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Using household travel surveys to adjust ITE trip generation rates

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Abstract: The Institute of Transportation Engineers (ITE) *Trip Generation Handbook* has become the predominant method for estimating vehicle trips generated by development. The handbook is often criticized for its inability to account for multimodal behavior in urban contexts, often overestimating vehicle traffic. The purpose of this research is to develop and test a ready-to-use method for adjusting the ITE handbook vehicle trip generation estimates for urban context. This method was created using household travel surveys from Oregon, Washington, and Maryland, as well as nationally available built environment data. Three adjustments were estimated for eight general land-use categories, including a "pooled" category considering all travel survey data. The performance of three adjustments were tested using 195 establishment-level vehicle trip generation datasets compiled from three independent sources. Using this data, the performances of four land-use categories were tested. The overall findings suggest that the simplest of the three adjustments developed provided similar results to the more complex adjustment methods. Moreover, adjustments applied using the "pooled" land-uses category also provided similar results to the more detailed segmentation of travel survey data. Both of these findings punctuate the need for a simple, urban adjustment for trip generation estimates.

1 Introduction

The Institute of Transportation Engineers (ITE) *Trip Generation Handbook* (Institute of Transportation Engineers 2004)—and its corresponding *Informational Report*[1] (Institute of Transportation Engineers 2008)—has become the predominant method for estimating vehicle trips generated by different land uses or establishments (Clifton et al. 2013). With data collected from more than 5500 studies across 170 land uses, the handbook provides average trip rates and equations to estimate vehicle trips generated for land uses ranging from coffee shops to commercial airports. The handbook was originally developed to provide a widely available, ready-to-use method for determining the impact of new or renovated developments on the nearby transportation facilities (Institute of Transportation Engineers 2004, Gard 2007) and has become the industry standard.

The recommendations in the ITE *Trip Generation Handbook* acknowledge that "[i]f the site is located in a downtown setting, served by significant public transportation…the site is not consistent with the ITE data" (Institute of Transportation Engineers 2004, p. 15). Instead, ITE recommends using local data collected in locations similarly situated within the urban context. Despite this guidance,

[1] For clarity throughout this text, we refer to the reference set of the *Trip Generation Handbook*—which contains the ITE's methods—and its corresponding *Informational Report*—which contains the data, rates, and regressions—as one document: the ITE's handbook.

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estimates using the ITE handbook have been applied to countless developments across urban, suburban and exurban area-types for more than 50 years. The probable outcome of this urban insensitivity is the over-building of vehicle facilities in urban area-types (Clifton et al. 2013).

The ITE recognizes the limitations of the handbook's data and reminds the analyst to consider the environment surrounding the development before applying the estimation method. The handbook "provides no recommended practices, procedures, or guidelines" related to urban adjustment (Institute of Transportation Engineers 2004). While the ITE is currently in the process of updating the method for data collection and estimation of traffic, the new extensive, nationally collected, multi-modal, person-oriented data will not likely be available for some time. Meanwhile, local governments continue to be hampered by methods of estimating transportation impact that are simply not sensitive to urban environments (Clifton et al. 2013, Nelson\Nygaard Consulting Associates 2005, Rizavi and Yeung 2010, Handy et al. 2013, Shafizadeh et al. 2012).

This research addresses the need to adjust vehicle trip estimates derived from the ITE's *Trip Generation Handbook* for urban contexts by accounting for non-automobile travel in areas with greater density, accessibility to transit, or a diversity of land uses. In this research, we utilized data from multiple regional household travel surveys (HTS) to develop three methods to adjust the handbook's vehicle-oriented trip rate estimates. These methods of adjustment were then tested using independently collected, establishment-level data from a variety of land-use types. The aim of this research was not to replace the ITE's handbook and data, but rather to develop a nationally applicable, ready-to-use adjustment for urban contexts to supplement the handbook until more urban-sensitive data can be collected and more robust methods for estimation are available. The availability of these people-based methods will allow planners and engineers to recommend transportation mitigation techniques appropriate for urban development.

2 Literature review

While some studies have investigated the extent to which error has been observed when the ITE handbook method is applied to urban land uses (Clifton et al. 2013), the focus of this literature review is on the ways in which jurisdictions and practitioners are accounting for the differences in travel between urban and suburban land uses as well as some of the available methods of urban-context adjustments. Or suntiae ctianis cimusdam, aut ipsant, odistio inimpe optium voluptatemos moluptatius et litia quo et ma quisciantium elestib usciae a velecus nullaborest, seque lab inveror runtius sequi con natissit quam et des reperion non perspeditat.

2.1 Non-ITE data collections

Collecting urban trip generation data can be more costly compared with data collected in suburban or exurban areas because of the more complex site layouts, the need to capture multimodal trips, and accounting for automobiles arriving that park offsite or in shared parking lots (Clifton et al. 2013, Daisa et al. 2013). Despite this, a few jurisdictions have started to collect their own trip generation data to better prepare local developers with trip rates that are sensitive to their urban contexts (San Francisco Planning Department 2002, San Diego Association of Governments (SANDAG) 2010, New York City 2010, Virginia Department of Transportation 2008). The rates or adjustment factors provided for each jurisdiction, however, are only relavent to the immediate location and are rarely tested for transferability outside of the region.

The company Arup has developed a promising online public tool called "trip genie," which is comprised of more detailed and transparent trip generation data collected from published studies from across the United States. This database provides a transparent and flexible method for practioners to select reasonable data that is similar to the built environment and context of the development site in question (Arup 2012). It provids a way to search through data, examine each site or data-point in more detail, conduct searches based on the urban-context of the location, and provides multimodal travel data where they were collected. While still in its development, this resource compiles data from published studies; and therefore, it relies on the data being collected and published by other institutions.

Ultimately, for most jurisdictions, the expense of collecting primary, establishment-level data to compile local trip generation rates outweighs the usefulness of having tailored, local trip generation rates. Moreover, it takes many years to compile enough sample data from published sources to represent a wide variaty of land uses, time periods, and urban contexts—which is why it took the ITE more than 50 years to compile over 5500 studies. As an intermediate step—while we wait to compile enough urban-based trip generation data—this paper looks to create adjustment methods that act as pivot models, allowing us to account for changes in the built enviornment using smaller samples of built environment data.

2.2 Urban context adjustments to the ITE estimates

There are two areas of research that focus on urban-context adjustments to the ITE trip generation estimates: those focusing on multi-use development adjustments and those focusing on single-use, infill development adjustments.

2.2.1 Multi-use development adjustments

A multi-use development is a site that has more than one land use. For these locations, analysts need to take into account both multimodal travel as well as internal capture—in other words, they need to account for the multiple trips generated from people walking to and between establishments that should be accounted for by a single trip to the development as a whole. There are three methods that account for multi-use development characteristics: the ITE's handbook multi-use approach (Institute of Transportation Engineers 2004 p. 85), the National Cooperative Highway Research Program (NCHRP) Report 684 (Bochner et al. 2011), and the US Environmental Protection Agency's Mixed-Use Development Method (US EPA 2013).

Although multi-use development adjustment methods like these have been applied to trip generation estimates at single-use developments, there is little evidence to suggest these multi-use methods account for the same type of behavior at single-use developments in urban areas. Shafizadeh et al. (2012) applied five multi-use adjustment methods to 12 single land-use developments for the California region. Their results were inconclusive, and they were not able to recommend one of these multi-use methods for the adjustment of single-land-use developments. In their conclusions, they determined the development of a new method may be necessary, one that is based on available data sources as additional data collection can be costly in both time and money.

2.2.2 Single-use development adjustments

There are currently a few adjustments available that account for multimodal travel at single-use developments in urban areas. ITE presents an approach in the handbook developed by JHK and Associates et al. (1996), which considers direct reductions of estimating trip generation rates based on proximity to transit with supportive land use (e.g. density, floor-to-area ratios, pedestrian or bike facilities). Although published as a "draft," this text has been the only adjustmnet method included in ITE's handbook, and even so, only as "information" for practicioners and not as guidelines.

Meanwhile, researchers in California and Oregon have developed tools to supplement the ITE's handbook vehicle trip rate estimates for specific land uses based on original, site-level data collections (Clifton et al. 2013, Schneider et al. 2013). In both these studies, adjustments to either the trip generation rates (Clifton et al. 2013) or the trip generation estimates (Schneider et al. 2013) were estimated as a function of the built enviornment. Both of these Oregon and California methods are limited to small sample sizes of a select few land-use types, and neither study has yet been tested for transferability to areas outside of its data collection region or city.

Currently, there are two studies that have applied travel survey data to develop trip generation adjustment methods. Most recently published, NCHRP Report 758 outlines a method to analyze regional travel survey data to provide local mode share adjustments to trip generation data (Daisa et al. 2013). In this method, the ability to develop a regional adjustment method is contingent upon the availability of a regional travel survey and the onus of data analysis is placed on the practitioner. Moreover, mode share adjustments are based on mode splits of trips in travel analysis zones (TAZs), limiting the applicability of adjustments to TAZs that have a large enough sample of trips to calculate a mode share rate. An earlier study used the 2006 Puget Sound Regional Travel Survey to estimate a binary logistic model that predicts an automobile/non-automobile mode share rate for an aggregate land-use category, which includes: shopping, dining and personal service land uses (Clifton et al. 2012). Since this method was limited to a single household travel survey, its application outside the region remains questionable.

2.3 Guiding principles

Based on this literature review, we established three guiding principles or criteria to develop a method to adjust the ITE's *Trip Generation Handbook* vehicle rates building on previous research (Clifton et al. 2012) and working to fill in the gaps where currently avaible primary data are unavailable. The objectives directing this research include developing a method that: (1) includes ready-to-use equations for practitioners to apply; (2) can be used anywhere in the United States; and (3) was tested on independently collected data. We present three methods of adjusting the ITE's *Trip Generation Handbook* vehicle trip end estimates to take into account other mode-share and vehicle occupancy. In order to create these methods, we used household travel diary data from three regions: Portland, Oregon; Puget Sound, Washington; and Baltimore, Maryland. This data provides trip observations across a range of urban contexts in three different regions. We organized the travel diary data into trip observations and collected built environment measures for all locations using nationally available data. We estimated three adjustments for eight different general land-use categories. Each of these methods was then tested on independently collected, establishment-level vehicle trip generation data to compare the error of these urban-context adjustment methods and the ITE's handbook estimates.

3 Framework for an urban-context adjustment

Before we discuss the development of the adjustment methods, we will first provide an overview of how to apply the proposed urban-context adjustments in a traffic impact analysis. The adjustments developed in this research are mode-share adjustments. There are five steps to applying a mode-share adjustment to ITE's *Trip Generation Handbook* estimates for any given urban development using the tool developed by this study [2].

- Step I: Calculate the vehicle trip generation estimate for the development location according to the ITE Trip Generation Handbook.
- Step II: Estimate the total person trip end estimates based on the ITE handbook and assumptions.

In this second step of adjustment, the analyst would convert the handbook's estimate of vehicle trip

[2] The equations corresponding with each of these five steps are found in "Appendix: Equations" on page 35.

ends for the development into an estimate of total person trip ends. This requires two assumptions to estimate the (1) mode split and (2) vehicle occupancy rates at the establishments of the data provided by the ITE handbook. Since developments located in "downtown setting(s), served by significant public transportation" are "not [considered] consistent with the ITE data" (Institute of Transportation Engineers 2004 p. 15) and because the ITE data tends to represent locations with "limited ability for pedestrians to walk into the site from nearby parcels" (p. 17), we assume a 100 percent automobile mode split and a vehicle occupancy ratio of one person per automobile for data provided in the ITE's handbook. Occasionally, the ITE reports additional information about certain land uses—such as transit mode shares or vehicle occupancy rates. When available, this information could be applied in Step II as a more robust assumption of the data provided in the ITE's handbook.

- Step III: Estimate the automobile mode share and vehicle occupancy for the urban development location using the adjustment methodologies developed in this research.
- Step IV: Use the estimated mode shares and vehicle occupancy rates from Step III to reallocate the total estimated person trips for that location from Step II into "urban" travel modes.
- Step V: Apply the new vehicle trip generation estimates for the development—adjusted for the urban context of the development in Step IV—in a traffic impact analysis.

The following two sections on "Data" and "Urban adjustment equation development" discuss the development of urban-context automobile mode share and vehicle occupancy rate estimates from household travel survey data. These equations are the heart of the adjustment method presented in this paper. In the subsequent Section 6, "Verification of method," we apply the mode-share and vehicle occupancy equations developed—using Steps I through V—on independently collected, establishment-level data as a practitioner would apply it. In this section, we compare the ITE's handbook estimates, the urban-context adjusted estimates, and the observed real-world trip counts to test the performance of these methods.

4 Data

We used two types of data to develop the urban adjustment. First, three household travel surveys from three cities across the United States were used to estimate changes in mode choices and vehicle occupancy rates across a variety of urban contexts. Second, we used built environment data to quantify the urban context of the development location. The following sections detail these data.

4.1 Household travel surveys

Travel surveys record travel observations in terms of trips. A household travel survey "trip" consists of: an origin or where the person came from; a destination or where the person is headed; and information about the trip itself, including mode choice, vehicle occupancy, time of departure and arrival, day of the week, etc. Conversely, establishment-level, trip-generation data provides the total number of automobile trip ends that enter and exit the establishment during the study time period. One benefit of using travel surveys to explain or estimate automobile mode shares and vehicle occupancy rates for different land uses is that—unlike the limited sample sizes of establishment-level data collections as in the ITE's handbook—travel surveys capture travel behavior across a wide range of urban areas and land-use types. This allows us to estimate changes in travel behavior at an establishment-level based on aggregate estimated changes in travel behavior on an individual level.

In order to provide parity between the travel surveys and the ITE's handbook, travel survey trips were disaggregated into "trip ends." We compiled the data into trips entering development locations (travel survey trip destinations) and trips exiting locations (travel survey trip origins). Each trip end represents unique observation.

We used three travel surveys: the 2011 Oregon Household Activity Survey (OHAS) for the Portland metropolitan area; the 2006 Puget Sound Regional Travel Survey from the Puget Sound Regional Council (PSRC); and the 2001 National Household Travel Survey Add-On Program for the Baltimore Regional Transportation Board (Baltimore). Each of these surveys provided spatial information about the location of each trip end. Using the XY-coordinates of the trip ends, we were able to calculate various measures of the built environment to describe the urban context of the trip end location (discussed in the following section). For a summary of all travel survey trip end data, see Table 1.

Data in this project were organized similarly to the ITE's *Trip Generation Handbook* land-use, time and day categories. Trip end observations occurring throughout the day were segmented into peak-hour periods that correspond to the common peak periods for the facilities: the a.m. peak period is from 7a.m. to 9 a.m., the p.m. peak period is from 4 p.m. to 6 p.m., and the midday period is from 9 a.m. to 4 p.m. Additionally, day of the week indicators identify activities that occur on the weekends (Saturday or Sunday), the workweek (Monday through Thursday) and Friday. A variable was created to indicate observations that occur during winter months to determine potential seasonal differences in observations for November through February.

In the travel survey diaries, an activity or purpose was recorded for each trip end. These activities or purposes do not directly translate into land-use types, as defined within the ITE handbook. In order to use these travel surveys to describe the travel behavior at different land uses, we developed a schema crosswalk to link the activities occurring at the trip ends and likely land use at which each type of activity may occur. Crosswalks for eight general land-use categories were developed: office, restaurant, residential (single-family detached, multi-family, and general residential), service (non-restaurant), and retail, as well as an eighth category considering all trip ends. In general, trip purposes reported by travel surveys are not easy to relate to land-use types provided by the ITE's handbook. As a result, trip purposes were grouped into these eight land-use categories based on observation and the authors' knowledge . To describe how this table is used in the adjustment methods, we will discuss how the trip purposes were classified into the general land-use categories. First, we examine the travel survey trip activities or purposes. Trip purposes that are not identified as being related to the trip-maker's home or place of work, were categorized as one of six land-use categories: (1) single-family residential, (2) multi-family residential, (3) restaurant, (4) service (non-restaurant), (5) retail and (6) office. Any trip that did not fit into one of these categories was classified as "miscellaneous" for the time being.

For any trip purpose that we identified as being "home-related," we investigated the trip-maker's home location and any relevant information about the housing structure type that the travel survey diary may have provided3. For example, if a trip-maker participated in a "work-at-home" activity—and this person also provided information about his or her "home-structure type" being a duplex—then we classified that trip in the "multifamily-residential" land-use type. We pooled the data from the land-use categories (1) single-family residential and (2) multi-family residential, as well as any trip purposes that were identified as "residential" without any distinguishing information about the housing structure, into a seventh land-use category: general residential. Following, for any trip purpose that we identified as being "work-related," we also investigated the trip-maker's occupational industry type to help assist the classification of that trip purpose into a general land-use category3. For example, if a trip-maker took a trip to a "work-based" location, and his or her primary occupational industry was listed as "grocery," then we classified that activity as "retail" (see Figure 1 for the example). Finally, we created an eighth general land-use category containing all trip end purposes—including miscellaneous purposes—to represent a "pooled" category containing all trip ends.

Table 1: Built environment measures for model development—definitions.

Built Environment Measure	Units	Source
Distance of Destination to the Regional Central Business District (CBD)	Miles, Euclidian	CBDs were taken from Pioneer Square in Portland; Union Square in Seattle; and City Hall in Baltimore
Presence of Transit-Oriented Development (TOD)	Binary	TOD Database accessed at http://toddata.cnt.org/
Residential		
Population Density	Residents per acre	Census 2000 SF3, P001
Household Density	Households per acre	Census 2000 SF3, H001
Urban Density	Number of "urban" households	Census 2000 SF3, H005
Rural Density	Number of "rural" households	Census 2000 SF3, H005
Employment		
Employment Density	Employees per acre	CTPP 2000, Part 2, Table 4x1
Retail Employment Density	Employees per acre	CTPP 2000, Part 2, Table 4x6
Professional Employment Density	Employees per acre	CTPP 2000, Part 2, Table 4x10
Arts/Entertainment Employment Density	Employees per acre	CTPP 2000, Part 2, Table 4x12
FIRE Employment Density	Employees per acre	CTPP 2000, Part 2, Table 4x9
Percent Retail Employment	Percent of total employment	CTPP 2000, Part 2, Tables 4x6, 4x1
Percent Professional Employment	Percent of total employment	CTPP 2000, Part 2, Tables 4x10, 4x1
Percent Arts/Entertainment Employment	Percent of total employment	CTPP 2000, Part 2, Tables 4x12, 4x1
Percent FIRE Employment	Percent of total employment	CTPP 2000, Part 2, Tables 4x9, 4x1
Activity		
Activity Density (Population + Employment)	Employees and residents per acre	CTPP 2000, Part 2, Table 4x1 and Census 2000 SF3, P001
Percent Population of Activity	Percent of total employment and residents	CTPP 2000, Part 2, Table 4x1 and Census 2000 SF3, P001
Connectivity		
Total Intersection Density	Intersections per acre	TIGER 2009, Edges and Faces
Four Approach (or more) Intersection Density	Intersections per acre	TIGER 2009, Edges and Faces
Percent Four Approach of Total Intersections	Percent of total intersections	TIGER 2009, Edges and Faces
Median Block Perimeter	Miles	TIGER 2009, Edges and Faces
Median Block Area	Acres	TIGER 2009, Edges and Faces

Notes:
Census 2000 (SF3) tables: P001, Total Population; H001, Housing Units, H005, Urban and Rural CTTP, Part2, Work-to-Place Tables:

Table 4x1: "All workers; For All 3 Categories of Sex; For All 15 Categories of Industry"
4.2.1.1.1.1.1 Table 4x6: "All workers; For All 3 Categories of Sex; from Retail Trade Industry"
4.2.1.1.1.1.2 Table 4x9: "All workers; For All 3 Categories of Sex; from Finance, Insurance, Real Estate and Rental and Leasing Industry"
4.2.1.1.1.1.3 Table 4x10: "All workers; For All 3 Categories of Sex; from Professional, Scientific, Management, Administrative, and Waste Management Services Industry"
Table 4x12: "All workers; For All 3 Categories of Sex; from Arts, Entertainment, Recreation, Accommodation and Food Services Industry"

We estimate the mode share adjustments and vehicle occupancy rates based on these general land-use category datasets organized using this schema crosswalk. Therefore, a schema crosswalk that might be developed using different assumptions (i.e., an "eating outside of the home" activity may be classified as a park, grandma's house, or a food cart) may provide different results in adjustment. Without knowing the actual land use at which each activity occurred, we do not know whether the schema crosswalk developed in this analysis is the most accurate. However, we assume that the very general categorization of these activities may provide better estimates of mode share and vehicle occupancy compared to a pooled dataset of all activities occurring in all travel diaries.

To test for whether the schema crosswalk provided in Table 8[3] improves the ability to estimate the urban-context adjustment to trip generation, we test the eighth "pooled" land-use category, which includes all trip ends in one comprehensive dataset. When testing whether the urban-context adjustment estimate method provides less overall error—an improvement in estimation—compared with the ITE's handbook, we will also test whether the schema crosswalk used to segment the dataset into general land-use categories provides an improvement when compared with using the "pooled" dataset. If not, the "pooled" dataset and corresponding adjustment could be recommended until a better method for categorizing the activities into land uses may be developed.

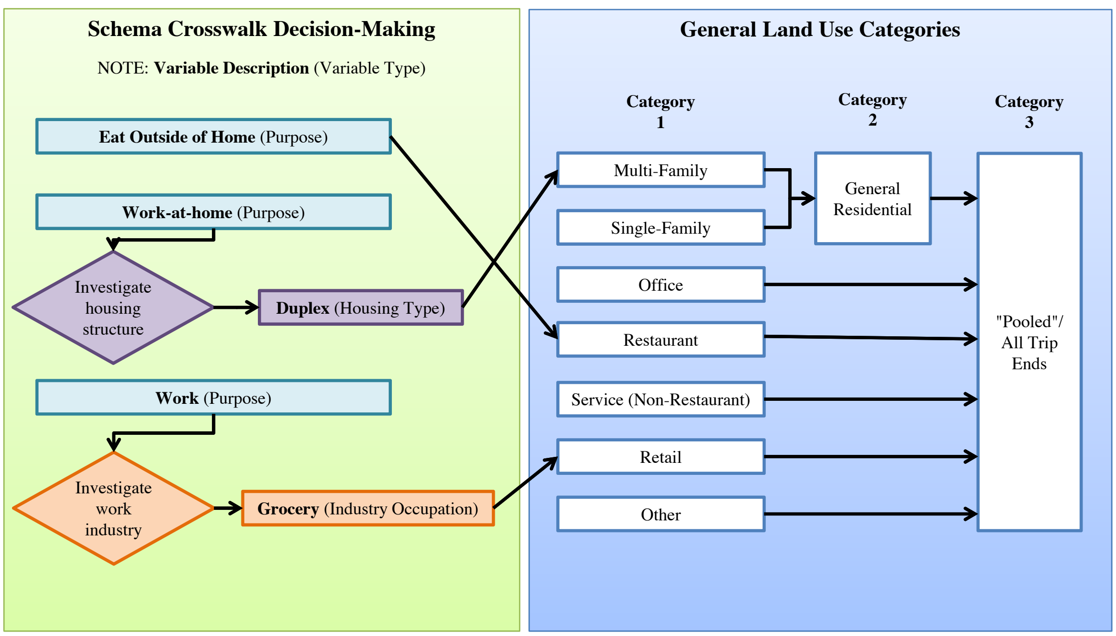

Figure 1: Classifying travel survey trip purposes into land-use categories: Three examples.

4.2 Built environment measures

In order to describe the urban area of each observed trip end location from the travel surveys, we collected data from built environment information for the surrounding environment. The most disaggregate way to describe urban context is through individual built environment (BE) measures for individual land-use types such as residential density or land-use mix. There is a large literature investigating the relationships between the built environment measures and travel behavior (Cervero and Kockelman 1997, Ewing and Cervero 2001, Ewing and Cervero 2010), but the findings supporting one defining measure to estimate changes in mode choice are inconclusive, and there are hundreds of these individually calculated built environment measures that could be used to represent the urban environment (D'sousa

[3] See Table 8 on p. 27 for the full schema crosswalk used in the analysis, including all variables describing travel survey trip purposes, housing types, and occupational industries, and their corresponding general land use categories.

et al. 2012, Ewing and Cervero 2001, Ewing and Cervero 2010). Alternative methods have been used to define the urban environment using composite indices or clusters constructed from many correlated individual measures (Clifton et al. 2013, Handy et al. 2013). Applying these methods in this analysis would require the practitioner to collect many built environment measures, conflicting with one of our guiding principles, which is to make the method ready-to-use and easy to apply.

While a significant amount of the literature is aimed at quantifying the impact of built environment on travel behavior, the purpose of this research is to select built environment measures that can be calculated using data widely available across the United States, such as the Census. Portland, for example, has rich built environment information data including: sidewalk coverage, tree cover, bike corral parking, LiDaR elevations, parcel floor-to-area ratio estimates, regional zoning and land-use shape files, and lot coverage. Although this detailed information may provide insight into how the trip-makers decide where and when to travel (Schneider 2011), these data are not ubiquitously collected and available for most regions or jurisdictions in the United States. For this reason, only datasets available everywhere were used to calculate built environment measures for each observed activity location. The data applied in this analysis include: the 2000 Census Summary File 3 (SF3); Part 2, the Place-to-Work Tables in the 2000 Census Transportation Planning Package (CTPP); 2009 Topologically Integrated Geographic Encoding and Referencing (TIGER) Files and; the 2012 Transit-Oriented Development (TOD) Database. For further descriptions of the data used, see Table 1.

We calculated 20 different built environment measures, described in Table 1, for each observed travel diary trip end. Each measure was calculated for the 0.5-mile Euclidian buffer area surrounding the location according to the GIS protocols by D'Sousa et al. (2012). In addition to the 20 built environment measures, we calculated two additional variables to help control for regional accessibility—Euclidean distance to the central business district (CBD)—and quality transit accessibility—whether the activity location occurred within 0.5 miles of a TOD. Table 2 provides a summary of the corresponding built environment observed at all trip ends in the three travel diaries, as well as the household, trip-maker, travel, time and date characteristics that describe the "pooled" dataset.

Table 2: Summary statistics of travel survey trip end dataset, "pooled" or all trip ends.

		Total Trip Ends	Percent of Total
All Household Travel Survey Trip Ends		243,671	100%
Portland, Oregon (OHAS, 2011)		41,795	17%
Seattle, Washington (PSRC, 2006)		150,040	62%
Baltimore, Maryland (NHTS Add-on, 2001)		51,836	21%
		Average	Standard Deviation
Built Environment (collected for 0.5-mile Euclidean buffer around location)			
Activity Density	People and employment per acre	20.1	38.4
Employment Density	Employment per acre	11.9	34.5
Intersection Density	Intersections per acre	0.2	0.15
Percent of Intersections with Four or More Approaches	Percent of intersections with four or more approaches	34.0%	
Percent Retail Employment	Percent of total employment	13.0%	
Distance to the CBD	Miles to the MPO CBD	12.4	10.4
Near a TOD	Percent of trip ends near a TOD	11.0%	
Household Characteristics			
Size	People per household	2.9	1.4
Vehicle ownership	Vehicles per household	2.1	1.1
Drivers	People per household	2.0	0.7
Income			
Below $50,000	Percent of total	27.0%	
Above $100,000	Percent of total	26.0%	
Workers	People per household	1.5	0.9
Trip-maker Characteristics			
Age	Years	42	21
Sex (Female)	Percent Total	55%	
Travel Characteristics			
Travel Distance (miles)	Miles	6.90	20.00
Vehicle Occupancy	People per vehicle	1.72	1.07
Mode Share			
Automobile	Percent of total	81%	
Walk	Percent of total	11%	
Transit	Percent of total	7%	
Bike	Percent of total	1%	
Time			
AM Peak Period (7-9 a.m.)	Percent of total	15%	
PM Peak Period (4-6 p.m.)	Percent of total	17%	
Midday (9 a.m.–4 p.m.)	Percent of total	43%	
Date			
Weekend (Saturday, Sunday)	Percent of total	2%	
Friday	Percent of total	14%	
Winter (Nov. thru Feb.)	Percent of total	5%	

5 Urban adjustment equation development

Once the travel survey data was organized into general land-use categories and the built environment data had been collected for all trip ends, we used the data to begin the urban adjustment equation development. This section details the development of each of the three different adjustments—all of which are adjustments using mode shares and vehicle occupancy applied directly to the ITE handbook vehicle trip generation estimates.

The first of the three adjustments—Adjustment A—is the most parsimonious. It consists of a table of the multimodal mode split (in percent) by one measure of the built environment (activity density). The second and third adjustments—Adjustment B and Adjustment C—use regression analysis to estimate the automobile mode share, controlling for additional information, such as the time of day, day of week, whether the observation occurred during winter months, and the trip activity location's built environment.

We estimated an additional set of regressions to predict vehicle occupancy rates. These vehicle occupancy regressions, or equations, are used in all three methods—A, B, and C—in the adjustment described in the earlier Section 3 "Framework for an urban-context adjustment." The outcomes of these three methods are the same; they provide a way to estimate the automobile mode share (as a percent) and vehicle occupancy rates at a given development. We describe each of the three adjustments methods developed in this research in the following sections.

5.1 Adjustment A: Multimodal mode share aggregate table

The ITE's handbook segments its vehicle trip generation rates by time of day, day of the week, and specific land-use type. While the latter two adjustment methods—B and C—control for variations in automobile mode share for these characteristics, we wanted to test the simplicity of parsimonious multimodal mode-share tables, which provide a mode split for incremental ranges of the built environment—i.e., 0 to 50 people per acre, 50 to 100 people per acre, etc.

For the purpose of simplicity, activity density is used as a measurement of urban context. There are a large number of built environment measures that could be used to describe the urban-ness of a location (e.g., intersection density, employment density, access to transit, and percent of total intersections that have four or more approaches). Activity density—a measurement of the number of residents and employment per acre within a 0.5-mile buffer of each trip end location—serves only as a proxy for the many elements that make up or describe urban form. Thus, we segment trip ends into incremental ranges of activity density, calculating the unweighted multimodal mode shares of trip ends in each activity density range for each general land-use category. Adjustment A (see Table 3) provides a look-up table of mode splits for each general land-use category, as well as a pooled "all trip ends" data. Practitioners can simply calculate the activity density of their development and look up the estimated mode split for the relevant general land-use category as shown in Table 3.

One of the advantages of using a simple, mode share look-up table like Adjustment A is that we can estimate the non-automobile mode shares for bicycling, walking and transit. Adjustments B and C employ a multivariate binary logistic regression to estimate the automobile mode share, which allows the user to control for more information (e.g., time of day or day of the week). More information about the non-automobile trip-makers, however, may help practitioners understand or estimate the number of people—and their modes—that may come to their development, not just the number of vehicles.

Caution should be used for activity density range categories with small sample sizes (less than approximately 50 trip ends observed). For example, there are far fewer observations in the densest category—300 to 350 people per acre—leading to a smaller sample of trips or activities observed. In these categories with small samples, the mode share estimate may be much less accurate. The sample size of each category in the activity density range is contingent on what was observed in the household travel surveys. Additional travel survey data—potentially from different regions in the United States—could be compiled to supplement this look-up table and increase the sample size for certain categories.

For some of the land-use categories, we observed higher rates of walk trips in the 150-200 people per acre range, compared to denser areas. The highest level of observed activity density in Portland and Baltimore was just under 200 people per acre. Trips observed at densities above 200 people per acre occurred in Seattle. We also know that the OHAS survey (Portland) script was administered with intentional prompting of participants to help capture the short walk trips that so often go underreported in many traditional surveys (Singleton and Clifton 2013). This means that observations occurring at densities less than 200 people per acre include the short walk trips in downtown Portland that would typically go unreported. Walk trips occurring in the densest parts of Seattle, where activities and land use are much closer and corresponding trip lengths are generally shorter, are likely underrepresented in this sample—leading to higher automobile estimates in the greater densities.

Look-up tables like Adjustment A do not control for differences in mode shares when other metrics change, e.g., time-of-day or access to rail transit. One way to control for these differences is to perform a regression analysis on the trip-level mode choice while controlling for additional trip characteristics that may bias the mode shares across different urban forms. This process was used to develop Adjustments B and C and is described in the next section.

Table 3: Adjustment A: Mode shares by activity density.

		Activity Density (residents and employment per acre)						
		0-50	50-100	100-150	150-200	200-250	250-300	300-350
"Pooled" All Trip Ends	Vehicle	84%	55%	41%	33%	44%	37%	25%
	Bike	1%	2%	3%	2%	1%	1%	3%
	Transit	6%	15%	19%	23%	28%	30%	34%
	Walk	9%	28%	38%	42%	28%	32%	38%
	Trip Ends	226,178	7359	3418	2964	1398	1878	192
Restaurant	Vehicle	88%	53%	36%	25%	27%	30%	24%
	Bike	1%	0%	3%	2%	2%	0%	5%
	Transit	2%	9%	5%	7%	17%	15%	7%
	Walk	9%	38%	56%	66%	54%	55%	64%
	Trip Ends	15,900	647	299	281	155	274	42
Service (Non-Restaurant)	Vehicle	90%	72%	56%	48%	58%	26%	0%
	Bike	1%	1%	3%	2%	0%	0%	0%
	Transit	3%	10%	16%	20%	22%	24%	75%
	Walk	6%	18%	25%	30%	19%	50%	25%
	Trip Ends	24,332	710	310	289	219	208	12
Retail	Vehicle	91%	52%	32%	34%	36%	25%	83%
	Bike	1%	2%	4%	1%	0%	0%	0%
	Transit	2%	10%	13%	26%	33%	20%	0%
	Walk	7%	37%	51%	39%	32%	55%	17%
	Trip Ends	27,299	730	156	214	206	148	12
Office	Vehicle	89%	56%	46%	36%	60%	32%	25%
	Bike	1%	5%	3%	3%	0%	2%	0%
	Transit	4%	17%	8%	14%	29%	40%	75%
	Walk	6%	22%	42%	46%	12%	25%	0%
	Trip Ends	8,566	900	464	648	42	276	24
General Residential	Vehicle	82%	48%	34%	34%	35%	52%	15%
	Bike	1%	1%	1%	3%	0%	0%	0%
	Transit	7%	19%	20%	21%	9%	38%	0%
	Walk	9%	31%	45%	43%	56%	10%	85%
	Trip Ends	82,217	1726	369	146	79	42	26
Single-Family Residential	Vehicle	85%	66%	69%	---	---	---	---
	Bike	2%	0%	0%	---	---	---	---
	Transit	6%	11%	0%	---	---	---	---
	Walk	7%	23%	31%	---	---	---	---
	Trip Ends	62,289	157	13	---	---	---	---
Multi-Family Residential	Vehicle	71%	47%	32%	30%	35%	60%	15%
	Bike	1%	1%	1%	3%	0%	0%	0%
	Transit	10%	20%	21%	22%	9%	30%	0%
	Walk	17%	32%	46%	45%	56%	10%	85%
	Trip Ends	15,959	1497	336	130	79	30	26

5.2 Adjustment B and C: Automobile mode share model

To build more robust estimations of automobile mode share rates across urban context, we apply binary logistic regressions to estimate the odds that people will take—versus not take—a personal automobile for his or her trip. While multinomial logistic models may provide an estimated multimodal mode share, we could not use this model because we do not have information about the alternative mode choices the trip-maker did not choose, in addition to the information we have about the mode choices the trip-maker did choose. In the methods B and C, we control for additional trip characteristics, such as time of day, day of week and whether the trip occurred during the winter months. Both of these methods allow the practitioner to use the estimated model as equations to estimate the automobile mode share (as a percent) using a particular built environment measure. While multinomial logistic models may provide an estimated percent mode share for all modes, this type of model was prevented from being used due to limitations in compiling three different regional travel surveys as well as availability of data describing the trip-makers alternatives not chosen.

The two adjustment methods vary in one way: the selection of the built environment measure used to represent the urban context of the development location. While Adjustment A provides an estimate of the automobile mode share using a built environment measure that provided the best statistical fit, Adjustment B provides an estimate of the automobile mode share using a built environment measure with sensitivity to land-use policies. Once controlling for other characteristics of the trip like time of day and day of the week, the built environment measure that provides the best statistical fit (e.g., the highest pseudo R^2 value) is most often intersection density (see Table 1 for definitions). For greenfield areas, intersection density provides an excellent guideline for planners and developers to create the built environment that can provide the backbone for multimodal travel. For areas that are already somewhat developed, it becomes very difficult to implement a change in intersection density if a practitioner or land-use planner desires to plan for an area according to some target automobile, or non-automobile, mode share rate.

For this purpose, we estimate a third set of equations—Adjustment C—that provides a strong statistical fit (often less than 3 percent difference compared with the Adjustment B fit), which also considers a built environment measure that is more sensitive to urban infill land-use planning policies. Secondary or complementary built environment measures were tested, but did not provide an improvement in the explanation of variance (pseudo R^2) of more than 1 percent. Thinking of the practitioner, we decided to use only one measure of the built environment to represent changes in the urban context for each adjustment.

For each general land-use category and each adjustment method, 20 models were estimated that consider each built environment measure described in Table 1. Each of these models control for the same set of general variables: time of day, day of the week, and whether the trip was observed during a winter month (November through February). Two additional variables were included in each regression to control for the general regional accessibility (Euclidean distance to the CBD) and quality transit accessibility (whether the location was located within 0.5 miles of a TOD). The Euclidean distance to the CBD and each of the built environment variables had statistically significant (p-value < 0.01) Pearson's correlations between zero and -0.25. This low correlation allowed both the distance to the CBD and each of the built environment variables to be included in the same regressions without concern for multicolinearity.

The binary logistic models selected for each land-use category for Adjustment B and C are shown in Table 4 and Table 5, respectively. Each model estimates the "odds ratio" that traffic will occur in a personal automobile, versus not in a personal automobile, for the inputted development location. This odds ratio can be converted into a probability that describes the estimated personal automobile mode share for the provided urban context.

When evaluating Adjustment B and C binary logistic models, the direction of the effects for each of the built environment variables was intuitive. For example, as intersection density increases, the area-type becomes more urban and automobile mode shares decrease. In general, as the distance from the regional CBD increases, the automobile mode share increases, and when the trip end is located within 0.5 miles of a TOD, the odds that an automobile was used for the trip decreases.

Table 4: Adjustment B, binary logistic regressions, automobile mode share, built environment with best predictive power.

		Restaurant		Service (Non-Restaurant)		Retail		Office		Residential						"Pooled" All Trip Ends	
										Multi-Family		Single-Family		General			
x^2 (Likelihood Radio Test)		3318		2180		4203		2741		1637		1791		5537		25,077	
Nagelkerke R^2		0.29		0.15		0.26		0.35		0.12		0.05		0.1		0.16	
Sample Size (N)		17,561		26,104		28,743		10,912		18,034		62,392		84,517		243,274	
		B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Time of Day	AM Peak	0.22	0.02	-0.35	0.00	-0.39	0.00	0.22	0.00	-0.05	0.34	-0.28	0.00	-0.19	0.00	-0.27	0.00
	PM Peak	0.23	0.00	0.02	0.67	0.09	0.09	0.25	0.00	0.16	0.00	0.14	0.00	0.15	0.00	0.18	0.00
	Before 7 AM, after 6 PM	0.66	0.00	0.20	0.00	0.10	0.05	0.45	0.00	0.20	0.00	0.18	0.00	0.19	0.00	0.27	0.00
	Midday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Daily**	0.28		0.00		0.02		0.17		0.08		0.03		0.05		0.06	
Date	Friday	0.16	0.01	-0.06	0.27	0.02	0.75	0.04	0.61	0.14	0.00	0.05	0.18	0.06	0.04	0.04	0.01
	Weekend	0.36	0.05	0.37	0.10	0.01	0.93	-0.01	0.97	0.77	0.00	0.22	0.03	0.46	0.00	0.32	0.00
	Weekday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Winter	0.53	0.00	0.53	0.00	0.21	0.02	0.22	0.04	0.24	0.00	0.28	0.00	0.17	0.00	0.13	0.00
Distance to CBD (miles)		0.02	0.00	0.02	0.00	0.04	0.00	0.12	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00
Presence of TOD		-0.55	0.00	-0.32	0.00	-0.33	0.00	-0.35	0.00	-0.11	0.02	0.01	0.86	-0.24	0.00	-0.46	0.00
Built Environment		Intersection Density		4-Approach Intersection Density		Intersection Density		4-Way Intersection Density		4-Way Intersection Density		4-Way Intersection Density		4-Way Intersection Density		4-Way Intersection Density	
Variable with the Best Prediction		-6.06	0.00	-5.77	0.00	-5.56	0.00	-0.03	0.00	-4.32	0.00	-4.39	0.00	-5.03	0.00	-4.80	0.00
(constant)		2.79	0.00	2.42	0.00	2.91	0.00	1.74	0.00	1.20	0.00	1.84	0.00	1.73	0.00	1.78	0.00

* Indicates dummy variable.

** "Daily" coefficient was a weighted average of the time-of-day coefficients based on proportion of observations in each dataset.

Table 5: Adjustment C, binary logistic regressions, automobile mode share, built environment with additional land-use policy.

		Restaurant		Service (Non-Restaurant)		Retail		Office		Residential						"Pooled" All Trip Ends	
										Multi-Family		Single-Family		General			
x^2 (Likelihood Radio Test)		2992		1967		4101		2710		1480		1573		5311		22,721	
Nagelkerke R^2		0.26		0.14		0.26		0.35		0.11		0.04		0.1		0.14	
Sample Size (N)		17,561		26,104		28,743		10,912		18,034		62,392		84,521		243,278	
		B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Time of Day*	AM Peak	0.16	0.09	-0.39	0.00	-0.36	0.00	0.27	0.00	-0.05	0.35	-0.28	0.00	-0.20	0.00	-0.29	0.00
	PM Peak	0.22	0.00	0.02	0.75	0.06	0.24	0.29	0.00	0.16	0.00	0.13	0.00	0.15	0.00	0.16	0.00
	Before 7 AM, after 6 PM	0.62	0.00	0.19	0.00	0.13	0.01	0.52	0.00	0.21	0.00	0.17	0.00	0.20	0.00	0.27	0.00
	Midday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Daily**	0.26		0.00		0.02		0.20		0.09		0.02		0.06		0.05	
Date*	Friday	0.19	0.00	-0.03	0.63	0.01	0.87	0.06	0.41	0.15	0.00	0.07	0.04	0.09	0.00	0.07	0.00
	Weekend	0.30	0.08	0.40	0.08	0.09	0.40	0.04	0.92	0.78	0.00	0.22	0.03	0.55	0.00	0.42	0.00
	Weekday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Winter	0.34	0.01	0.57	0.00	0.24	0.01	0.44	0.00	0.30	0.00	0.32	0.00	0.27	0.00	0.23	0.00
Distance to CBD (miles)		0.04	0.00	0.02	0.00	0.05	0.00	0.13	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.03	0.00
Presence of TOD*		-1.03	0.00	-0.81	0.00	-0.73	0.00	-0.12	0.13	-0.32	0.00	-0.03	0.73	-0.35	0.00	-0.86	0.00
Built Environment Variable with Policy Sensitivity		Population Density		Population Density		Population Density		Activity Density		Population Density		Population Density		Population Density		Population Density	
		-0.08	0.00	-0.06	0.00	-0.09	0.00	-0.01	0.00	-0.04	0.00	-0.06	0.00	-0.06	0.00	-0.05	0.00
(constant)		2.00	0.00	2.38	0.00	2.48	0.00	0.70	0.00	1.16	0.00	1.97	0.00	1.83	0.00	1.75	0.00

* Indicates dummy variable.

** "Daily" coefficient was a weighted average of the time-of-day coefficients based on proportion of observations in each dataset.

5.3 Vehicle occupancy models

The second part of a mode share adjustment accounts for changes in the vehicle occupancy rate for each general land-use category and the trip characteristics, such as time of day, day of the week, etc. We used linear ordinary least square (OLS) regression estimation to estimate vehicle occupancy rates. Although we tested all 20 measures of the built environment in the regression analysis, no one model estimated provided a moderate or strong statistical fit explaining the variation in vehicle occupancies. To avoid overcomplicating this portion of the adjustment method—especially since the ITE handbook does not report vehicle occupancy rates very often—we selected activity density as a proxy for the urban environment for each general land-use category.

For each of the eight general land-use categories, Table 6 provides the estimated vehicle occupancy regressions. The model performances for all models were low. Although all the included variables remain highly significant in explaining the variation, the effect size of activity density remains very small. Although theory might suggest that vehicle occupancies would be greater in more urban areas, the results indicated that—while occupancy rates vary significantly across the built environment—the effect size of this variation is still very near zero. Vehicle occupancy may be more strongly related to the trip-maker's socio-demographic information, which is not controlled for in this analysis. Despite the low explanatory power of these models, the output of these regressions provide a means for estimating average vehicle occupancy rates while controlling for varying time of day, day of week and season, and they should be used until improved models can be estimated.

Table 6: Adjustment A, B and C: Ordinary least squares regressions, vehicle occupancy.

		Restaurant		Service (Non-Restaurant)		Retail		Office		Residential: Multi-Family		Residential: Single-Family		Residential: General		"Pooled" All Trip Ends	
Adjusted R^2		0.045		0.03		0.037		0.011		0.025		0.006		0.01		0.011	
Sample Size (N)		68,547		22,896		25,280		8,705		12,209		52,973		68,547		197,426	
		B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Time of Day	AM Peak	-0.37	0.00	0.03	0.17	-0.26	0.00	-0.05	0.00	-0.07	0.01	0.11	0.00	0.08	0.00	-0.47	0.00
	PM Peak	0.24	0.00	0.15	0.00	0.03	0.02	-0.06	0.00	0.03	0.33	0.10	0.00	0.09	0.00	0.33	0.00
	Before 7 AM, after 6 PM	0.37	0.00	0.37	0.00	0.18	0.00	-0.04	0.04	0.08	0.00	0.06	0.00	0.08	0.00	0.26	0.00
	Midday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Daily**	0.15		0.10		0.03		-0.03		0.02		0.05		0.05		0.06	
Date	Friday	0.16	0.00	0.02	0.20	0.12	0.00	-0.01	0.66	0.08	0.00	0.05	0.00	0.05	0.00	0.22	0.00
	Weekend	0.50	0.00	0.17	0.01	0.59	0.00	0.20	0.01	0.54	0.00	0.45	0.00	0.52	0.00	1.05	0.00
	Weekday	base	-	base	-	base	-	base	-	base	-	base	-	base	-	base	-
	Winter	0.25	0.00	-0.24	0.00	0.16	0.00	0.08	0.00	0.09	0.00	0.09	0.00	0.08	0.00	0.07	0.19
Distance to CBD (miles)		0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.64	0.01	0.00	0.00	0.22	0.00	0.00	0.00	0.00
Presence of TOD*		-0.12	0.01	-0.09	0.00	0.03	0.18	0.04	0.11	-0.04	0.13	-0.02	0.56	-0.01	0.60	0.10	0.02
Activity Density		0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.88	0.00	0.48	0.00	0.00	0.00	0.00
(constant)		1.75	0.00	1.53	0.00	1.40	0.00	1.18	0.00	1.51	0.00	1.61	0.00	1.60	0.00	1.66	0.00

* Indicates dummy variable.

** "Daily" coefficient was a weighted average of the time-of-day coefficients based on proportion of observations in each dataset.

6 Verification of method

From the model development in the previous section, we have some understanding of how well the regression equations fit the travel survey data when estimating automobile mode shares and vehicle occupancy rates (e.g., pseudo R^2, coefficient standard errors, p-values). To test the effectiveness of the proposed adjustments in improving trip generation estimation for urban areas, we applied the adjustments—as a practitioner would—on 195 existing automobile trip count data collected at known establishments where we can calculate different measures of the built environment.

6.1 Process and data

In order to test the proposed adjustment methods, we compiled traffic impact analysis data—or vehicle trip counts—from three sources: a Portland State University study from 2011 (Clifton et al. 2013), a California-based data collection prepared by Kimley-Horn and Associates (Daisa et al. 2009), and more recent data collections provided by the ITE. Each of the studies collected the trip count data in accordance with the ITE's *Trip Generation Handbook* where possible. For more urban locations, the studies adjusted their data collection efforts to control for the urban environment—collecting person trip counts, mode shares, and vehicle occupancy rates. Limited establishment-level data were available; and therefore, not every land-use category was tested. From these data, we tested the adjustment methods for four of the eight general land-use categories: residential, office, restaurant and retail. Additionally, we tested each data point using the relevant general land-use category as well as the "pooled" land-use category to evaluate the usefulness of the segmentation of land-use categories.

Out of the 195 points: 71 percent were collected within the Portland, Oregon, region; 24 percent around Oakland, San Diego, and Los Angeles, California; and the rest in Maryland (near Washington, DC) and Vermont. Approximately 86 percent of the data were collected during the p.m. peak hour of the adjacent street traffic.

6.2 Results

Although 195 data points may sound like a substantial amount of data, once segmented by land-use type and time of day, the sample size for some categories of comparison becomes very small. Despite the sometimes small sample sizes, we present all results in Table 7. The ITE handbook requires three data points to establish a new land-use category and provide a new vehicle trip rate (Institute of Transportation Engineers 2004 p. 16). With such low standards for sample size before conclusions on trip generation rates are drawn, we think that the inclusion of any data and results may be valuable for the practitioner's interpretation. Further data collection and testing is required before this method can be considered fully validated for the purpose of application in traffic impact analysis for certain land-use types. Before a full conclusion on the application of these adjustment methods can be made for some of these categories, we encourage users to use their own judgment to determine whether the data presented in this analysis meets their own standards for sample size given the provided developments.

To test the three proposed adjustment methods, we employ the method discussed in Section 3 "Framework for an urban-context adjustment" on page 88 using Steps I through V. The results include four estimates for each data point: an estimate from the ITE handbook and three adjusted estimates from Adjustment A, B and C. Each of these vehicle trip generation estimates are then compared with the observed—or the actual—vehicle trip generation counts. The normalized root-mean-squared error (NRMSE) metric is used to compare each of the estimates with the observed counts (see Equation 3 in the Appendix: Equations on page 119).

The NRMSE metric, expressed as a percent, is an approximation of the standard deviation (or squared variance) of the error (the difference between the estimate and the observed value) normalized across the range of observed values. Generally, smaller percentage values are preferred, which indicate a rate of error that is respectively small compared to the range of observed vehicle trip generation counts. Moreover, when the sample size for any given category is small and the range of observed trip generation rates is small, the NRMSE becomes inflated. Smaller sample sizes and smaller observed ranges of vehicle trip counts, therefore, are penalized with a higher NRMSE value. Sample sizes for each general land-use category and ITE Land Use Code, as well as the calculated NRMSE values, are provided in Table 7. Overall conclusions about how estimates from the ITE's handbook compared to each of the Adjustment methods for each general land-use category are discussed in the following section.

Table 7: Verification results for adjustment methodologies.

The ITE's *Trip Generation Handbook* Land Use Code and Name		General Land Use Category	Count	Normalized Root Mean Squared Error							
				Adjustment A		Adjustment B		Adjustment C		REFERENCE	
				Mode Shares Across Activity Density		Regression: Best Predictor Available		Regression: Best Policy Variable		The ITE's *Trip Generation Handbook* Estimation	
Residential											
222	High-Rise Apartments	Multifamily	2	53%	*	317%	*	26%	*	1323%	
		Residential	2	46%	*	300%	*	134%	*		
		Pooled	2	173%	*	283%	*	156%	*		
223	Mid-Rise Apartments	Multifamily	15	27%	*	26%	*	28%	*	32%	
		Residential	15	26%	*	27%	*	29%	*		
		Pooled	15	25%	*	27%	*	33%			
230	Residential Condominiums / Townhouses	Multifamily	2	536%		492%		570%		213%	•
		Residential	2	566%		509%		609%			
		Pooled	2	503%		517%		652%			
232	High-Rise Residential Condominiums / Townhouses	Multifamily	2	60%	*	65%	*	50%	*	412%	
		Residential	2	56%	*	51%	*	49%	*		
			2	109%	*	11%	*	88%	*		
Office											
710	General Office Building	Office	8	56%	*	68%	*	63%	*	109%	
		Pooled	8	50%	*	44%	*	63%	*		
Retail											
820	Shopping Center	Retail	13	174%	*	163%	*	148%	*	427%	
		Pooled	13	108%	*	105%	*	85%	*		
850	Supermarket	Retail	14	56%		59%		62%		26%	•
		Pooled	14	71%		73%		76%			
851	Convenience Market (Open 24-Hours)	Retail	39	37%	*	27%	*	30%	*	78%	
			39	23%	*	22%	*	23%	*		
Restaurants (Service)											
925	Drinking Place	Restaurant	31	25%	*	26%	*	19%	*	80%	
		Pooled	31	23%	*	23%	*	19%	*		
931	Quality (Sit-Down) Restaurant	Restaurant	4	59%		57%		64%		33%	•
		Pooled	4	58%		55%		61%			
932	High-Turnover (Sit-Down) Restaurant	Restaurant	59	26%	*	28%	*	27%	*	35%	
		Pooled	59	27%	*	27%	*	27%	*		
936	Coffee/Donut Shop without Drive-Through Window	Restaurant	4	193%	*	129%	*	59%	*	345%	
		Pooled	4	195%	*	101%	*	52%	*		
939	Bread/Donut/Bagel Shop without Drive-Through Window	Restaurant	2	646%	*	427%	*	297%	*	1051%	
			2	647%	*	355%	*	271%	*		
Overall (Summary of land-Use Categories)											
	Multifamily		21	23%	*	25%	*	24%	*	63%	
	Office		8	56%	*	68%	*	63%	*	109%	
	Residential		21	24%	*	25%	*	26%	*	63%	
	Restaurant		100	47%	*	35%	*	25%	*	82%	
	Retail		66	77%	*	72%	*	66%	*	190%	
	Pooled/All Trip Ends		195	28%	*	27%	*	22%	*	110%	

* Indicates an adjustment method that improves the ITE's *Trip Generation Handbook* estimations.

• Indicates the ITE's *Trip Generation Handbook* remains the best prediction method.

Bold indicates the lowest estimation method for each land-use category.

7 Conclusions

In this study, we developed and tested three methods for adjusting the ITE's *Trip Generation Handbook* estimates for developments located in different urban contexts. The three approaches made use of readily available household travel survey data for three metropolitan regions in the United States: Baltimore, Maryland; Seattle, Washington; and Portland, Oregon. These regions have a wide variety of urban environments, with differing transportation and land-use characteristics. By basing the adjustment approaches on travel surveys from different regions, we aimed to reduce regional bias that may occur with data analyzed from a single region in order to provide a more robust adjustment method that could be broadly applied to communities throughout the United States.

Out of all of the land uses tested and verified, the ITE's *Trip Generation Handbook* estimates the vehicle trip generation counts with less error for residential condominiums/ townhouses, supermarkets and quality (sit-down) restaurants, compared with the urban-context adjusted estimates. Moderate or small improvements from the urban adjustments were observed for mid-rise apartments and high-turnover (sit-down) restaurants. The most substantial improvements in vehicle trip estimates were found with high-rise apartments and condominiums/townhouses, shopping centers, and coffee/donut or bread/donut/bagel shops without drive-through windows. The greatest improvements in estimating automobile trip generation counts using any of the three adjustment methods—A, B, or C—were found for land-use types commonly used as infill developments in more urban areas.

On average, all of the three methods developed and tested here perform better than the ITE's handbook (see Table 7). The results demonstrate that urban context adjustments should be considered when using the ITE's handbook trip generation rates for infill developments in densely populated areas with more mixed-use development, smart growth sites, TODs and other locations with strong built environment supports for non-automobile modes.

Of the three approaches, the simplest adjustment approach (Adjustment A) performs similarly to the approaches derived using more complex models (Adjustments B and C). This approach is easy to use in a variety of urban environments and suggests that simple adjustments that account for more multimodal travel to urban destinations to the ITE method can have marked improvements. This finding illustrates one of the shortcomings of the ITE Trip Generation Handbook, which is one of the most widely used transportation references in use throughout the country.

Its lack of sensitivity to urban context is just one of many issues that need to be addressed. Other considerations include: the lack of guidance for estimating non-automobile trips, the need to account for person trips, the inability to include location information, the influence of site design, and the lack of a behavioral framework, to name a few. The current version of the handbook is undergoing a revision, and the ITE is considering changes to the data-collection procedures to address these current limitations. The findings from this study provide a stop-gap mechanism to deal with the urban context adjustment issue until an adequate amount of new data exist or an alternate approach is available. Additional establishment-level trip generation counts representing more land uses, time periods and regions are necessary to determine how the ITE's handbook performs in other circumstances, including assessing the transferability of the vehicle trip end rates or mode share reductions across the United States.

However, this study is not without limitations. In terms of the representation of urban context, this analysis employed only one measure of the built environment at a time, selected based on its predictive power or sensitivity to land-use policy in the planning practice. While a single built environment measure provides a parsimonious way to account for often-correlated measures, methods that distill built environment information into composite measures (i.e., factor and/or cluster analysis) may allow for a more robust representation of many measures of the built environment and how they work together to define the urban context (Clifton et al. 2012, Cervero and Kockelman 1997, Handy et al. 2013). Future iterations of this research may consider developing and testing these composite measures from across the United States. More research is needed to test additional measures describing the environment and the corresponding performance in the application for establishment-level data. Moreover, as more data becomes more ubiquitously available, it will become feasible to incorporate more robust measures of the built environment. For example, future iterations of this work could control for bus transit and the quality of public transportation services using the Google Transit Feed Specification data compiled nationally and available online.[4]

Considering the method itself, there are also biases introduced through using travel survey data and the assumptions made about data collected for the ITE's handbook. Travel surveys, for example, capture trips for one household based on a sample of households in the region. Historically, travel surveys have typically underrepresented non-motorized travel, specifically short walk trips (Singleton and Clifton 2013). This means that the mode share estimates in Adjustments A, B, and C are likely overestimating automobile mode shares. Delivery and truck traffic is also not accounted for in traditional travel surveys and should be considered in a separate but complementary trip generation analysis. In another example, there may be an underrepresentation of activities, locations, vehicle occupancies, and/or modal decisions taken by households that were less likely to participate in the travel survey or were underrepresented in the sample. Weighting the travel surveys according to sampling schemes becomes problematic when combining several different regionally developed surveys. Ideally, we would also like to weight our sample by urban context and land use, making sure we adequately represent the availability of the general land-use categories across all urban area types in the United States. Further exploration and development of context-based weights may prove useful if this method is adopted into practice.

Moreover, the assumptions we make in our adjustment methods may also lead to biased estimates. We assume the data from the ITE's handbook has a 100 percent automobile mode share and a person per vehicle occupancy rate—unless information is otherwise provided. Applying a mode share adjustment like this method is consistent with the JHK and Associates method for adjusting for transportation impact factors (1996, Institute of Transportation Engineers 2004 p. 121) and has been recommended in at least two other methods that accounts for non-automobile trip-makers (Ewing et al. 2011, Daisa et al. 2013). The assumption that the locations observed in the ITE's handbook have a 100 percent automobile mode share and a 1.0 vehicle occupancy for the ITE's handbook data—where other information is not available—implies a one-to-one direct adjustment between vehicle trips to person trips. Each vehicle trip is assumed to be a person trip. For urban contexts, therefore, we assume that every person who comes by a mode other than a personal automobile equates to one fewer automobile trip to that establishment. Assuming values lower than 100 percent for an automobile mode share and greater than a 1.0 vehicle occupancy rate will result in a higher estimate of the ITE person trips, corresponding with a higher estimate for urban context adjusted vehicle trips at the study location (see Equation 1 and Equation 2 in "Appendix: Equations" on page 119 for more information). If the user has information that describes the mode share or vehicle occupancy at locations situated in areas similar to the ITE handbook locations, we recommend that it be used in lieu of the 100 automobile/1.0 persons per vehicle assumptions.

However, considering both the biases in the assumptions of the direct adjustment as well as those inherent when using travel survey data, the question we are now forced to ask is: What is a conservative estimate? Naturally, we want to reduce the overall error in estimating vehicle trip generation rates, but if one method consistently overestimates automobile trip rates—leading to a greater automobile facility build-out than necessary—and a second method consistently underestimates them—leading to more congestion—which method should we prefer? And how much error is tolerable in either overestimation

[4] Google Transit Feed Specification. Available at https://developers.google.com/transit/gtfs/.

or underestimation? These are the questions we must ask before we are able to move forward evolving the practice of trip generation estimation.

In terms of other future work, the literature suggests that the relationship between the built environment and travel behavior changes significantly when controlling for socio-demographic characteristics of the trip-maker and travel characteristics of the trip itself (Ewing et al. 1996, Ewing and Cervero 2010, Crane 2000). The ITE's *Trip Generation Handbook* method, initially developed in the 1960s, ignores the individual-level characteristics of the trip-makers. Total vehicle trips are considered a function of the size of the establishment, whether measured in square footage, employees or seats. Subsequently, socio-demographics are not controlled for in trip generation analysis despite the fact that it has been long understood that trip-maker characteristics play an important role in determining trip-maker behavior and most regional travel models use them as the primary predictors of trip generation.

Overall, this study provides another method to accommodate the increasing demand for a more urban-sensitive framework to estimate travel demand at a variety of land uses. In part, this demand is due to changes in the goals of jurisdictions to grow more dense or diverse cities. Moreover, this growing interest in urban-sensitive trip generation methods reflects a promising desire to accommodate biking, walking and transit modes when planning for new developments and their impacts on the transportation network.

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Table 8: Land-use and trip-purpose schema crosswalk.[5]

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Baltimore	Housing Type	Apartment, condominium		MF	HOU	PLD
Baltimore	Housing Type	Boat				PLD
Baltimore	Housing Type	Detached single house		SF	HOU	PLD
Baltimore	Housing Type	Don't know				PLD
Baltimore	Housing Type	Dorm room, fraternity or sorority house				PLD
Baltimore	Housing Type	Duplex, triplex		MF	HOU	PLD
Baltimore	Housing Type	Government/public housing (type unspecified)				PLD
Baltimore	Housing Type	Military base housing (type unspecified)				PLD
Baltimore	Housing Type	Mobile home or trailer				PLD
Baltimore	Housing Type	Other (specify)				PLD
Baltimore	Housing Type	Quadplex		MF	HOU	PLD
Baltimore	Housing Type	Refused				PLD
Baltimore	Housing Type	Row house, townhouse		MF	HOU	PLD
Baltimore	Housing Type	Semi-attached/semi-detached house		MF	HOU	PLD
Baltimore	Occ. Industry	Appropriate skip				PLD
Baltimore	Occ. Industry	Clerical or administrative support		OFF		PLD
Baltimore	Occ. Industry	Don't know				PLD
Baltimore	Occ. Industry	Manufacturing, construction, maintenance, or family				PLD
Baltimore	Occ. Industry	Military				PLD
Baltimore	Occ. Industry	Other (specify)				PLD
Baltimore	Occ. Industry	Police/firefighter/corrections officer				PLD
Baltimore	Occ. Industry	Professional, managerial, or technical		OFF		PLD
Baltimore	Occ. Industry	Refused				PLD
Baltimore	Occ. Industry	Sales or service		SER		PLD
Baltimore	Occ. Industry	Skilled trade/craftsperson				PLD
Baltimore	Occ. Industry	Transportation/machine operator				PLD
Baltimore	Purpose	Home	Home-related			PLD
Baltimore	Purpose	Attend business meeting/trip	Work-related			PLD
Baltimore	Purpose	Go to work	Work-related			PLD
Baltimore	Purpose	Looking for a job/job interview	Work-related			PLD
Baltimore	Purpose	Meeting (unspecified)	Work-related			PLD
Baltimore	Purpose	Other work related	Work-related			PLD
Baltimore	Purpose	Return to work	Work-related			PLD
Baltimore	Purpose	Work	Work-related			PLD
Baltimore	Purpose	Pickup someone				PLD
Baltimore	Purpose	Appropriate skip				PLD
Baltimore	Purpose	At a motel/hotel				PLD
Baltimore	Purpose	At daycare/babysitter				PLD

[5] General land-use category acronyms: HOU = residential; MF = multi-family; OFF = office; PLD = "pooled"/all trip ends; RES = restaurant; RET = retail; SER = service (non-restaurant); and SF = single-family.

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Baltimore	Purpose	Attend funeral/wedding				PLD
Baltimore	Purpose	Attend meeting (PTA, homeowners association, local)				PLD
Baltimore	Purpose	Buy gas				PLD
Baltimore	Purpose	Buy goods (groceries, clothing, hardware store)		RET		PLD
Baltimore	Purpose	Buy services (video rentals, dry cleaner, post office)		SER		PLD
Baltimore	Purpose	Coffee/ice cream/snacks		RES		PLD
Baltimore	Purpose	Don't know				PLD
Baltimore	Purpose	Drop someone off				PLD
Baltimore	Purpose	Family personal business/obligations		SER		PLD
Baltimore	Purpose	Funeral				PLD
Baltimore	Purpose	Get/eat meal		RES		PLD
Baltimore	Purpose	Getting a ride/changing transportation				PLD
Baltimore	Purpose	Go out/hand out (entertainment, theater, sports event)				PLD
Baltimore	Purpose	Go to gym, exercise, play sports				PLD
Baltimore	Purpose	Go to library (school-related)				PLD
Baltimore	Purpose	Go to religious activity				PLD
Baltimore	Purpose	Go to school as a student				PLD
Baltimore	Purpose	Jury duty				PLD
Baltimore	Purpose	Meals		RES		PLD
Baltimore	Purpose	Medical/dental services				PLD
Baltimore	Purpose	Other (specify)				PLD
Baltimore	Purpose	Pet care (walk the dog, vet visits)				PLD
Baltimore	Purpose	Refused				PLD
Baltimore	Purpose	Rest or relaxation/vacation				PLD
Baltimore	Purpose	School/religious activity				PLD
Baltimore	Purpose	Shopping/errands		RET		PLD
Baltimore	Purpose	Social event		RES		PLD
Baltimore	Purpose	Social/recreational				PLD
Baltimore	Purpose	Spend the night/sleep				PLD
Baltimore	Purpose	Take and wait				PLD
Baltimore	Purpose	Transport someone				PLD
Baltimore	Purpose	Use professional services: attorney/ accountant		SER		PLD
Baltimore	Purpose	User personal services: grooming/haircut/ nails		SER		PLD
Baltimore	Purpose	Visit friends/relatives			HOU	PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Baltimore	Purpose	Visit public place (historical site, museum, park)				PLD
Baltimore	Purpose	Volunteer work				PLD
Baltimore	Purpose	Voting				PLD
Portland	Housing Type	Building with three or more apartments		MF	HOU	PLD
Portland	Housing Type	Duplex		MF	HOU	PLD
Portland	Housing Type	Mobile home				PLD
Portland	Housing Type	Or something else?				PLD
Portland	Housing Type	Refused				PLD
Portland	Housing Type	Single family unit		SF	HOU	PLD
Portland	Occ. Industry	Accommodation or food services		RES		PLD
Portland	Occ. Industry	Administrative support, waste management or remediation service				PLD
Portland	Occ. Industry	Agriculture, forestry, mining				PLD
Portland	Occ. Industry	All other miscellaneous responses				PLD
Portland	Occ. Industry	Arts, entertainment or recreation				PLD
Portland	Occ. Industry	Construction				PLD
Portland	Occ. Industry	Don't know				PLD
Portland	Occ. Industry	Don't know/refused				PLD
Portland	Occ. Industry	Educational services				PLD
Portland	Occ. Industry	Everything				PLD
Portland	Occ. Industry	Finance and insurance		OFF		PLD
Portland	Occ. Industry	Government		OFF		PLD
Portland	Occ. Industry	Health care or social assistance				PLD
Portland	Occ. Industry	Management of companies or enterprises				PLD
Portland	Occ. Industry	Manufacturing				PLD
Portland	Occ. Industry	None/nothing				PLD
Portland	Occ. Industry	Or other services (specify)				PLD
Portland	Occ. Industry	Other (specify)				PLD
Portland	Occ. Industry	Professional, scientific, or technical services		OFF		PLD
Portland	Occ. Industry	Real estate, rental or leasing		OFF		PLD
Portland	Occ. Industry	Refused/no response				PLD
Portland	Occ. Industry	Retail trade		RET		PLD
Portland	Occ. Industry	Service				PLD
Portland	Occ. Industry	Transportation, communications, utilities, or warehousing				PLD
Portland	Occ. Industry	Wholesale trade				PLD
Portland	Purpose	All other at home activities	Home			PLD
Portland	Purpose	Working at home	Home			PLD
Portland	Purpose	All other activities at work	Work			PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Portland	Purpose	Work/business related	Work			PLD
Portland	Purpose	Work/job	Work			PLD
Portland	Purpose	All other activities at school				PLD
Portland	Purpose	Attending class				PLD
Portland	Purpose	Change of mode/transportation				PLD
Portland	Purpose	Civic/religious activities				PLD
Portland	Purpose	Dropped off passenger from car				PLD
Portland	Purpose	Eat meal outside of home		RES		PLD
Portland	Purpose	Health care (doctor, dentist)				PLD
Portland	Purpose	Household errands (bank, dry cleaning, etc.)		SER		PLD
Portland	Purpose	Indoor recreation/entertainment				PLD
Portland	Purpose	Loop trip				PLD
Portland	Purpose	Other, specify				PLD
Portland	Purpose	Other, specify				PLD
Portland	Purpose	Outdoor recreation/entertainment				PLD
Portland	Purpose	Personal business (Visit government office, attorney, accountant)		SER		PLD
Portland	Purpose	Picked up passenger from car				PLD
Portland	Purpose	Routine shopping (groceries, clothing, convenience store, HH maintenance)		RET		PLD
Portland	Purpose	Service private vehicle				PLD
	Occ. Industry	Finance and insurance		OFF		PLD
Portland	Purpose	Shopping from major purchases or specialty items (appliances, electronics, new vehicle, major HH repairs)				PLD
Portland	Purpose	Visit friends/relatives			HOU	PLD
Seattle	Housing Type	All other miscellaneous responses				PLD
Seattle	Housing Type	Apartment, condominium		MF	HOU	PLD
Seattle	Housing Type	Boat				PLD
Seattle	Housing Type	Detached single house		SF	HOU	PLD
Seattle	Housing Type	Don't know				PLD
Seattle	Housing Type	Dorm room, fraternity or sorority house (do not read)				PLD
Seattle	Housing Type	Duplex		MF	HOU	PLD
Seattle	Housing Type	Military housing				PLD
Seattle	Housing Type	Mobile home or trailer			HOU	PLD
Seattle	Housing Type	Refused				PLD
Seattle	Housing Type	Rented room/room in a house				PLD
Seattle	Housing Type	Row house, townhouse		MF	HOU	PLD
Seattle	Housing Type	Triplex or four-plex		MF	HOU	PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Seattle	Housing Type	Warehouse				PLD
Seattle	Occ. Industry	Accounting/bookkeeping/CPA		OFF		PLD
Seattle	Occ. Industry	Aerospace				PLD
Seattle	Occ. Industry	Agriculture (farms/dairy, egg production etc.)				PLD
Seattle	Occ. Industry	Airline/air craft/aviation				PLD
Seattle	Occ. Industry	Animal care/control (veterinary/ boarding/grooming/supplies)		SER		PLD
Seattle	Occ. Industry	Architecture		OFF		PLD
Seattle	Occ. Industry	Art gallery/studio		RET		PLD
Seattle	Occ. Industry	Automotive dealer/repair				PLD
Seattle	Occ. Industry	Bakery		RES		PLD
Seattle	Occ. Industry	Bank/financial institution (enclosed mall)		SER		PLD
Seattle	Occ. Industry	Bank/financial institution (standalone or strip mall)		SER		PLD
Seattle	Occ. Industry	Bank/financial institution (unknown)		SER		PLD
Seattle	Occ. Industry	Barber/beauty/nail salon (enclosed mall)		SER		PLD
Seattle	Occ. Industry	Barber/beauty/nail salon (standalone or strip mall)		SER		PLD
Seattle	Occ. Industry	Barber/beauty/nail salon (unknown)		SER		PLD
Seattle	Occ. Industry	Bookstore/library/newsstand (enclosed mall)		RET		PLD
Seattle	Occ. Industry	Bookstore/library/newsstand (standalone or strip mall)		RET		PLD
Seattle	Occ. Industry	Bookstore/library/newsstand (unknown)		RET		PLD
Seattle	Occ. Industry	Car wash				PLD
Seattle	Occ. Industry	Casino				PLD
Seattle	Occ. Industry	Cemeteries				PLD
Seattle	Occ. Industry	Clubs/county club/social club				PLD
Seattle	Occ. Industry	Collections/collection agency		OFF		PLD
Seattle	Occ. Industry	Commercial services (Shipping/ packaging/plumbing/tailoring)				PLD
Seattle	Occ. Industry	Communications		OFF		PLD
Seattle	Occ. Industry	Community center/meeting hall/ convention center				PLD
Seattle	Occ. Industry	Computers/software		OFF		PLD
Seattle	Occ. Industry	Construction site				PLD
Seattle	Occ. Industry	Consulting services		OFF		PLD
Seattle	Occ. Industry	Contractor				PLD
Seattle	Occ. Industry	Convenience/drug store (enclosed mall)		RET		PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Seattle	Occ. Industry	Convenience/drug store (standalone or strip mall)		RET		PLD
Seattle	Occ. Industry	Convenience/drug store (unknown)		RET		PLD
Seattle	Occ. Industry	Counseling		OFF		PLD
Seattle	Occ. Industry	Daycare facility/preschool/nursery school				PLD
Seattle	Occ. Industry	Design/clothing/graphics/arts/crafts/pottery		RET		PLD
Seattle	Occ. Industry	Distribution/distributor				PLD
Seattle	Occ. Industry	Downtown area				PLD
Seattle	Occ. Industry	Engineering		OFF		PLD
Seattle	Occ. Industry	Entertainment				PLD
Seattle	Occ. Industry	Gas station				PLD
Seattle	Occ. Industry	Government/municipal/city offices/library/fire station/post		OFF		PLD
Seattle	Occ. Industry	Grocery		RET		PLD
Seattle	Occ. Industry	Home improvement/builders store				PLD
Seattle	Occ. Industry	Hotel/motel/other lodging facility				PLD
Seattle	Occ. Industry	Indoor recreation—gym/health club, skating rink (unknown)				PLD
Seattle	Occ. Industry	Indoor recreation (enclosed mall)				PLD
Seattle	Occ. Industry	Indoor recreation (standalone or strip mall)				PLD
Seattle	Occ. Industry	Indoor work (non-industrial labor/small production)				PLD
Seattle	Occ. Industry	Industrial site/manufacturing plant				PLD
Seattle	Occ. Industry	Insurance/health insurance		OFF		PLD
Seattle	Occ. Industry	Legal/law		OFF		PLD
Seattle	Occ. Industry	Library				PLD
Seattle	Occ. Industry	Lumber yard/store				PLD
Seattle	Occ. Industry	Management		OFF		PLD
Seattle	Occ. Industry	Manufacturers rep				PLD
Seattle	Occ. Industry	Marina/yacht club				PLD
Seattle	Occ. Industry	Marketing/market research/public Relations/advertising		OFF		PLD
Seattle	Occ. Industry	Medical facility/hospital		OFF		PLD
Seattle	Occ. Industry	Military				PLD
Seattle	Occ. Industry	Movie theater/theatre/concert venue/sports arena Enclosed				PLD
Seattle	Occ. Industry	Movie theater/theatre/concert venue/sports arena Standalone				PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Seattle	Occ. Industry	Movie theater/theatre/concert venue/sports arena (Unknown)				PLD
Seattle	Occ. Industry	Museum/zoo/historic site				PLD
Seattle	Occ. Industry	Music store/shop		RET		PLD
Seattle	Occ. Industry	Newspaper/media/publishing/writer/editor		OFF		PLD
Seattle	Occ. Industry	Non-profit				PLD
Seattle	Occ. Industry	Nursery/garden				PLD
Seattle	Occ. Industry	Office building		OFF		PLD
Seattle	Occ. Industry	Other academic (unspecified teaching/school administration)				PLD
Seattle	Occ. Industry	Outdoor recreation—park, athletic field, beach				PLD
Seattle	Occ. Industry	Photo studio		SER		PLD
Seattle	Occ. Industry	Professional services		OFF		PLD
Seattle	Occ. Industry	Public market/outdoor market/fruit stand		RET		PLD
Seattle	Occ. Industry	Real estate/property management		OFF		PLD
Seattle	Occ. Industry	Religious—church/synagogue/houses of worship				PLD
Seattle	Occ. Industry	Rental facility				PLD
Seattle	Occ. Industry	Research		OFF		PLD
Seattle	Occ. Industry	Residential			HOU	PLD
Seattle	Occ. Industry	Resort/vacation				PLD
Seattle	Occ. Industry	Restaurant/fast food/bar and grill (enclosed mall)		RES		PLD
Seattle	Occ. Industry	Restaurant/fast food/bar and grill (standalone or strip mall)		RES		PLD
Seattle	Occ. Industry	Restaurant/fast food/bar and grill (unknown)		RES		PLD
Seattle	Occ. Industry	Retail (retail shops/unspecified sales)		RET		PLD
Seattle	Occ. Industry	School, college/university/technical/vocational				PLD
Seattle	Occ. Industry	School, K-12				PLD
Seattle	Occ. Industry	Self-employed				PLD
Seattle	Occ. Industry	Senior care (assisted living/retirement communities/nursing)			HOU	PLD
Seattle	Occ. Industry	Shopping mall/department store (enclosed mall)				PLD

HTS	Variable Type	Variable Description	Work- or Home-Related Trip Purpose	General Land-Use Categories		
				1	2	3
Seattle	Occ. Industry	Shopping mall/department store (standalone or strip mall)				PLD
Seattle	Occ. Industry	Shopping mall/department store (unknown)				PLD
Seattle	Occ. Industry	Storage facility				PLD
Seattle	Occ. Industry	Taking a walk/street/intersection (unspecified)				PLD
Seattle	Occ. Industry	Tanning salon		SER		PLD
Seattle	Occ. Industry	Tattoo parlor		SER		PLD
Seattle	Occ. Industry	Technical		OFF		PLD
Seattle	Occ. Industry	Technology/electronics		OFF		PLD
Seattle	Occ. Industry	Telecommunication/phone		OFF		PLD
Seattle	Occ. Industry	Transportation station, stop, terminal (airport, train, bus)				PLD
Seattle	Occ. Industry	Travel				PLD
Seattle	Occ. Industry	Trucking				PLD
Seattle	Occ. Industry	Union		OFF		PLD
Seattle	Occ. Industry	Utilities (gas/electric/water/waste disposal etc.)				PLD
Seattle	Occ. Industry	Video store		RET		PLD
Seattle	Occ. Industry	Warehouse/wholesaler				PLD
Seattle	Occ. Industry	Winery				PLD
Seattle	Occ. Industry	Work related/job site				PLD
Seattle	Purpose	Home, other	Home			PLD
Seattle	Purpose	Home, paid work	Home			PLD
Seattle	Purpose	Work	Work			PLD
Seattle	Purpose	Accompany another person				PLD
Seattle	Purpose	Attend childcare				PLD
Seattle	Purpose	Attend college				PLD
Seattle	Purpose	Attend School				PLD
Seattle	Purpose	Eat out		RES		PLD
Seattle	Purpose	Everyday shopping		RET		PLD
Seattle	Purpose	Major shopping				PLD
Seattle	Purpose	Personal business		SER		PLD
Seattle	Purpose	Pick-up/drop-off passenger				PLD
Seattle	Purpose	Recreation - Participate				PLD
Seattle	Purpose	Recreation - Watch				PLD
Seattle	Purpose	Religious/community				PLD
Seattle	Purpose	Social		RES		PLD
Seattle	Purpose	Turn around				PLD

Appendix: Equations

Equation 1: Converting an ITE vehicle trip and estimate into an ITE person trip end.

$$\mathbf{PTE_{ITE}} = \frac{\mathbf{VTE_{\mathit{ITE}} * \%AUTOMODE_{\mathit{ITE}}}}{\mathbf{VEHOCC_{\mathit{ITE}}}}$$

Equation 2: Converting an ITE person trip end estimate info an urban context adjusted (UCA) vehicle trip end estimate.

$$\mathbf{VTE_{\mathit{UCA}}} = \frac{\mathbf{PTE_{\mathit{ITE}} * \%AUTOMODE_{\mathit{UCA}}}}{\mathbf{VEHOCC_{\mathit{UCA}}}}$$

Where,

$\mathbf{VTE_{UCA}}$ This is the outcome of the adjustment, a vehicle trip end estimate adjusted for urban context [vehicle trip ends per independent variable per time-period studied].

$\mathbf{\%AUTOMODE_{\mathit{UCA}}}$ Urban context adjustment automobile mode share as a percent of total person trip ends, estimated using a travel survey Adjustment methodology described within this section.

$\mathbf{VEHOCC_{\mathit{UCA}}}$ Urban context adjustment vehicle occupancy rate as a percent of total person trip ends, estimated using a travel survey Adjustment methodology described within this section.

$\mathbf{PTE_{\mathit{ITE}}}$ The ITE's *Trip Generation Handbook* estimated person trip ends, from the ITE's *Trip Generation Handbook* vehicle trip end estimates [person trip ends per independent variable per time period studied].

$\mathbf{VTE_{\mathit{ITE}}}$ The ITE's *Trip Generation Handbook* vehicle trip end estimations [vehicle trip ends per independent variable per time period studied].

$\mathbf{\%AUTOMODE_{\mathit{ITE}}}$ The ITE automobile mode share as a percent of total person trip ends, provided within the ITE's *Trip Generation Handbook* and representative of a suburban "base case" land use. If no values are available, assume a 100 percent automobile mode share.

$\mathbf{VEHOCC_{\mathit{ITE}}}$ The ITE vehicle occupancy rate as a percent of total person trip ends, provided with the ITE's *Trip Generation Handbook* and representative of a suburban "base case" land use. If no values are available, assume a rate of one person per vehicle.

Equation 3: Normalized root mean squared error.

$$NRMSE = \frac{\sqrt{\frac{\sum_{i=1}^{n}(Observed - Estimated)^2}{n-1}}}{Maximum\ (Observed) - Minimum\ (Observed)}$$

Where,

NRMSE ≡ Normalized root mean squared error, expressed as a percent
Observed ≡ Observed vehicle trip ends
Estimated ≡ Estimated vehicle trip ends
n ≡ Number of land use sites studied