time, and transit fares (in 2006 constant dollars) estimates developed in this project for any neighborhood would be the proportional area of each TAZ covering the neighborhood boundaries.

Lastly, it is important to note there is an implicit assumption in this method; a uniform distribution of the attribute over the entire geographic space of the target area (e.g., the population of Census Block Group XXX is uniformly distributed/not concentrated anywhere; every location within TAZ #8 is equally well served by transit, so that the average bus travel and wait times are uniformly applicable to all households in a zone). In some cases, such assumptions may not be warranted. This can be partially addressed in the way the proportional contributions from each zone are calculated (e.g., assigning population of a census block group by proportion of residential square footage in the block group that falls within a study area).

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Final Model Recommendations: 12-20-2010

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

	Household Daily VMT (Remove VMT Outliers)				Household Daily CO2 (Remove CO2 Outliers)			
	Coefficient	T	Beta	VIF	Coefficient	T	Beta	VIF
1. Total number of workers in the household	**8.8157**	**13.56**	**0.3070**	1.25	**3670.4220**	**14.72**	**0.3258**	1.25
2. Total number of children age 16 or younger in the household	**4.6306**	**6.64**	**0.1440**	1.15	**2148.0400**	**8.03**	**0.1702**	1.15
3. Number of vehicles per licensed driver (blank for households with no licensed drivers)	**5.2573**	**4.84**	**0.1103**	1.27	**2068.4330**	**4.97**	**0.1106**	1.26
4. Dummy variable indicating household reported higher income than CPI adjusted King County median (i.e., $64,324.44; 1 = Above Median, 0 = At or Below Median)	**3.2460**	**3.50**	**0.0735**	1.08	***624.5501***	***1.75***	***0.0360***	1.08
5. Signalized Intersection Density within 1km network buffer around household location	0.1900	1.20	0.0769	**10.09**	71.7513	1.18	0.0740	**10.10**
6. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office residential, and retail uses) for 1km network buffer around household location	------------	------------	------------	------------	**-3890.2870**	**-2.53**	**-0.0702**	1.96
6a. Mixed Use Index (based on building sq. ft. of civic & education, entertainment, office, and retail uses; no residential square footage) for 1km network buffer around household location	**-10.1157**	**-2.05**	**-0.0579**	1.95	------------	------------	------------	------------
7. Ratio of total sidewalk length within the 1km buffer compared to total length of street right of way within 1km buffer (Min.=0, Max = 2.00)	-1.2152	-1.15	-0.0290	1.56	***-734.6875***	***-1.81***	***-0.0447***	1.55
8. Number of different bus routes served by King County, Community Transit and/or Pierce Transit for the active stops within the 1km buffer for the household	-0.0812	-1.18	-0.0720	**9.06**	-30.8855	-1.17	-0.0697	**9.03**
9. Jobs/Housing balance for the census block group where the household is located, based on the regional avg. jobs/housing ratio for King County ONLY	-2.9433	-1.53	-0.0332	1.16	-880.9328	-1.19	-0.0253	1.15
*10. Weighted Average of Bus In Vehicle Time**	***0.0836***	***1.92***	***0.0597***	2.34	**32.6198**	**1.96**	**0.0593**	2.35
*11. Weighted Average of Bus Wait Time***	**0.3130**	**2.40**	**0.0683**	1.98	**130.0958**	**2.64**	**0.0733**	1.97
12. Household average of imputed parking charges per person ($/Hr, in 2006 Constant Dollars), using PSRC zone based parking survey data and trips reported by household occupants	**-3.6693**	**-7.74**	**-0.1758**	1.26	**-1360.8620**	**-7.49**	**-0.1661**	1.26
13. Household average of imputed transit fares per person ($/trip, in 2006 Constant Dollars), using PSRC zone based fare estimate data and trips reported by household occupants	**10.3679**	**5.51**	**0.1163**	1.09	**4163.8020**	**5.83**	**0.1202**	1.08
Regression Constant	-7.9403	-1.34	NA	NA	-1717.5720	-0.76	NA	NA
R^2				0.3277				0.357
Adj. R^2				0.3223				0.3519
Root MSE (aka Std. Error of the Estimate)				19.594				7518.4
N				1654				1655

Note: Coefficients in **bold** are significant at the 5% level

Coefficients in ***bold italic*** are significant at the 10% level

Coefficients with **bold red** VIF values are likely co-linear

** Weighted Average of Bus In Vehicle Time =* .25 x AM Peak Period Bus In Vehicle Time (Mins) + .75 x Mid Day Period Bus In Vehicle Time (Mins)

*** Weighted Average of Bus Wait Time =* .25 x AM Peak Period Bus Wait Time (Mins) + .75 x Mid Day Period Bus Wait Time (Mins)

BITTER LAKE: CASE STUDY RESULTS

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

INPUT FACTORS	Existing Conditions in Plan Area			Anticipated Conditions in Plan Area			Percentage Changes	
		Estimated VMT	Estimated CO2		Estimated VMT	Estimated CO2		
Average Number of Workers per Household	0.86	7.57	3151.37	0.86	7.57	3,151.37	0.00%	
Average Number of Children per Household	0.16	0.72	335.65	0.16	0.72	335.65	0.00%	
Average Number of Vehicles per Licensed Driver in Household	1.10	5.77	2270.23	1.10	5.77	2,270.23	0.00%	
Percentage of Households Above County Median Income	0.27	0.86	165.89	0.27	0.86	165.89	0.00%	
Signalized Intersection Density	6.86	1.30	492.46	6.86	1.30	492.46	0.00%	
Land Use Mix		-6.39	-2229.27		-6.39	-1,781.27	0.00%	
Civic & Educational Sq. Footage	*337,813*			*384,069*				
Entertainment Square Footage	*0*			*0*				
Office Square Footage	*130,424*			*148,283*				
Residential Square Footage	*2,587,623*			*4,887,623*				
Retail Square Footage	*802,506*			*912,391*				
Subtotal of Sq. Footage for Mixed Use Index		1,270,743.00	3,858,366.00		1,444,743.00	6,332,366.00		
Mixed Use Index Value		0.63	0.57		0.63	0.46		
Sidewalk Ratio	0.60	-0.73	-441.92	*2*	-2.43	-1,469.38	232.50%	
Number of Transit Routes servicing the area	6	-0.49	-185.31	6	-0.49	-185.31	0.00%	
Jobs/Population Balance	0.95	-2.81	-840.83	0.9310715	-2.74	-820.21	-2.45%	
Total Employment	2548.20			3748.20				
Total Population	4062.00			7513.94				
Average Transit Travel Time	105.68	8.84	3447.15	105.68	8.84	3,447.15	0.00%	
Average Transit Wait Time	12.59	3.94	1637.57	10.069918	3.15	1,310.05	-20.00%	
Average hourly parking charge	4.36	-16.01	-5937.50	4.36	-16.01	-5,937.50	0.00%	
Average transit trip fare	2.04	21.17	8500.40	2.04	21.17	8,500.40	0.00%	
Household Constant (assuming all other impact factors balance to ze		-7.94	-1717.57		-7.94	-1,717.57		
		Daily VMT	**Daily CO2 (grams)**		**Daily VMT**	**Daily CO2 (grams)**	**Daily VMT**	**Daily CO2 (grams)**
Estimate of Average Household Output		**15.80**	**8648.32**		**13.39**	**7,761.96**	**-15.30%**	**-10.25%**
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		54.31	23,421.97		51.89	22,535.62		
Number of Households in Planning Area	2236.05			4,136.27				
Estimated Total Planning Area Output		**35,338.95**	**19,338,077.35**		**55,366.63**	**32,105,599.44**		
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		121,431.84	52,372,720.75		214,622.30	93,213,483.73		

BITTER LAKE: CASE STUDY RESULTS

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

INPUT FACTORS	Existing Conditions in Plan Area			Anticipated Conditions in Plan Area			Percentage Changes		
		Estimated VMT	Estimated CO2		Estimated VMT	Estimated CO2			
Average Number of Workers per Household	0.86	7.57	3151.37	0.86	7.57	3,151.37	0.00%		
Average Number of Children per Household	0.16	0.72	335.65	0.16	0.72	335.65	0.00%		
Average Number of Vehicles per Licensed Driver in Household	1.10	5.77	2270.23	1.10	5.77	2,270.23	0.00%		
Percentage of Households Above County Median Income	0.27	0.86	165.89	0.27	0.86	165.89	0.00%		
Signalized Intersection Density	6.86	1.30	492.46	6.86	1.30	492.46	0.00%		
Land Use Mix		-6.39	-2229.27		-8.10	-1,910.20	26.69%		
Civic & Educational Sq. Footage	*337,813*			*384,069*					
Entertainment Square Footage	*0*			*50,000*					
Office Square Footage	*130,424*			*250,000*					
Residential Square Footage	*2,587,623*			*4,887,623*					*562200*
Retail Square Footage	*802,506*			*760,673*					
Subtotal of Sq. Footage for Mixed Use Index		1,270,743.00	3,858,366.00		1,444,741.98	6,332,364.98			
Mixed Use Index Value		0.63	0.57		0.80	0.49			
Sidewalk Ratio	0.60	-0.73	-441.92	2	-2.43	-1,469.38	232.50%		
Number of Transit Routes servicing the area	6	-0.49	-185.31	6	-0.49	-185.31	0.00%		
Jobs/Population Balance	0.95	-2.81	-840.83	0.9310715	-2.74	-820.21	-2.45%		
Total Employment	2548.20			3748.20					
Total Population	4062.00			7513.94					
Average Transit Travel Time	105.68	8.84	3447.15	100.00	8.36	3,261.98	-5.37%		
Average Transit Wait Time	12.59	3.94	1637.57	9	2.82	1,170.86	-28.50%		
Average hourly parking charge	4.36	-16.01	-5937.50	5.00	-18.35	-6,804.31	14.60%		
Average transit trip fare	2.04	21.17	8500.40	2.00	20.74	8,327.60	-2.03%		
Household Constant (assuming all other impact factors balance to ze		-7.94	-1717.57		-7.94	-1,717.57			
		Daily VMT	Daily CO2 (grams)		Daily VMT	Daily CO2 (grams)	Daily VMT	Daily CO2 (grams)	
Estimate of Average Household Output		**15.80**	**8648.32**		**8.10**	**6,269.06**	**-48.73%**	**-27.51%**	
95% Confidence Interval									
Lower Bound		-	-		-	-			
Upper Bound		54.31	23,421.97		46.60	21,042.72			
Number of Households in Planning Area	2236.05			4,136.27					
Estimated Total Planning Area Output		**35,338.95**	**19,338,077.35**		**33,514.22**	**25,930,547.88**			
95% Confidence Interval									
Lower Bound		-	-		-	-			
Upper Bound		121,431.84	52,372,720.75		192,769.90	87,038,432.18			

RAINIER BEACH: CASE STUDY RESULTS

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

INPUT FACTORS	Existing Conditions in Plan Area			Anticipated Conditions in Plan Area			Percentage Changes	
		Estimated VMT	Estimated CO2		Estimated VMT	Estimated CO2		
Average Number of Workers per Household	1.39	12.28	5,112.09	1.39	12.28	5,112.09	0.00%	
Average Number of Children per Household	0.86	3.99	1,850.16	0.86	3.99	1,850.16	0.00%	
Average Number of Vehicles per Licensed Driver in Household	1.10	5.77	2,270.23	1.10	5.77	2,270.23	0.00%	
Percentage of Households Above County Median Income	0.37	1.19	228.10	0.37	1.19	228.10	0.00%	
Signalized Intersection Density	4.10	0.78	294.44	4.10	0.78	294.44	0.00%	
Land Use Mix		-4.83	-1,329.54		-6.63	-1,257.97	37.18%	
Civic & Educational Sq. Footage	*280,193*			*260,000*				
Entertainment Square Footage	*0*			*11,774*				
Office Square Footage	*20,504*			*33,000*				*5226*
Residential Square Footage	*1,875,473*			*2,450,473*				
Retail Square Footage	*61,577*			*80,000*				
Subtotal of Sq. Footage for Mixed Use Index		362,274.00	2,237,747.00		384,774.00	2,835,247.00		
Mixed Use Index Value		0.48	0.34		0.66	0.32		
Sidewalk Ratio	1.04	-1.27	-766.47	2	-2.43	-1,469.38	91.71%	
Number of Transit Routes servicing the area	12	-0.97	-370.63	10	-0.81	-308.85	-16.67%	
Jobs/Population Balance	0.26	-0.78	-232.75	0.27	-0.79	-236.59	1.65%	
Total Employment	402.24			552.24				
Total Population	4614.36			6216.59				
Average Transit Travel Time	92.27	*7.72*	*3,009.67*	90.00	*7.53*	*2,935.78*	-2.46%	
Average Transit Wait Time	8.91	*2.79*	*1,159.26*	6.5	*2.03*	*845.62*	-27.06%	
Average hourly parking charge	4.36	*-16.01*	*-5,937.50*	5.00	*-18.35*	*-6,804.31*	14.60%	
Average transit trip fare	2.04	*21.16*	*8,497.95*	2.00	*20.74*	*8,327.60*	-2.00%	
Household Constant (assuming all other impact factors balance to zero)		-7.94	-1,717.57		-7.94	-1,717.57		
		Daily VMT	**Daily CO2 (grams)**		**Daily VMT**	**Daily CO2 (grams)**	**Daily VMT**	**Daily CO2 (grams)**
Estimate of Average Household Output		23.8653	12,067.44		17.35	10,069.36	-27.30%	-16.56%
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		62.37	26,841.10		55.85	24,843.01		
Number of Households in Planning Area	1370.20			1,845.97				
Estimated Total Planning Area Output		32,700.21	16,534,819.22		32,026.79	18,587,750.44		
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		85,455.98	36,777,698.18		103,100.79	45,859,504.44		

RAINIER BEACH: CASE STUDY RESULTS

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

INPUT FACTORS	Existing Conditions in Plan Area			Anticipated Conditions in Plan Area			Percentage Changes	
		Estimated VMT	Estimated CO2		Estimated VMT	Estimated CO2		
Average Number of Workers per Household	1.39	12.28	5,112.09	1.39	12.28	5,112.09	0.00%	
Average Number of Children per Household	0.86	3.99	1,850.16	0.86	3.99	1,850.16	0.00%	
Average Number of Vehicles per Licensed Driver in Household	1.10	5.77	2,270.23	1.10	5.77	2,270.23	0.00%	
Percentage of Households Above County Median Income	0.37	1.19	228.10	0.37	1.19	228.10	0.00%	
Signalized Intersection Density	4.10	0.78	294.44	4.10	0.78	294.44	0.00%	
Land Use Mix		-4.83	-1,329.54		-4.83	-1,177.17	0.00%	
Civic & Educational Sq. Footage	*280,193*			*297,595*				
Entertainment Square Footage	*0*			*0*				
Office Square Footage	*20,504*			*21,777*				
Residential Square Footage	*1,875,473*			*2,450,473*				
Retail Square Footage	*61,577*			*65,401*				
Subtotal of Sq. Footage for Mixed Use Index		362,274.00	2,237,747.00		384,774.00	2,835,247.00		
Mixed Use Index Value		0.48	0.34		0.48	0.30		
Sidewalk Ratio	1.04	-1.27	-766.47	2	-2.43	-1,469.38	91.71%	
Number of Transit Routes servicing the area	12	-0.97	-370.63	10	-0.81	-308.85	-16.67%	
Jobs/Population Balance	0.26	-0.78	-232.75	0.27	-0.79	-236.59	1.65%	
Total Employment	402.24			552.24				
Total Population	4614.36			6216.59				
Average Transit Travel Time	92.27	*7.72*	*3,009.67*	92.26	*7.72*	*3,009.52*	0.00%	
Average Transit Wait Time	8.91	*2.79*	*1,159.26*	7.128662946	*2.23*	*927.41*	-20.00%	
Average hourly parking charge	4.36	*-16.01*	*-5,937.50*	4.36	*-16.01*	*-5,937.50*	0.00%	
Average transit trip fare	2.04	*21.16*	*8,497.95*	2.04	*21.16*	*8,497.95*	0.00%	
Household Constant (assuming all other impact factors balance to zero)		-7.94	-1,717.57		-7.94	-1,717.57		
		Daily VMT	**Daily CO2 (grams)**		**Daily VMT**	**Daily CO2 (grams)**	**Daily VMT**	**Daily CO2 (grams)**
Estimate of Average Household Output		23.8653	12,067.44		22.29	11,342.84	-6.58%	-6.00%
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		62.37	26,841.10		60.80	26,116.50		
Number of Households in Planning Area	1370.20			1,845.97				
Estimated Total Planning Area Output		32,700.21	16,534,819.22		41,154.16	20,938,565.94		
95% Confidence Interval								
Lower Bound		-	-		-	-		
Upper Bound		85,455.98	36,777,698.18		112,228.16	48,210,319.94		

HOUSEHOLD LEVEL CO2/VMT CALCULATOR

The CO2 / VMT Spreadsheet Calculator can be used to estimate changes in transportation-related CO2 and Vehicle Miles Traveled (VMT) based on changes in urban form, sidewalks, transit service, and transit and parking pricing.

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

Contents of the CO2 / VMT Calculator

The Calculator contains the following tabs:

1. The correlation matrix of input variables
2. The final model results
3. The spreadsheet calculator
4. These instructions
5. A lookup table for average AM Peak and Mid Day off peak for transit in-vehicle time, transit wait time, and transit fares (in 2006 constant dollars) from any traffic analysis zone (TAZ) in King County to all other destination TAZs within King County. For instructions on how to apply these numbers to a non-TAZ geography, see Appendix C of the final WSDOT research report WA-RD 765.1, or refer to the "instructions for apportioning the TAZ transit time / fare data" below.

Instructions for using the CO2 / VMT Calculator

Green cells: user input needed for existing conditions scenario

Blue cells: user input needed for change / future scenario

Orange cells: estimates based on other calculations

cells containing formulas are password protected. To change the password, use the menu tools > protection > unprotect sheet and enter the password co2vmt (case-

Column A shows the input factors used for the estimates. The user will need to generate data on these factors in order to use the calculator.

Column B has supplementary direction about data sources for the input factors, how they should be used /entered in the spreadsheet, and how they should be developed.

To see final **land use mix** values, UNHIDE rows 22 and 23.

Instructions for apportioning the TAZ transit time / fare data

When inserting transit travel time and fare data into the spreadsheet tool, it will likely be necessary to assign information from one spatial boundary to another. The transit travel time and fare data is based on travel model output data from the PSRC at the TAZ (traffic analysis zone) level. Each TAZ should have its travel, wait time and fare data assigned to the case study area based on the proportion of area within the study area boundary.

The spreadsheet tool includes a table of average wait time, travel time, imputed parking charge and imputed transit fares, for both AM and Mid Day travel conditions, from each TAZ in King County to all other destination TAZs within King County (see adjacent tab "**TAZAvgTransitTimesandFares**"). The proportion of a TAZ within each case study neighborhood can be estimated using the Intersect Tool in ArcGIS 9.3.1 to "cut" the relevant areas of each TAZ for each case study neighborhood.

For example, if TAZ #8 covers 46.76% of a particular study area, average values for AM peak and mid day Transit Travel and Wait Time from TAZ #8 to all other TAZs within King County should be multiplied by 0.4676 to get the contribution of that TAZ to the transit and wait times for that study area. The process should then be repeated for the other TAZs that overlap the study area.

The proportional times from each TAZ should be summed in order to generate a total estimated AM Peak and Mid Day Transit Travel and Wait Time for the study area. Finally, these estimates should be weighted 25%/75% for AM peak vs. mid day operations, then added together. This will result in a weighted average of transit travel and wait times for the study area.

HOUSEHOLD LEVEL CO2/VMT CALCULATOR

DISCLAIMER: these results are based on incomplete, skewed data and therefore, in the opinion of the research team, may be biased or incomplete. These results are due to factors outside of our control.

Key to color scheme:

Green cells: user input needed for existing conditions scenario
Blue cells: user input needed for change / future scenario
Orange cells: estimates based on other calculations

cells containing formulas are password protected. Password is co2vmt (case sensitive); however changing cell formulas is not recommended

INPUT FACTORS	*Instructions / Data Source*	Existing Conditions in Plan Area			Anticipated Conditions in Plan Area			Percentage Changes	
			Estimated VMT	Estimated CO2		Estimated VMT	Estimated CO2		
Average Number of Workers per Household	*PSRC can provide census block group level data*		0	0		0	0	0.00%	
Average Number of Children per Household	*PSRC can provide census block group level data*		0	0		0	0	0.00%	
Average Number of Vehicles per Licensed Driver in Household	*PSRC can provide census block group level data*		0	0		0	0	0.00%	
Percentage of Households Above County Median Income	*Format as decimal (e.g., enter 25% as 0.25). Census, PSRC or local data*		0	0		0	0	0.00%	
Signalized Intersection Density	*Per square kilometers. Use GIS data or hand count*		0	0		0	0	0.00%	
Land Use Mix			0	0		0	0	0.00%	
Civic & Educational Sq. Footage	*Use local planning data / information / projections*								
Entertainment Square Footage	*Use local planning data / information / projections*								
Office Square Footage	*Use local planning data / information / projections*								
Residential Square Footage	*Residential square footage is included in the calculation*								
Retail Square Footage	*Use local planning data / information / projections*								
Sidewalk Ratio	*Ratio of total sidewalk length to street right of way*		0	0		0	0	0.00%	
Number of Transit Routes servicing the area			0	0		0	0	0.00%	
Jobs/Population Balance	***Expressed in relation to the average jobs/population***	0	0	0	0	0	0	0.00%	
Total Employment	*PSRC can provide census block group level data. Local planning data and projections can also be used.*								
Total Population	*PSRC can provide census block group level data. Local planning data and projections can also be used.*								
Average Transit Travel Time	*any TAZ in King County, based on PSRC model data and*		*0*	*0*		*0*	*0*	0.00%	
Average Transit Wait Time	*any TAZ in King County, based on PSRC model data and*		*0*	*0*		*0*	*0*	0.00%	
Average hourly parking charge	*King County average, based on PSRC travel model data*		*0*	*0*		*0*	*0*	0.00%	
Average transit trip fare	*Average for King County, for trips originating from planning area TAZ(s). Use 2006 constant dollars*		*0*	*0*		*0*	*0*	0.00%	
Household Constant (assuming all other impact factors balance to zero)			-7.9403	-1717.5720		-7.9403	-1717.5720		
			Daily VMT	Daily CO2 (grams)		Daily VMT	Daily CO2 (grams)	Daily VMT	Daily CO2 (grams)
Estimate of Average Household Output			(7.9403)	(1,717.57)		(7.94)	(1,717.57)	0.00%	0.00%
95% Confidence Interval									
Lower Bound			-	-		-	-		
Upper Bound			30.56	13,056.08		30.56	13,056.08		
Number of Households in Planning Area									
Estimated Total Planning Area Output			-	-		-	-		
95% Confidence Interval									
Lower Bound			-	-		-	-		
Upper Bound			-	-		-	-		

TAZ Average Transit Times and Fares

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
1	106.8418802	10.20470244	100.9360939	11.60195681	2.038528243	1.3199999
2	103.8161547	7.557461918	99.8659449	11.07078528	2.038528243	1.3199999
3	112.5438596	11.33414475	107.2639803	15.11097747	2.038528243	1.3199999
4	111.369292	9.592772328	100.887921	14.10036676	2.038528243	1.3199999
5	120.3000841	10.20020988	115.5160472	12.41307806	2.038528243	1.3199999
6	109.0320114	15.76283912	106.3225302	18.5048156	2.038528243	1.3199999
7	121.3683942	18.60188116	116.8034597	25.59909715	2.038528243	1.3199999
8	95.16120686	9.439563474	97.58373096	11.29657163	2.038528243	1.3199999
9	106.5261908	11.27223228	102.8581688	12.60415697	2.038528243	1.3199999
10	104.7339774	7.577070665	100.4746097	11.08772632	2.038528243	1.3199999
11	106.7634181	12.71540299	101.3072446	11.60978731	2.038528243	1.3199999
12	103.0949262	13.83072957	97.92624394	23.11375818	2.038528243	1.3199999
13	104.1551577	15.0307291	98.48152809	14.4239341	2.038528243	1.3199999
14	101.3027188	10.55879695	97.61436179	14.21135702	2.038528243	1.3199999
15	97.99150934	6.187470731	103.1235246	6.557185298	2.038528243	1.3199999
16	97.92125646	6.141102021	103.0716977	6.506558283	2.038528243	1.3199999
17	93.48577324	7.877589385	95.15586105	9.091004784	2.038528243	1.3199999
18	101.8591068	10.40420875	104.2041868	10.82011363	2.038528243	1.3199999
19	104.3420819	8.100113701	110.3799452	10.36607528	2.038528243	1.3199999
20	110.8778851	13.66925778	109.8402917	14.57019033	2.038528243	1.3199999
21	113.3639242	13.66925764	113.1417116	18.09752262	2.038528243	1.3199999
22	94.79887033	7.889961398	97.12472854	8.953594045	2.038528243	1.3199999
23	99.85828485	7.994007268	102.8930193	10.35544865	2.038528243	1.3199999
24	88.57245922	7.401294763	87.50335705	8.813485535	2.038528243	1.3199999
25	101.4608565	6.960247322	106.4140564	7.461294637	2.038528243	1.3199999
26	90.92408562	11.82316003	93.66805533	13.4267888	2.038528243	1.3199999
27	99.5776149	16.24999963	100.4216871	23.84712262	2.038528243	1.3199999
28	103.3972027	13.81266704	101.4342126	23.81865871	2.038528243	1.3199999
29	104.073182	13.83880222	101.2925304	23.39826757	2.038528243	1.3199999
30	96.06235248	14.64009635	91.46879568	14.05443334	2.038528243	1.3199999
31	95.47678714	13.98331295	91.41140329	13.76789342	2.038528243	1.3199999
32	92.47551196	9.648125828	90.72666154	13.90292285	2.038528243	1.3199999

TAZ Average Transit Times and Fares

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
33	84.33062452	9.71349938	84.71495646	12.21397974	2.038528243	1.3199999
34	90.15577307	9.06858188	90.64849981	9.141930404	2.038528243	1.3199999
35	92.8037706	8.698106063	92.58575661	8.447861633	2.038528243	1.3199999
36	87.59282916	9.450037321	86.48308725	11.4880721	2.038528243	1.3199999
37	95.09341287	10.86353081	97.1363565	10.94741188	2.038528243	1.3199999
38	96.52281323	11.21351693	100.524373	12.84433662	2.038528243	1.3199999
39	104.0100734	6.500378428	106.7713591	7.605008057	2.038528243	1.3199999
40	101.6611794	12.68931247	107.3910486	13.01604907	2.038528243	1.3199999
41	95.12657304	9.979960643	99.34954978	13.0312802	2.038528243	1.3199999
42	93.67878474	7.731657572	97.74855769	10.14853075	2.038528243	1.3199999
43	95.48484916	11.22026882	96.03600147	13.98082802	2.038528243	1.3199999
44	95.64564133	9.136326166	96.96730646	11.3916598	2.038528243	1.3199999
45	90.15995497	7.826953347	92.32961305	11.27394173	2.038528243	1.3199999
46	89.19940867	12.03323646	86.69298247	12.59238803	2.038528243	1.3199999
47	92.89779291	7.536340103	89.64614636	8.666819245	2.038528243	1.3199999
48	88.15501217	8.001558343	91.72539971	10.29588525	2.038528243	1.3199999
49	92.49658425	14.42123583	89.68844085	13.94432524	2.038528243	1.3199999
50	96.97165002	10.30885548	94.06318396	14.25447348	2.038528243	1.3199999
51	98.24805647	10.42471147	94.37633146	14.28678039	2.038528243	1.3199999
52	98.58212513	11.77342813	95.61279587	17.41965477	2.038528243	1.3199999
53	99.90096388	9.188079045	98.55668813	12.66093198	2.038528243	1.3199999
54	98.46825742	9.479010112	97.46834769	16.31340811	2.038528243	1.3199999
55	100.5758777	9.213773569	99.53758343	12.70460449	2.038528243	1.3199999
56	96.51245893	7.714771857	94.59769564	11.75868283	2.038528243	1.3199999
57	93.0061062	11.33687629	90.45754351	14.04312632	2.038528243	1.3199999
58	89.85034872	9.633364659	88.29002688	13.87996037	2.038528243	1.3199999
59	93.68457996	7.612851194	92.38647736	11.4731866	2.038528243	1.3199999
60	82.64042938	5.940764167	82.45202885	6.897183405	2.038528243	1.3199999
61	81.01601365	8.096551016	81.93557859	7.576364534	2.038528243	1.3199999
62	91.73027111	8.865037854	91.85532853	8.666551189	2.038528243	1.3199999
63	86.2183531	8.436621127	83.87164059	11.06574624	2.038528243	1.3199999
64	87.78492463	7.604473228	90.48132458	9.834110173	2.038528243	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
65	89.59242652	6.623953869	94.17520283	7.957185736	2.038528243	1.3199999
66	89.7308729	9.006213063	91.81169621	12.18443252	2.038528243	1.3199999
67	83.03882053	7.980723594	82.75083255	8.851752054	2.038528243	1.3199999
68	85.85235163	8.385609794	82.72761046	8.621332425	2.038528243	1.3199999
69	82.49279672	7.956049095	85.39657291	10.38854629	2.038528243	1.3199999
70	83.99288885	7.118470131	78.45159605	7.239999265	2.038528243	1.3199999
71	83.20330476	4.641474554	80.02262862	5.375765611	2.038528243	1.3199999
72	79.78877646	4.312285322	76.31643157	5.154971134	2.038528243	1.3199999
73	81.92046886	4.1531869	79.60528225	4.858950011	2.038528243	1.3199999
74	82.83689701	7.695400592	81.42690341	8.706596218	2.038528243	1.3199999
75	105.9798892	11.94854898	104.1715618	14.56036316	2.038528243	1.3199999
76	95.24276757	10.33506594	92.75592618	13.29857091	2.038528243	1.3199999
77	108.2458903	11.77317434	106.4629945	16.24582817	2.038528243	1.3199999
78	106.1389085	11.94938794	104.1670359	14.52453112	2.038528243	1.3199999
79	98.07850729	13.34604532	104.7149308	17.03994173	2.038528243	1.3199999
80	92.41359926	11.37737977	89.77904068	15.01699207	2.038528243	1.3199999
81	94.94929795	14.40845785	94.01948057	14.64579095	2.038528243	1.3199999
82	87.62451227	8.360705947	85.2993715	10.48631642	2.038528243	1.3199999
83	93.28855248	8.491582629	91.47220751	11.34612865	2.038528243	1.3199999
84	89.65682057	8.455980481	87.80134128	10.57109117	2.038528243	1.3199999
85	89.56985361	8.291923549	87.54376662	10.60144939	2.038528243	1.3199999
86	79.69106041	7.361086981	84.10548769	11.27623995	2.038528243	1.3199999
87	79.62508391	6.859715299	78.5419844	7.540701894	2.038528243	1.3199999
88	79.27895529	6.759980417	80.19756481	7.715987883	2.038528243	1.3199999
89	76.32901029	6.556875806	77.00289365	7.776825376	2.038528243	1.3199999
90	91.13207954	22.32856971	77.76490406	8.967768637	2.038528243	1.3199999
91	78.53758188	9.017203428	77.6283037	8.978868621	2.038528243	1.3199999
92	75.98538569	6.128858594	76.36783432	7.440208627	2.038528243	1.3199999
93	82.06601397	6.800765733	80.97010435	8.629213914	2.038528243	1.3199999
94	83.13591814	13.6998837	80.86709317	13.61799502	2.038528243	1.3199999
95	84.74151616	9.219941676	79.43913949	11.08955726	2.038528243	1.3199999
96	83.47559973	7.377584828	93.89538675	10.7258283	2.038528243	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
97	92.30143041	15.20876325	94.66281516	17.3331797	2.038528243	1.3199999
98	82.17901515	6.838221689	85.93037287	8.1257933	2.038528243	1.3199999
99	81.84793448	6.28055207	85.2090396	7.708761352	2.038528243	1.3199999
100	83.52020285	4.907007415	81.34814281	5.954138557	2.038528243	1.3199999
101	82.59672731	7.640564005	79.56708424	8.477310095	2.038528243	1.3199999
102	77.95122046	5.109172652	75.04237808	5.993155295	1.985603715	1.277660281
103	82.05200986	7.915783891	78.61364485	8.942509525	2.038528243	1.3199999
104	78.46050701	6.444822928	76.37677093	6.544023155	2.038528243	1.3199999
105	78.51920026	6.366302619	75.45753748	7.138127539	1.985603715	1.277660281
106	76.17194977	6.665410369	74.93613425	7.354958987	2.038528243	1.3199999
107	81.94738519	7.938511069	75.02438201	9.602035114	2.038528243	1.3199999
108	75.55955495	6.348727304	75.13876395	6.986559146	2.038528243	1.3199999
109	77.72722294	5.613975486	77.38996688	6.159800218	2.038528243	1.3199999
110	78.26965541	6.810380541	78.26391188	6.576550885	2.038528243	1.3199999
111	80.14568166	6.60500874	80.02670455	7.882436864	2.038528243	1.3199999
112	75.57970135	5.80528561	76.151179	6.904970637	2.038528243	1.3199999
113	76.67528269	7.638086722	77.35849634	8.967341237	2.038528243	1.3199999
114	76.330774	6.18401167	77.99942355	7.448272437	2.038528243	1.3199999
115	78.79387852	9.041152974	77.92465863	9.074777431	2.038528243	1.3199999
116	78.59119081	8.768321658	79.71569017	9.156892683	2.038528243	1.3199999
117	76.76706198	7.72770543	76.69206531	8.899693798	2.038528243	1.3199999
118	78.77033482	7.401969101	76.95668682	9.564258062	2.038528243	1.3199999
119	82.11292144	5.592870548	78.66966942	5.270805175	2.038528243	1.3199999
120	83.8651618	5.706935803	83.49837901	6.410637833	2.038528243	1.3199999
121	79.08019109	5.332474733	76.22008454	5.766823886	2.038528243	1.3199999
122	77.38802067	4.924509664	75.50949088	5.406357684	1.985603715	1.277660281
123	79.92023318	4.615886187	77.90822176	5.464254763	1.985603715	1.277660281
124	79.41238699	4.592039384	76.80284452	5.63061584	1.985603715	1.277660281
125	78.17373625	4.733586177	76.17514506	5.51050905	1.985603715	1.277660281
126	79.52559212	4.667533494	77.16802452	5.420531791	2.038528243	1.3199999
127	78.19974288	4.670019164	75.79169776	5.663005504	1.985603715	1.277660281
128	76.74489981	4.567072145	75.50813917	5.362944126	1.985603715	1.277660281

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
129	80.46066132	4.614074412	78.06588488	5.394378475	1.985603715	1.277660281
130	78.70672991	4.745627179	76.2964562	5.513038952	1.985603715	1.277660281
131	76.67701207	4.377518813	75.42630366	5.294814292	1.985603715	1.277660281
132	77.37089075	5.474296846	77.06970484	5.74735328	2.038528243	1.3199999
133	79.66172048	4.79583902	77.00718452	5.534888842	2.038528243	1.3199999
134	77.54314929	5.304949787	77.06286727	5.880038906	2.038528243	1.3199999
135	77.33179278	4.938078474	77.09808461	5.312697652	1.985603715	1.277660281
136	80.30681385	4.599840349	77.70969537	5.446886038	1.985603715	1.277660281
137	79.52880199	4.906500622	76.78016914	5.604780456	1.985603715	1.277660281
138	77.79421852	5.259502495	76.53182632	5.753544942	1.985603715	1.277660281
139	77.48241019	6.281421845	76.40164773	5.715268153	2.038528243	1.3199999
140	77.71814593	5.787837423	76.45958113	6.080698639	2.038528243	1.3199999
141	79.82078743	7.15535044	76.5797184	5.668410148	2.038528243	1.3199999
142	78.97483058	6.42262452	77.56407403	6.399495353	2.038528243	1.3199999
143	79.83412258	5.612581579	78.59640377	7.131514456	2.038528243	1.3199999
144	78.85175599	5.250156771	77.05275373	6.139880722	1.985603715	1.277660281
145	79.34941877	7.734852611	81.45475361	8.451735368	2.038528243	1.3199999
146	81.87143356	4.959699653	78.66152772	5.742465143	2.038528243	1.3199999
147	80.57356473	8.159070908	81.35283161	8.407236076	2.038528243	1.3199999
148	79.1948797	5.413814127	77.3244199	6.379025791	2.038528243	1.3199999
149	80.26208506	4.805396295	77.57416331	5.57599118	1.985603715	1.277660281
150	73.15279956	6.783307437	76.3751408	7.126504678	2.038528243	1.3199999
151	76.78790021	6.93231312	77.41429974	7.837475765	2.038528243	1.3199999
152	76.90634757	6.602289428	77.58717081	7.819999789	2.038528243	1.3199999
153	82.35061953	8.211716937	82.33950865	8.852766501	2.038528243	1.3199999
154	78.47588538	7.912537501	79.68970301	9.008245948	2.038528243	1.3199999
155	79.68355768	7.438886287	79.73883211	9.058037359	2.038528243	1.3199999
156	80.73462735	8.201457815	81.48179383	10.30429012	2.038528243	1.3199999
157	75.70952368	6.621719937	77.28134388	7.85959672	2.038528243	1.3199999
158	78.65377634	5.751975691	78.16864678	6.851575128	2.038528243	1.3199999
159	78.65385517	4.519745497	77.42234329	5.258749218	2.038528243	1.3199999
160	79.22163676	7.001765374	76.05715114	7.010999556	2.038528243	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
161	86.47849954	8.519066086	79.46474807	9.612952103	2.038528243	1.3199999
162	80.31483799	8.30878798	76.94527499	7.762489826	2.038528243	1.3199999
163	79.56051718	8.512423132	76.93314584	8.346538652	2.038528243	1.3199999
164	80.98018823	10.5295609	77.55427431	9.345408746	2.038528243	1.3199999
165	84.80762589	8.350075868	78.92789951	9.500344257	2.038528243	1.3199999
166	77.79433384	5.300057289	77.22568419	6.534931746	2.038528243	1.3199999
167	80.58537098	7.843218014	76.53545162	7.844298807	2.038528243	1.3199999
168	75.05937126	7.508160536	75.92997569	7.740590662	2.038528243	1.3199999
169	80.3873638	5.498125472	80.95253403	6.748412855	2.038528243	1.3199999
170	80.0636562	5.503896729	80.59267264	6.758763547	2.038528243	1.3199999
171	107.1600291	15.03622687	101.6373708	15.21453154	2.038528243	1.3199999
172	127.2563205	20.46676851	108.8094023	22.37679318	2.038528243	1.3199999
173	101.2286109	9.140227701	98.04134743	10.7492925	2.038528243	1.3199999
174	106.8396882	14.96409124	101.9487723	15.16760931	2.038528243	1.3199999
175	101.2471136	9.080552115	97.98393696	10.35599098	2.038528243	1.3199999
176	94.33723172	11.58824338	88.72155387	12.4452188	2.038528243	1.3199999
177	96.39952913	11.10826282	90.68526759	12.25512385	2.038528243	1.3199999
178	97.73634686	9.600844482	93.17269007	11.348169	2.038528243	1.3199999
179	94.00210329	12.16353714	88.36996367	12.34389266	2.038528243	1.3199999
180	88.15725649	9.696919513	83.58227616	8.393823303	2.038528243	1.3199999
181	88.48402558	8.162446648	82.92265381	8.496867706	2.038528243	1.3199999
182	80.65973561	9.96925852	78.04209765	9.898841057	2.038528243	1.3199999
183	85.77112908	6.619161459	86.02154673	8.164285091	2.038528243	1.3199999
184	84.06658993	8.02383214	86.71501979	10.33544515	2.038528243	1.3199999
185	88.73578847	12.74196398	89.96983249	17.24984541	2.038528243	1.3199999
186	87.08645161	9.123047085	90.75666159	11.52344156	2.038528243	1.3199999
187	83.20189565	7.35870383	83.20729363	9.00203729	2.038528243	1.3199999
188	87.67384331	10.4988129	88.20990716	13.67543416	2.038528243	1.3199999
189	101.0810188	9.091352532	97.81624117	10.3569333	2.038528243	1.3199999
190	95.70798198	12.03321257	101.812899	12.01353588	2.038528243	1.3199999
191	126.9766386	26.38055485	107.9214401	22.66125223	2.038528243	1.3199999
192	98.83785989	12.56136228	94.11879007	14.55646064	2.038528243	1.3199999

TAZ Average Transit Times and Fares

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
193	95.70505539	12.07146341	107.2868015	15.19891554	2.038528243	1.3199999
194	108.3507322	25.56934691	106.4286678	20.67446403	2.038528243	1.3199999
195	96.21902549	10.21815468	94.81704649	11.31714186	2.038528243	1.3199999
196	86.77363959	11.31866329	87.16401655	13.98948282	2.038528243	1.3199999
197	89.76081365	9.504637655	90.78862936	11.65531431	2.038528243	1.3199999
198	87.78448059	9.910553322	85.34222335	11.78513344	2.038528243	1.3199999
199	91.44979285	9.067346799	88.55180113	10.43080087	2.038528243	1.3199999
200	90.8211052	7.141465723	90.32126807	9.068033036	2.038528243	1.3199999
201	89.55153681	7.128666114	88.68967833	9.051447098	2.038528243	1.3199999
202	96.06382941	11.24895413	99.21068621	13.86744268	2.038528243	1.3199999
203	94.82342014	11.24733175	98.83108867	14.56284184	2.038528243	1.3199999
204	95.77527985	11.56264806	93.24955059	11.19412636	2.038528243	1.3199999
205	96.25883464	9.744979387	93.84379398	11.13399525	2.038528243	1.3199999
206	101.3362579	10.20028556	98.59829772	11.35881852	2.038528243	1.3199999
207	103.0231736	8.571115134	100.9444918	9.587749775	2.038528243	1.3199999
208	104.4192456	16.28965342	110.7893075	14.40517189	2.038528243	1.3199999
209	114.2474965	9.580879741	116.1130903	12.71533593	2.038528243	1.3199999
210	114.7870116	19.23896066	107.5700191	22.8859991	2.038528243	1.3199999
211	118.8207846	11.4293156	113.4968322	14.52489489	2.038528243	1.3199999
212	84.290387	8.262523632	92.30038669	9.621217102	2.038528243	1.3199999
213	92.60725106	13.16173288	97.46682773	15.31759061	2.038528243	1.3199999
214	87.9742021	5.85481925	94.20245149	7.097361935	2.038528243	1.3199999
215	101.3880641	10.35830531	99.22772172	15.00438091	2.038528243	1.3199999
216	98.77435881	12.77489442	97.54076293	17.34595767	2.038528243	1.3199999
217	110.5953981	11.58158619	115.6570903	12.71856479	2.038528243	1.3199999
218	121.3124706	16.62784783	127.2712541	24.79214102	2.038528243	1.3199999
219	122.4429758	25.72740838	130.033456	26.54102659	1.921471657	1.3199999
220	112.5469485	5.629065077	110.338307	8.403045974	1.921471657	1.3199999
221	111.9275012	5.615426262	110.0896913	8.319486438	1.921471657	1.3199999
222	119.160959	13.36315413	109.2075554	13.28363087	1.921471657	1.3199999
223	122.8174444	20.06680078	128.1970055	20.44708554	1.921471657	1.3199999
224	116.360814	12.90116614	117.936645	15.85749007	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
225	117.3591704	15.58007625	118.5961718	16.00565093	1.921471657	1.3199999
226	112.6979174	11.25682502	107.9079927	14.59522887	1.921471657	1.3199999
227	109.2558078	8.743319894	105.4555358	14.67142008	1.921471657	1.3199999
228	120.0057253	14.48733316	120.7792197	16.35676894	1.921471657	1.3199999
229	115.3227176	9.903792121	112.075261	12.69929056	1.921471657	1.3199999
230	112.8028892	12.00300123	111.3665751	14.7772596	1.921471657	1.3199999
231	114.1986027	9.391850642	96.237646	14.44507607	1.921471657	1.3199999
232	111.8202414	9.689236537	109.8398958	15.23391785	1.921471657	1.3199999
233	111.4962822	14.68706606	111.9842786	23.13051912	1.921471657	1.3199999
234	108.8789426	9.912894731	108.8626866	16.74802188	1.921471657	1.3199999
235	110.3707178	13.15794256	115.1265171	14.24321858	1.921471657	1.3199999
236	113.2822642	10.62493269	118.7549908	13.98676105	1.921471657	1.3199999
237	112.8253696	10.43316101	118.2326817	13.36723704	1.921471657	1.3199999
238	113.1887565	11.94152041	120.6115449	11.72771751	1.921471657	1.3199999
239	112.0912858	10.1587253	131.642991	10.95842106	1.921471657	1.3199999
240	113.5151977	8.508140405	133.0465255	8.82641365	1.921471657	1.3199999
241	130.5314516	10.89808367	143.714677	12.38901329	1.921471657	1.3199999
242	140.8223261	14.93620538	148.898444	15.93781438	1.921471657	1.3199999
243	125.2491537	26.75809886	137.748232	27.57268618	1.921471657	1.3199999
244	111.078117	9.373060405	125.6094855	13.12760456	1.921471657	1.3199999
245	113.4484067	10.01789265	128.2042846	12.76898434	1.921471657	1.3199999
246	117.2788466	17.88086243	131.5692005	23.2954799	1.921471657	1.3199999
247	106.27273	12.39775113	131.2713328	11.39736535	1.921471657	1.3199999
248	108.5110832	20.55435052	144.4553147	26.49297592	1.921471657	1.3199999
249	117.2269247	11.91177167	115.0596171	17.246248	1.921471657	1.3199999
250	118.6015665	10.15258457	110.1290797	15.05765639	1.921471657	1.3199999
251	127.2252321	18.22047411	133.1931638	19.88163486	1.921471657	1.3199999
252	126.1492694	25.6871416	129.2157272	26.80087708	1.921471657	1.3199999
253	123.5528741	17.46757991	124.8999484	19.86066732	1.921471657	1.3199999
254	118.3322376	12.81032413	112.6142852	19.69038142	1.921471657	1.3199999
255	133.0671327	32.54213091	127.3965068	28.81618085	1.921471657	1.3199999
256	132.3637196	32.62570683	131.9111935	35.81753919	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
257	105.8743281	15.79041825	107.8509442	17.13733806	1.921471657	1.3199999
258	99.40954768	7.768173927	103.3569607	8.767832162	1.921471657	1.3199999
259	103.8236677	9.020512471	106.4358576	10.95000023	1.921471657	1.3199999
260	98.63211155	6.782090471	101.3600377	8.549676365	1.921471657	1.3199999
261	104.7491487	15.57572199	111.406603	14.61372014	1.921471657	1.3199999
262	98.54873182	9.926977548	109.7266443	11.50953964	1.921471657	1.3199999
263	108.1858501	9.38554594	119.6228277	13.59190258	1.921471657	1.3199999
264	107.6199218	14.89937072	113.2700298	17.12184849	1.921471657	1.3199999
265	99.56482235	15.81636789	94.49342831	16.46060898	1.921471657	1.3199999
266	89.23016366	12.54908685	93.86381478	14.48849722	1.921471657	1.3199999
267	87.79526289	12.35007532	112.8347312	20.44768634	1.921471657	1.3199999
268	117.9352728	10.42881606	125.3922238	12.33714973	1.921471657	1.3199999
269	112.2613173	10.82102635	119.3098405	14.03599991	1.921471657	1.3199999
270	111.1655881	11.3222279	117.5084983	15.08045726	1.921471657	1.3199999
271	112.4563718	10.56526613	120.4804226	14.10827819	1.921471657	1.3199999
272	103.8627962	9.909980126	123.9072274	10.74458976	1.921471657	1.3199999
273	111.2813681	9.707914368	121.9469026	12.16969119	1.921471657	1.3199999
274	125.6030513	29.42824913	137.4180937	42.91447067	1.921471657	1.3199999
275	96.05856025	10.10625887	113.6304357	10.25589621	1.921471657	1.3199999
276	101.3763001	18.36697749	121.7075041	24.08202922	1.921471657	1.3199999
277	92.22645242	8.245198977	110.7838767	10.93644855	1.921471657	1.3199999
278	95.42156373	10.89209518	110.4806405	10.93333386	1.921471657	1.3199999
279	99.32937372	16.209749	123.617045	23.43791758	1.921471657	1.3199999
280	95.96813777	11.99319201	113.0368999	12.06284824	1.921471657	1.3199999
281	95.80247382	8.486659621	113.8976174	10.11389223	1.921471657	1.3199999
282	113.0315566	19.38375893	145.8800474	23.00873426	1.921471657	1.3199999
283	100.8583928	11.05165276	104.2431344	15.07714712	1.921471657	1.3199999
284	87.20072642	11.48302028	107.9597729	16.03748975	1.921471657	1.3199999
285	78.02319518	7.573421739	96.98400916	6.338390111	1.921471657	1.3199999
286	91.23206745	11.59628083	110.2320331	14.11458861	1.921471657	1.3199999
287	95.15670507	12.08693254	121.7492361	16.80866437	1.921471657	1.3199999
288	82.666755	14.20245113	90.79029959	17.88396482	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
289	83.44173367	9.817950058	92.93073562	15.88538337	1.921471657	1.3199999
290	93.9988995	13.94917533	111.6800626	16.76210606	1.921471657	1.3199999
291	87.32421102	7.663035882	96.21622789	9.489018196	1.921471657	1.3199999
292	103.9653702	13.86873007	106.5872576	16.54466448	1.921471657	1.3199999
293	86.17042042	4.887709751	97.63862399	5.759484558	1.921471657	1.3199999
294	84.73636572	7.918122615	94.77014552	9.759214567	1.921471657	1.3199999
295	94.47986975	7.008833072	96.57718391	8.215448491	1.921471657	1.3199999
296	86.33598342	5.119922613	98.20366668	5.963976302	1.921471657	1.3199999
297	103.4862986	13.3553267	105.5088137	15.82297902	1.921471657	1.3199999
298	103.7968096	13.85884803	106.4192057	16.53177431	1.921471657	1.3199999
299	90.12832295	15.76403779	111.9173722	16.02359242	1.921471657	1.3199999
300	104.6576341	11.36382871	98.76989127	12.18354969	1.921471657	1.3199999
301	90.75844818	15.96477919	93.01616614	19.08048196	1.921471657	1.3199999
302	86.41298179	15.94057009	93.87074031	23.63370754	1.921471657	1.3199999
303	89.72305275	16.53992213	93.87074031	23.61370751	1.921471657	1.3199999
304	68.81933759	9.034612934	73.52429485	16.59299867	1.921471657	1.3199999
305	104.1631858	13.85787276	107.4153128	16.57501258	1.921471657	1.3199999
306	102.9333453	13.75336413	102.4572316	16.02149913	1.921471657	1.3199999
307	114.7253369	29.98512411	130.0327213	47.19418485	1.921471657	1.3199999
308	115.131004	30.01613868	130.2665063	47.22798744	1.921471657	1.3199999
309	105.5489744	15.13602497	116.0668829	21.84408183	1.921471657	1.3199999
310	104.5796732	16.60853855	116.0071453	21.78414427	1.921471657	1.3199999
311	113.9220588	12.62979039	125.2166805	16.98720219	1.921471657	1.3199999
312	90.85233031	9.299257727	110.746281	11.52216646	1.921471657	1.3199999
313	92.67730289	12.64839622	109.7074569	16.94950125	1.921471657	1.3199999
314	114.8706911	12.64954216	125.187988	17.20593312	1.921471657	1.3199999
315	92.39790895	12.89360774	112.8892246	16.09563737	1.921471657	1.3199999
316	142.280743	12.56508504	141.3640436	23.12404491	1.921471657	1.3199999
317	103.2393176	16.63558068	116.5259535	21.8068377	1.921471657	1.3199999
318	112.3883264	37.79032646	107.951763	20.69676028	1.921471657	1.3199999
319	103.3988854	16.68076234	117.1870176	21.84859769	1.921471657	1.3199999
320	102.7030765	24.09618702	117.0008778	25.53535435	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
321	89.97573487	20.82063446	110.6885247	21.42819045	1.921471657	1.3199999
322	94.0290271	13.07365705	112.3047941	14.32994273	1.921471657	1.3199999
323	91.2918743	18.58391599	112.1721492	25.56806825	1.921471657	1.3199999
324	82.06896402	6.13918204	100.9304846	7.973953938	1.921471657	1.3199999
325	93.84089776	18.08303931	109.6992708	19.2404198	1.921471657	1.3199999
326	94.60082217	14.88311594	111.912358	16.1240148	1.921471657	1.3199999
327	92.92153963	21.3151423	110.0486233	21.35579232	1.921471657	1.3199999
328	109.8940535	41.92783418	124.6275621	46.13460033	1.921471657	1.3199999
329	82.14450518	6.979315412	100.5516358	8.919179986	1.921471657	1.3199999
330	114.0101091	21.40878292	131.4904477	23.99472868	1.921471657	1.3199999
331	95.7331276	24.74344597	116.2031443	26.04093195	1.921471657	1.3199999
332	107.1245657	25.24837804	124.4472445	29.18094536	1.921471657	1.3199999
333	107.0140243	25.23851242	124.3625334	28.96071299	1.921471657	1.3199999
334	100.4691104	20.36691507	100.2804815	23.67994194	1.921471657	1.3199999
335	84.38077649	13.2997311	101.1791514	16.76734087	1.921471657	1.3199999
336	80.85997684	7.926977284	99.02047836	11.87880264	1.921471657	1.3199999
337	100.4691104	20.34691455	100.2804815	23.65994165	1.921471657	1.3199999
338	102.2090007	20.36130123	102.1972013	23.67739308	1.921471657	1.3199999
339	83.14450422	11.01402177	105.3310751	14.06661453	1.921471657	1.3199999
340	83.24984148	11.762854	105.9669552	14.09628462	1.921471657	1.3199999
341	90.74820673	11.69737187	111.7351739	20.93885418	1.921471657	1.3199999
342	95.86832854	9.954140896	96.51543675	16.42061114	1.921471657	1.3199999
343	86.97022989	10.73900882	95.81242238	23.28414208	1.921471657	1.3199999
344	86.98122466	12.61076098	90.93725506	11.6974849	1.921471657	1.3199999
345	93.43939491	13.14106337	103.7997494	18.35760879	1.921471657	1.3199999
346	99.42239822	22.36990275	98.98765815	14.39268141	1.921471657	1.3199999
347	96.37811611	9.511180525	94.32142445	9.811653314	1.921471657	1.3199999
348	97.70655294	7.878179787	95.98917584	8.257600517	1.921471657	1.3199999
349	106.3756111	10.10799964	101.1835555	11.89553754	1.921471657	1.3199999
350	105.1931543	10.1976662	98.81380277	12.03171964	1.921471657	1.3199999
351	109.3068726	12.72215989	104.3998212	15.11910211	1.921471657	1.3199999
352	105.3592004	14.83404332	108.4150897	16.90258401	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)	
353	104.7746619	17.50548846	109.7973353	18.84802208	1.921471657	1.3199999	
354	94.90328106	13.16713685	105.3889763	18.35154805	1.921471657	1.3199999	
355	91.80222432	12.68197637	98.42267061	22.71971059	1.921471657	1.3199999	
356	98.04364391	19.16690326	99.14007888	17.50163609	1.921471657	1.3199999	
357	103.2783993	13.58918923	105.4765632	15.20314654	1.921471657	1.3199999	
358	110.9018304	12.72542781	106.5422477	15.17655153	1.921471657	1.3199999	
359	112.3996796	12.75497102	108.5275118	15.19732739	1.921471657	1.3199999	
360	92.03649281	21.74797499	110.2025468	82.36045454	2.252499976	1.65	Note: Data
361	97.76295726	21.7579736	115.4912811	82.39469409	2.252499976	1.65	Note: Data
362	102.9264152	10.66515212	101.7125657	12.40157016	1.921471657	1.3199999	
363	104.3366338	8.292060836	103.2401263	11.11597265	1.921471657	1.3199999	
364	114.6335595	14.9849711	114.1297693	13.08845352	1.921471657	1.3199999	
365	92.84931307	9.636678408	99.07585322	14.56283719	1.921471657	1.3199999	
366	93.91733059	12.42614433	99.30410254	23.10476911	1.921471657	1.3199999	
367	103.4669793	21.00615655	89.10929562	13.49183402	1.921471657	1.3199999	
368	98.4378463	23.64294267	113.6555492	21.42091519	1.921471657	1.3199999	
369	100.582773	10.15330759	84.69125223	9.561368334	1.921471657	1.3199999	
370	99.43298748	9.852613894	84.39234538	10.69423651	1.921471657	1.3199999	
371	99.93822482	9.894528436	88.19154204	13.5659186	1.921471657	1.3199999	
372	115.6732704	12.21260007	114.3620357	13.08778126	1.921471657	1.3199999	
373	116.0257572	12.26776491	114.1728858	13.02905342	1.921471657	1.3199999	
374	136.8472135	23.59802378	128.9846878	16.54579351	1.921471657	1.3199999	
375	115.7897938	21.09843595	118.1277521	22.55258064	1.921471657	1.3199999	
376	112.7251595	21.12452892	92.9914825	15.73353025	1.921471657	1.3199999	
377	108.4016488	21.1262634	92.08168118	14.24257548	1.921471657	1.3199999	
378	113.6411247	21.11092516	115.5020876	22.86363989	1.921471657	1.3199999	
379	137.1829632	23.62911596	129.1660212	16.52247041	1.921471657	1.3199999	
380	119.0344987	20.59680029	138.7361526	19.07065345	1.921471657	1.3199999	
381	125.6778618	25.88152396	127.3343324	17.02809569	1.921471657	1.3199999	
382	120.8015199	14.56775918	136.6039243	16.54594663	1.921471657	1.3199999	
383	121.1219599	20.50468481	121.0113485	21.53133284	1.921471657	1.3199999	
384	155.9545695	18.28458073	140.2720635	20.05226173	1.921471657	1.3199999	

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385	101.9290746	24.79090628	89.23366934	21.07221105	1.921471657	1.3199999
386	154.1864322	18.68081758	144.574082	16.78978757	1.921471657	1.3199999
387	103.7419645	20.62360224	142.8019858	13.77084985	1.921471657	1.3199999
388	105.8204939	24.67238863	117.4290209	19.25788563	1.921471657	1.3199999
389	115.2801447	12.07902218	142.4128422	13.26823693	1.921471657	1.3199999
390	110.5567081	14.71094655	132.6573809	16.49545318	1.921471657	1.3199999
391	105.2890458	24.7955786	125.1876182	26.05098348	1.921471657	1.3199999
392	117.5337225	25.1875518	132.4116536	26.97148734	1.921471657	1.3199999
393	105.8057862	25.092609	125.4393656	26.29483576	1.921471657	1.3199999
394	107.1035899	25.1503885	126.8894673	26.35495969	1.921471657	1.3199999
395	117.6359218	25.1443201	135.5951923	27.19826284	1.921471657	1.3199999
396	112.9359416	25.14197238	132.7527819	22.8944868	1.921471657	1.3199999
397	113.3902219	25.1384201	133.1676623	22.92118357	1.921471657	1.3199999
398	114.3734537	15.13453572	134.7822051	15.395093	1.921471657	1.3199999
399	113.008388	24.65733241	132.9441525	22.38128388	1.921471657	1.3199999
400	113.5388295	15.1049409	133.6959069	15.36965163	1.921471657	1.3199999
401	114.4397665	15.0020413	134.5702698	15.26516084	1.921471657	1.3199999
402	116.5502737	15.04003876	136.790256	14.61482777	1.921471657	1.3199999
403	116.2811683	15.11392782	136.5287494	15.38362129	1.921471657	1.3199999
404	117.1334771	17.67738226	137.4649924	17.80399403	1.921471657	1.3199999
405	165.9882518	23.00581014	146.0532063	25.91926521	1.921471657	1.3199999
406	117.3478832	11.66319169	143.5085402	15.83381383	1.921471657	1.3199999
407	116.5960109	11.75992194	143.4874886	13.69800568	1.921471657	1.3199999
408	143.1985158	15.01415344	144.987237	14.97635232	1.921471657	1.3199999
409	152.5317568	34.83066907	129.5907703	45.02764054	1.921471657	1.3199999
410	138.9157985	11.54101472	111.5291958	7.519427165	1.921471657	1.3199999
411	150.437309	33.9603828	127.0307764	43.98781768	1.921471657	1.3199999
412	133.1435562	16.04331289	130.5255982	17.30526965	1.921471657	1.3199999
413	124.813026	14.95344764	124.7683618	17.14775822	1.921471657	1.3199999
414	126.1325933	20.48610499	125.3915507	22.60436807	1.921471657	1.3199999
415	133.8951418	16.1776703	130.6973257	17.39316656	1.921471657	1.3199999
416	134.8992631	12.64718667	113.460993	14.26538064	1.921471657	1.3199999

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417	157.5004713	17.3617075	128.3539441	20.05345478	1.921471657	1.3199999
418	157.2493368	17.38618694	128.3539441	20.08345476	1.921471657	1.3199999
419	151.2402642	13.45896078	122.7433699	15.03988284	1.921471657	1.3199999
420	143.5961517	11.14515153	116.2483135	12.22473275	1.921471657	1.3199999
421	153.5189446	17.46173236	126.4034884	19.86961683	1.921471657	1.3199999
422	160.2333073	25.45260921	132.5405966	26.41759559	1.921471657	1.3199999
423	157.5354028	17.3658719	128.3866886	20.05786845	1.921471657	1.3199999
424	177.7568873	21.78940264	139.4278224	22.86875049	1.921471657	1.3199999
425	162.2423527	16.07255252	133.2017963	16.96262936	1.921471657	1.3199999
426	150.6858667	13.43848796	122.2952293	15.01634616	1.921471657	1.3199999
427	170.3412816	24.82634027	142.6854314	25.77231714	1.921471657	1.3199999
428	162.2423527	16.08255222	133.441817	16.98055652	1.921471657	1.3199999
429	167.4047494	19.6882787	138.6043682	22.40625191	1.921471657	1.3199999
430	158.5313471	27.25701567	131.4406666	26.44867933	1.921471657	1.3199999
431	161.39184	20.19619038	133.7939493	20.34590487	1.921471657	1.3199999
432	164.774964	20.19032612	136.9235428	20.34475918	1.921471657	1.3199999
433	148.415019	13.51165889	131.2315275	13.39801394	1.921471657	1.3199999
434	114.6864205	12.98689402	143.1113604	13.55858474	1.921471657	1.3199999
435	148.5117543	12.75368353	132.1840288	13.61178342	1.921471657	1.3199999
436	115.1639847	13.53339697	134.9423657	13.33898614	1.921471657	1.3199999
437	148.5117543	12.70368497	132.1840288	13.56178549	1.921471657	1.3199999
438	147.8043868	12.68173744	131.6968338	13.3884735	1.921471657	1.3199999
439	156.3035181	31.50435676	135.9766603	32.31822117	1.921471657	1.3199999
440	152.1858066	19.84874635	123.4913481	19.97400285	1.921471657	1.3199999
441	154.8227054	19.07397188	127.2895334	20.06806433	1.921471657	1.3199999
442	166.5383243	31.58446906	150.1254504	28.51492968	1.921471657	1.3199999
443	156.7512278	25.19095017	140.0905497	26.6819027	1.921471657	1.3199999
444	154.5370331	19.93631091	124.958513	20.92069081	1.921471657	1.3199999
445	167.3745105	35.32030486	150.7966355	32.22405237	1.921471657	1.3199999
446	161.4288575	28.87299351	144.5194831	28.97599667	1.921471657	1.3199999
447	161.3708558	28.79399339	145.0477412	29.04678597	1.921471657	1.3199999
448	175.627417	69.41169913	152.8908789	70.12526787	1.921471657	1.3199999

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449	191.3613006	69.349384	167.3932559	70.06568809	1.921471657	1.3199999
450	174.8705825	20.77326856	146.4650013	22.58575413	1.921471657	1.3199999
451	165.794279	20.86545559	144.2342864	22.25117839	1.921471657	1.3199999
452	135.4721952	38.2153072	145.013458	28.46754708	1.921471657	1.3199999
453	137.9265838	38.79494991	163.0277117	29.00401294	1.921471657	1.3199999
454	191.0245736	69.34563891	166.8323736	70.0986624	1.921471657	1.3199999
455	189.8045601	69.44353132	163.7938763	68.6709194	1.921471657	1.3199999
456	205.4395858	69.3235267	177.2409515	45.27043869	1.921471657	1.3199999
457	204.2438347	69.27556395	176.7715421	45.27043908	1.921471657	1.3199999
458	145.9088334	42.24093836	195.9040156	95.46629149	1.921471657	1.3199999
459	135.8557233	39.7137362	165.6011758	31.52339778	1.921471657	1.3199999
460	146.8652971	42.04047957	146.2499812	81.50017357	1.921471657	1.3199999
461	154.8318422	42.02688993	154.8982216	58.67745137	1.921471657	1.3199999
462	139.6385395	49.95194648	158.0609122	49.72693478	1.921471657	1.3199999
463	136.7540836	49.65361526	155.3353226	49.36468981	1.921471657	1.3199999
464	147.1328966	31.89665255	163.7118319	28.4259294	1.921471657	1.3199999
465	110.5152085	25.04721456	131.0251006	26.51420428	1.921471657	1.3199999
466	114.0199201	24.93899231	134.0351479	22.96123308	1.921471657	1.3199999
467	132.3535412	41.01809789	165.7493917	28.26174886	1.921471657	1.3199999
468	104.6242649	40.77152508	109.9007255	40.25662592	1.921471657	1.3199999
469	122.1525512	42.05500802	123.5293365	81.17960209	1.921471657	1.3199999
470	114.1085521	21.36236064	131.5976423	23.95844547	1.921471657	1.3199999
471	117.2862546	25.13902301	134.9851598	27.19995848	1.921471657	1.3199999
472	117.5018934	25.16085772	135.3905745	27.23227215	1.921471657	1.3199999
473	117.0861388	42.02248077	134.6065169	28.13554537	1.921471657	1.3199999
474	118.3929541	41.90290835	135.293323	27.06690642	1.921471657	1.3199999
475	129.7542564	41.99438041	136.080586	83.8721577	1.921471657	1.3199999
476	130.3905012	42.03621133	135.8188695	83.72169581	1.921471657	1.3199999
477	130.9929061	42.12140566	129.7806321	81.33421626	1.921471657	1.3199999
478	138.4488395	42.00493802	142.142392	82.2885681	1.921471657	1.3199999
479	134.9126677	40.86607863	165.1608875	28.51814684	1.921471657	1.3199999
480	144.1209764	41.99902657	141.552747	78.91347451	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
481	147.2592036	31.88001834	164.3631084	28.46705113	1.921471657	1.3199999
482	133.5861391	39.18841869	166.1796914	28.67504993	1.921471657	1.3199999
483	139.5066374	10.90921687	157.9029481	11.11832014	1.921471657	1.3199999
484	139.5066374	10.92841579	157.7501476	11.17534293	1.921471657	1.3199999
485	83.76539496	18.49115405	108.8097546	36.25429258	1.921471657	1.3199999
486	112.2159356	40.41605158	151.2569318	27.33544979	1.921471657	1.3199999
487	152.5404549	29.35464158	195.7586986	29.95620388	1.921471657	1.3199999
488	152.5404549	29.37464485	196.0703262	29.99115305	1.921471657	1.3199999
489	172.9760938	18.54617735	152.57456	12.45254684	1.921471657	1.3199999
490	154.7363809	29.3970695	196.0476944	30.03710256	1.921471657	1.3199999
491	163.2420066	23.07971416	168.0857411	21.97094043	1.921471657	1.3199999
492	158.198562	29.33856747	194.2778917	29.86749728	1.921471657	1.3199999
493	153.8435939	45.69595226	180.7266909	48.61745921	1.921471657	1.3199999
494	164.6118573	62.14988011	161.3425019	45.15291657	1.921471657	1.3199999
495	143.255643	26.6717576	160.9915717	45.17501797	1.921471657	1.3199999
496	153.4725318	56.62532188	161.3425019	45.15291676	1.921471657	1.3199999
497	135.1579755	15.27038151	144.6139455	17.30239336	1.921471657	1.3199999
498	134.1101212	19.36872607	148.0322276	26.29040058	1.921471657	1.3199999
499	122.4917441	11.16546823	133.0749869	12.5435055	1.921471657	1.3199999
500	129.6247178	18.16157375	135.5932548	19.83653886	1.921471657	1.3199999
501	131.2581294	18.11365264	136.7918006	19.83021076	1.921471657	1.3199999
502	126.4096073	9.546165829	129.0285258	11.34375987	1.921471657	1.3199999
503	126.820761	9.427862838	129.9144325	11.32873061	1.921471657	1.3199999
504	129.9181947	11.76570151	132.1833446	12.54893404	1.921471657	1.3199999
505	144.7866228	53.8094049	140.908879	20.21557514	1.921471657	1.3199999
506	148.0055607	36.98867531	210.3254669	48.73042449	1.921471657	1.3199999
507	141.9259207	13.95740822	152.717012	14.35460719	1.921471657	1.3199999
508	144.9743517	38.88850256	153.3228195	21.80777825	1.921471657	1.3199999
509	144.7403163	26.69389857	160.5815288	45.11744348	1.921471657	1.3199999
510	143.255643	26.66175805	160.9915717	45.16502015	1.921471657	1.3199999
511	134.8460409	19.20435055	148.0770968	19.37071458	1.921471657	1.3199999
512	128.2035233	25.02773556	124.2530428	12.14740171	1.921471657	1.3199999

OriginTAZ	Avg. Bus In Vehicle Time, AM Peak Minutes	Avg. Bus Wait Time, AM Peak Minutes	Avg. Bus In Vehicle Time, MidDay Period Minutes	Avg. Bus Wait Time, MidDay Period Minutes	Avg. Transit Fare during AM Peak (in 2006 Constant Dollars)	Avg. Transit Fare during MidDay Period (in 2006 Constant Dollars)
513	134.1285944	15.31215116	144.0182889	17.37580024	1.921471657	1.3199999
514	134.1101212	19.38872527	148.0322276	26.31039874	1.921471657	1.3199999
515	117.1064321	9.040361845	124.6058367	9.207446984	1.921471657	1.3199999
516	114.3620486	7.117504091	122.5496555	9.802818127	1.921471657	1.3199999
517	123.4515767	21.8238241	135.5630728	27.83984678	1.921471657	1.3199999
518	114.7244693	7.222657591	123.1008285	9.84820207	1.921471657	1.3199999
519	129.8963643	18.21767664	135.2114278	19.82780012	1.921471657	1.3199999
520	171.5820019	46.96870534	162.5464672	45.24076194	1.921471657	1.3199999
521	172.5754817	46.93005437	137.8116472	19.89758448	1.921471657	1.3199999
522	185.8442813	82.50037655	190.5908123	27.24830952	1.921471657	1.3199999
523	190.0836337	26.99612941	189.923684	27.20278903	1.921471657	1.3199999
524	205.9051384	42.28045229	207.8423582	43.28361466	1.921471657	1.3199999
525	209.8225842	42.280454	212.0294619	43.28361549	1.921471657	1.3199999
526	214.928998	42.29073918	217.4670232	43.29407305	1.921471657	1.3199999
527	216.5557062	42.43074049	219.2211432	43.43407444	1.921471657	1.3199999
528	205.9051384	42.53045308	207.8423582	43.533615	1.921471657	1.3199999
529	216.5557062	42.34074083	219.2211432	43.34407643	1.921471657	1.3199999
530	204.7065007	69.43555365	177.2409515	45.43042954	1.921471657	1.3199999