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Evaluation of the Operation and Accuracy of Five Available Smart Growth Trip Generation Methodologies

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Executive Summary

No standard methodology exists in the U.S. for estimating trip generation that takes into account the smart growth characteristics of a land use development project. As a first step toward developing such a methodology, this report assesses the available alternatives to the traditional ITE *Trip Generation* methodology. We identified eight available methods. For five of these methods, we completed a two-part assessment. The first part was to evaluate the methods against a variety of operational criteria developed through discussions with a panel of transportation practitioners. The second part was to test the accuracy of the methods by comparing the predictions of the various methods against available traffic counts and other data at 22 California sites that have at least some characteristics of smart growth

Existing Methodologies

We searched for existing tools that provide trip generation estimates for projects located within urban environments where transit and non-motorized transportation is more common. Most of the identified tools adjust the ITE trip generation rates to better reflect the effects of location, density, mixed land uses, and other design characteristics on trip generation. In addition, we identified two other types: tools that provide rates based on trip generation data collected at sites with smart growth characteristics, and one tool that uses person-trip data from a travel survey. Of these eight, we determined that five were candidate methodologies:

1. The current ITE *Handbook* Chapter 7 method for Multi-use development (referred to as **ITE Multi-use method**).
2. The EPA/SANDAG MXD Multi-use analysis method developed for the US EPA and subsequently adapted for use in the SANDAG region (**EPA MXD**).
3. The NCHRP 8-51 method, based on a recently completed research project. It is an enhancement of the current ITE Handbook Chapter 7 method (**NCHRP 8-51**).
4. A prototype method that adjusts ITE trip generation rates using travel survey with factors derived from data compiled by the Metropolitan Transportation Commission in the San Francisco Bay Area (**MTC Survey**).
5. URBEMIS 2007, the most recent version of a tool developed for analysis of emissions from land development projects, including mobile source emissions (**URBEMIS**).

Evaluation of Candidate Methods on Operational Criteria

We evaluated each of the five candidate methods with respect to key operational criteria identified and rated on their importance by a panel of transportation practitioners with experience in traffic impact analysis. The operational criteria are grouped into the following categories: 1) Ease of use; 2) Sensitivity to key smart growth elements; 3) Input requirements; 4) Output features; and 5) Usability of a methodology or tool in helping to define smart growth projects based on their performance.

No clear "winner" emerges among currently available methods based on the operational criteria; the methods all both meet and fall short of desired goals. However, criteria highly rated by the panel could be focal points in considering the merits of both existing methods and a final preferred methodology (Table ES-1).

Table ES-1: Top-Rated Criteria

Criterion	Criteria Type	Average Rating from 1-6 (6=Highest Rating)
1. Sensitivity of output to inputs	Input Data Mechanics	6.0
2. Results replicable by other analysts	Output	5.8
3. Results should not fluctuate excessively.	Additional Criteria	5.6
4. Method measures the performance of different kinds of land use projects	Additional Criteria	5.6
5. AM / PM / daily / Other time frames reported	Output	5.4
6. Auto vs. "other" trip generation rates	Output	5.3
7. LU context variables	Sensitivity	5.1
8. "Internal capture" shown	Output	5.0
9. Project-level Variables	Sensitivity	5.0
10. Transport Variables	Sensitivity	4.9
11. Project description by land use(s) and size	Output	4.9

Evaluation of the Accuracy of Candidate Methods

Panel members unanimously ranked accuracy as the highest priority criterion for trip generation estimation methodologies. To assess the relative accuracy of each of the five candidate methods, we compared available cordon counts at ten multi-use sites and twelve infill sites in California against estimates produced by the methodologies. These methods were also compared to the industry standard ITE trip generation rates for single land uses. The summary tables in the report show the error for each method, calculated as the percentage deviation between the actual traffic count and the estimate. Two summary statistics were also computed for each method: the average error, calculated as the sum of the errors for all sites divided by the number of sites; and the average absolute error, calculated as the sum of the absolute values of the errors for all sites divided by the number of sites.

Table ES-2 (below) indicates *for each site* the method that most accurately matches the observed traffic counts for the two sets of land use sites. For sites where the raw ITE rate is the best match, the candidate method that mostly closely matches the observed count is also shown. For the multi-use sites, all of which are large-scale projects not located in a central business district, the EPA MXD method produces the most accurate estimate in the greatest number of sites. It is not surprising that the EPA MXD method is most accurate for the multi-use sites, given that these sites were chosen based on their similarity to the sites used to calibrate the method. For the single-use urban infill sites, a clearly best method does not emerge.

Conclusions

This report provides an assessment of five candidate smart growth trip generation methodologies with respect to their performance regarding operational criteria and their accuracy. The results show that all of the candidate methodologies performed better than the ITE rates, but they do not point to a clear "winner" – one methodology that is clearly superior to the others. Nevertheless, this assessment generated many insights that could guide the selection or development of a recommended methodology.

These initial results also point to the critical need for further collection of trip generation data at smart growth sites. Based on only 22 sites, the evaluation presented here is not adequate to fully assess the performance of available methods. In addition, the validation sites do not reflect the full spectrum of smart growth development projects but instead cluster around two extremes – large multi-use suburban sites, and individual urban infill projects. Data from more sites of more types are needed to better understand the performance of the available methods.

Table ES-2. Most Accurate Method for Each Evaluation Site (Showing Method with Lowest Error Rate)							
Multi-Use Site and Location	**Daily**	**% Error**	**AM Peak Hour**	**% Error**	**PM Peak Hour**	**% Error**	**Notes on Site**
Gateway Oaks, Sacramento	ITE Multi-Use	0%	na		na		Large site, little use mix
Jamboree Center, Irvine	EPA MXD	-3%	MTC survey	9%	MTC survey	5%	Large site, little use mix
	ITE Rate	*1%*					
Park Place, Irvine	EPA MXD	15%	EPA MXD	23%	EPA MXD	20%	Mulit-use, low-density
	MTC Survey	15%					
The Villages, Irvine	URBEMIS	-7%	MTC survey	0%	URBEMIS	8%	Higher density, lowest WalkScore (40)
Rio Vista Station Village, San Diego	EPA MXD	4%	MTC survey	28%	URBEMIS	2%	Multi-use suburban, LRT
La Mesa Village Plaza, San Diego	EPA MXD	-5%	EPA MXD	10%	EPA MXD	-12%	Multi-use suburban, LRT
	ITE Rate	*-3%*	NCHRP 8-51	-10%	URBEMIS	-12%	
Uptown Center, San Diego	EPA MXD	1%	URBEMIS	3%	EPA MXD	10%	Multi-use urban; no rail
The Village @Morena Linda Vista, San Diego	EPA MXD	11%	MTC survey	22%	MTC survey	19%	Multi-use suburban, LRT
Hazard Center, San Diego	URBEMIS	2%	NCHRP 8-51	11%	MTC survey	7%	Office+retail, LRT no res'l
Heritage Center @ Otay Ranch, Chula Vista	EPA MXD	-20%	URBEMIS	10%	ITE Multi-	-3%	Suburban, no LRT
	ITE Rate	*-13%*					
Infill Study Site and Location							
Retail, Oakland	na		EPA MXD	-92%	EPA MXD	-18%	Retail only, Oakland
			ITE Rate	*-92%*	*ITE Rate*	*-7%*	
Office, San Francisco	na		EPA MXD	-17%	NCHRP 8-51	-2%	Office Only, CBD
Office, Los Angeles	na		URBEMIS	-23%	URBEMIS	-3%	Office Only, CBD
Residential, San Diego	na		MTC Survey	101%	EPA MXD	31%	High–rise res'l, CBD
Residential, San Diego	na		MTC Survey	-6%	MTC Survey	4%	Res'l + coffee shop, CBD
Office, Los Angeles	na		URBEMIS	79%	URBEMIS	-3%	Office Only, CBD
Office, Los Angeles	na		URBEMIS	-25%	MTC Survey	-3%	Office Only, CBD
Residential, San Diego	na		NCHRP 8-51	-7%	URBEMIS	2%	Mid–rise res'l Only, CBD
Residential, Pasadena	na		NCHRP 8-51	-25%	NCHRP 8-51	1%	High–rise res'l Only,
			URBEMIS	-25%			
			ITE Rate	*-12%*			
Residential, San Francisco	na		NCHRP 8-51	-14%	NCHRP 8-51	-15%	High–rise res'l Only, CBD
Restaurant, San Francisco	na		EPA MXD	12%	NCHRP 8-51	3%	Quality restaurant only
					MTC Survey	3%	
Restaurant, San Francisco	na		NCHRP 8-51	24%	EPA MXD	-20%	Quality restaurant only
					ITE Rate	*-10%*	

Evaluation of the Operation and Accuracy of Five Available Smart Growth Trip Generation Methodologies

1. Introduction

Many communities are encouraging development that follows “smart growth” principles – higher densities, mixed land uses, infill locations – as a strategy for reducing vehicle travel. A substantial body of evidence suggests that vehicle use is generally lower in such developments (Ewing and Cervero 2010). However, forecasting the effects of any single smart growth development on traffic is difficult. In compliance with the California Environmental Quality Act (CEQA), developers in California must estimate the transportation impacts of their proposed developments in the form of a Traffic Impact Analysis (TIA). Often developers are required to mitigate these traffic impacts by paying impact fees or providing facility improvements. The basis for such mitigation is the project's TIA. Accuracy in TIAs is thus important to ensure that mitigations are adequate but not excessive.

Estimating the number and type of trips that a development project will produce is the first step of a TIA, a step known as “trip generation.” The guidance used most often for estimating trip generation is the Institute of Transportation Engineers' (ITE) *Trip Generation*. This manual provides average vehicle trip generation rates (daily and peak-hours) for a variety of land use categories. However, the data used in *Trip Generation* are mostly collected at isolated developments that lack public transit and good bicycle and pedestrian infrastructure. Thus, the manual specifies that while these rates are appropriate for conventional suburban developments, they should not be used in downtowns or other areas served by transit, where the ITE rates tend to overestimate the vehicle trips.

Despite an awareness of this limitation, no standard methodology exists in the U.S. for estimating trip generation that takes into account the smart growth characteristics of a development project. Because of the lack of a standard methodology, analysts sometimes improvise. But improvised methods often produce more controversial results than the standard technique using the ITE’s *Trip Generation* rates, if only because the latter is the standard. To avoid this controversy and its potential legal ramifications, many analysts revert to using the ITE rates, even when they recognize their limitations. Applying the ITE rates to smart growth projects is likely to produce over-estimates of vehicle trips and may lead to mitigation measures that over-emphasize vehicle needs while under-supplying appropriate transit, bicycle, and pedestrian facilities.

As a first step toward the development of a standard trip generation methodology for smart growth projects, this report assesses the available alternatives to the ITE rates. We identified eight available methods, as described in Section 2. For five of these methods, we completed a two-part assessment. The first part was to evaluate the methods against a variety of operational criteria developed through discussions with a panel of transportation practitioners (described in Section 3). The second part was to test the accuracy of the methods by comparing the predictions of the various methods against available traffic counts and other data at 22 California sites that have at least some characteristics of smart growth (described in Section 4). As summarized in Section 5, the results of this assessment do not point to a clear “winner” but provide important insights for the effort to develop a smart growth trip generation methodology.

2. Available Methods

2.1 Background

Many studies have illuminated the drawbacks of the ITE *Trip Generation* methodology, especially when this method is used to estimate trip generation rates for development projects with smart growth characteristics. For instance, one study concluded that "...traffic impact studies for mixed use developments are little more than exercise in speculation" (Ewing et al. 2001). Similar findings have been made at transit-oriented developments (TODs) as well as infill developments. One infill development study using traffic counts and intercept surveys found that, with the exception of a few sites, observed trips were an average of 26 to 40 percent lower during peak periods than those indicated by the ITE method (Kimley Horn & Associates 2009).

In another study, traffic counts at TODs found that residential TODs averaged 44 percent fewer vehicle trips than those estimated by ITE (Arrington and Cervero 2008). Based on a multivariate regression analysis, this study also found that residential density within one-half mile of the transit station is the variable most correlated with trip generation rates. Thus, the risks of overestimating trip generation rates for TODs are significant. Typically, higher trip generation estimates lead to increased parking provisions, which in turn can lead to lower development density. In effect, inaccurate ITE data can create a feedback cycle in which developers decide to decrease density and increase parking provision at a TOD in order to get the development approved, which in turn leads to less transit use than originally anticipated, and which ultimately reaffirms initial concerns regarding the traffic impacts of the development. This study concluded that more accurate predictions of TOD-generated traffic are essential for TODs to reach their full potential.

Overestimation of trips using ITE rates is not limited to TODs. In one analysis, case studies at actual developments showed that ITE peak-hour trip generation rates often overestimated traffic impacts, regardless of development type (Muldoon and Bloomberg 2008). Researchers in that study attributed the overestimation to improper ITE land-use code selection, inadequate assessment of pass-by trip reductions, failure to consider seasonal variations in traffic counts, and lack of multi-modal evaluation. Such studies indicate that planners need a more flexible, context-sensitive, and accurate trip generation tool to produce traffic impact analyses.

2.2 Existing Methodologies

We searched for existing tools that provide trip generation estimates for projects located within urban environments where transit and non-motorized transportation is more common. A key consideration was the tool's ability to respond to location, density, mixed land uses, and other design characteristics that have been found to facilitate non-motorized travel. In general, the search emphasized tools that are more context-sensitive than the traditional ITE *Trip Generation* methodology.

A majority of the identified tools adjust the ITE trip generation rates (or an alternative set of rates compiled by the San Diego Association of Governments (SANDAG)) to better reflect the effects of location, density, mixed land uses, and other design characteristics on trip generation. In addition to this type of tool, we identified two other types: tools that provide rates based on trip generation data collected at sites with smart growth characteristics, and one tool that uses person-trip data from a travel survey. All of these tools are potentially better than the traditional ITE *Trip Generation* method, though none is without flaws. This section describes each identified tool.

2.1.1 Adjustments to ITE/SANDAG Rates

- **ITE Trip Generation**

The ITE *Trip Generation Handbook* (*Handbook*) guides practitioners on the proper use of the data provided in *Trip Generation,* and includes supplemental material regarding the trip generation estimation process. Chapter Seven of the *Handbook* provides a methodology for estimating trip generation rates at mixed-use sites, using a worksheet in the document. However, the analyst is instructed to "exercise caution" when using this methodology to estimate reductions, as the data on which the method is based come from a very small sample of sites, and all sites are located in a single state. According to the *Handbook*, this methodology is only applicable to multi-use developments and does not account for other factors known to affect trip rates, such as density, transit availability, street design, etc. In fact, the *Handbook* specifically cautions against using ITE trip rates data in downtowns or locations served by transit.[1] Also, because trip generation rates calculated using this worksheet are expressed as reductions from the ITE vehicle trip generation rates, there is no modal split information. Though *Trip Generation* is widely used and is the most cited authority on trip generation estimates in the United States, it has serious drawbacks, as listed above.

- **EPA MXD Model/SANDAG Mixed-Use Model**

These two tools are assessed together because they adjust trip estimates using the same elasticities for any given set of land use and transportation variables. The elasticities were derived from travel survey data collected at 239 multi-use developments[2] in six metropolitan regions around the United States. These models reduce the vehicle trip estimates in ITE's *Trip Generation* or San Diego's *Traffic Generators* (a tool similar to *Trip Generation*, but specific to the San Diego area). These reductions to vehicle trips are categorized as internally-captured trips within multi-use developments, walking/biking external trips, or transit external trips ("external" refers to trips outside of a multi-use site or neighborhood). The EPA tool is in spreadsheet format, with some basic data input requirements. These tools take into account the "D-factors" in land use known to affect travel (i.e. density, diversity (land use mix), design (usually measured as street connectivity), distance to transit, "destination accessibility," and others). The EPA MXD tool has been validated at 16 sites in the U.S. for which vehicle trip counts were collected; six of these sites are in California. The SANDAG tool has been validated at six sites in the San Diego region for which vehicle trips counts were collected, as well as 20 areas in that region for which an adequate number of records were available from the SANDAG 2006 Regional Household Travel Behavior Survey.

- **Eakland's Model**

Peter Eakland, an independent transportation planner, developed a tool that provides an input module for analysts to estimate trip generation using the numbers in the City of San Diego's *Traffic Generators* (a somewhat more detailed version of SANDAG's *Traffic Generators*). This tool puts rates and equations into a spreadsheet format, which makes the trip generation estimation process more user-friendly and transparent. Other attractive features of this tool include its ability to estimate city center

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[1] ITE *Trip Generation Handbook, Second Edition*. June 2004. Page 15: "If the site is located in a downtown setting, served by significant public transportation, or is the site of an extensive transportation demand management program, the site is **not consistent with the ITE data** and the analyst should collect local data and establish a local rate." [*Emphasis added.*]

[2] Although the method is labeled "MXD" for "mixed-use development," we reserve the use of this term for areas where land uses are mixed at a finer grain, as is typically found in a downtown or town center. The 239 sites used in the cited study are more appropriately labeled "multi-use" in that they tend to have larger blocks of single land uses separated by arterial streets and are thus less walkable.

vehicle trip rates, and its ability to take into account vehicle trips generated by existing developments. One drawback is that it provides no distinction between non-motorized and pass-by trips (these are all grouped under “pass-by”). Further, it does not account for land use characteristics such as density and mix of uses as it is based purely on the information provided in *Traffic Generators*.

- **URBEMIS**

This tool, which stands for “urban emissions,” was originally created by the California Air Resources Board to facilitate the assessment of criteria pollutant emissions from light-duty vehicle travel related to land use projects in California. During the late 1990s, it was upgraded and a “mobile source mitigation component” added under the direction of a consortium of air quality management districts in California, which continued to update and disseminate URBEMIS via the Internet until recently. Among other things, URBEMIS is capable of estimating trip generation for smart growth developments based on various land use, locational, and transportation characteristics. It is a user-friendly tool and has withstood several legal challenges for use in air quality impacts analyses of land use projects in California. However, because it was developed as an air quality analysis tool, it does not provide peak-hour trip generation rates which are of significant importance in traffic impact analyses. Further, the interface of this software provides the user with little insight into the calculations being performed, so its transparency is somewhat limited. However, the analyst can find descriptions of most of the module’s calculations in the user guide. This limitation could potentially be viewed as an advantage as the calculations cannot be inappropriately manipulated by the user.

- **NCHRP 8-51 Method and Spreadsheet Tool**

The National Cooperative Highway Research Program (NCHRP) is in the midst of finalizing a project (*Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*) aimed at outlining a methodology for analysts to collect appropriate data in order to estimate internal capture rates for multi-use developments,[3] and to apply these rates as reductions to trip generation rates. This tool is in spreadsheet format, which enhances its user-transparency. In addition to internal capture rates, it provides mode split estimates, which is ideal for the analysis of smart growth projects. However, since this tool is meant to assist analysts in collecting their own trip generation rates data, it is extremely data-intensive and thus unlikely to be used as a primary trip generation estimation tool.

2.1.2 Organized Empirical Database Tools

- **UK's TRICS**

The Trip Rate Information Computer System (TRICS) is a trip generation rates tool that has been used in the United Kingdom (UK) since 1989. It is a comprehensive and dynamic database consisting of trip generation estimates based on actual vehicle counts and multi-modal survey data for a variety of different land use types at numerous locations (in England, Scotland, Wales, and Ireland). The system is based on multi-modal data and provides trip generation estimates for multiple travel modes for proposed development projects. Further, the estimates are sensitive to urban versus suburban locational factors. Users have access to all of the available survey data from existing development to estimate trip generation, as well as detailed information regarding the survey sites and collection dates. The database is updated with new survey data regularly, and data older than ten years is removed. The

[3] Although the title of the project used the term “mixed-use development,” we label the sites “multi-use development” for reasons noted in Footnote 2.

TRICS system is an exemplary tool for calculating multi-modal trip generation rates of proposed development projects of various types, locations and designs. However, it is based solely on UK data.

- **New Zealand Trips and Parking Database**

This tool is similar to TRICS in that it is a comprehensive database of trip generation rates data. It provides users with information on trip generation rates based on land use groups and activity subgroups. The Trips and Parking Database, like TRICS, provides multi-modal estimates, and seems to be context-sensitive to an even higher degree than the TRICS database, utilizing even more of the factors found to affect trip generation. However, this database is only directly applicable to developments in New Zealand.

2.1.3 Person-Trip Based Tools

- **San Francisco Method**

The *Transportation Impact Analysis Guidelines for Environmental Review,* published by the Planning Department of the City and County of San Francisco in 2002, provides a trip generation methodology used in analyzing developments proposed in the City and County of San Francisco. This tool is in the form of a look-up table with trip rates (per square feet) for various land use types. Unique to this tool is its ability to estimate person trips in place of vehicle trips, and to estimate mode split based on local travel survey data. The tool itself is based on a combination of ITE's *Trip Generation,* data from the San Francisco Citywide Travel Behavior Survey, and traffic analyses from various environmental impact reports. However, the accuracy of using travel survey data to estimate trip generation rates for individual sites is uncertain. Further, as this tool is based on San Francisco survey data, its applicability outside San Francisco is questionable.

2.3 Candidate Methods

In the remainder of this report, we assess five available “candidate” methods as to: 1) which, if any, of the methods best meet operational requirements (Section 3), and 2) which may be the most accurate for what types/locations of land use projects (Section 4). We omitted three methods from this assessment: the UK’s TRICs and the New Zealand Trips and Parking Database, because the data are not applicable to California; and Ekland’s model, because it is based solely on San Diego data. In place of the San Francisco method, we tested a survey-based approach based on analysis of travel survey data for the San Francisco Bay Area provided by the Metropolitan Transportation Commission. The five available candidate methods examined were:

6. The current ITE *Handbook* Chapter 7 method for Multi-use development (referred to as **ITE Multi-use method**).
7. The EPA/SANDAG MXD Multi-use analysis method developed for the US EPA and subsequently adapted for use in the SANDAG region (**EPA MXD**).
8. The NCHRP 8-51 method, based on a recently-completed research project; it is an enhancement of the current ITE Handbook Chapter 7 method (**NCHRP 8-51**).
9. A prototype method that adjusts ITE trip generation rates using travel survey with factors derived from data compiled by the Metropolitan Transportation Commission in the San Francisco Bay Area (**MTC Survey**).

10. URBEMIS 2007, the most recent version of a tool developed for analysis of emissions from land development projects, including mobile source emissions (**URBEMIS**).

Summaries of key features of each of these methods are listed in Table 1. Appendix A provides detailed information about each of these methodologies (including detailed references). It also lists the key data sources and assumptions used to test the accuracy of each method in estimating traffic generation at 22 multi-use and infill sites in California for which traffic cordon count data is available (the results of which are described in Section 4 of this report).

Table 1: Brief Overview of Five "Candidate" Methodologies

ITE Handbook Multi-use Methodology*

- Available and in use since 2001.
- Calculates internalization of trips due to multiple land uses only.
- Daily and PM peak hour – no AM.
- Based on only three cases studies – all in Florida.
- Does not predict the mode of internalized trips (e.g., driving, walk/bike, shuttle or transit).
- Does not account for other on-site or context variables (such as density, location, design, etc.).

* Source: *ITE Trip Generation Handbook, 2nd Edition. June 2004*

EPA MXD Method

- Developed for US EPA based on analysis of travel survey data at multi-use sites in six metro areas in the U.S.* The San Diego Association of Governments (SANDAG) adopted it for use in June 2010.
- Key Inputs (in addition to land uses):
  - Area (in acres); number of intersections within project.
  - Employment within one mile of the multi-use development.
  - Employment that can be reached from project within a 30-minute transit trip.
- Outputs: reductions for internal capture, and external transit and pedestrian/bicycle trips.

* See: "EPA Mixed Use Trip Gen Research 05 09.pdf" on the Project website; and *Trip Generation for Smart Growth: Planning Tools for the San Diego Region*, SANDAG, June 2010. http://www.sandag.org/tripgeneration

NCHRP 8-51 Method

- Enhanced version of ITE Handbook Multi-use methodology.
- Based on data collected at six sites.
- Provides PM peak hour rates, plus AM peak hour (Current ITE Method lacks AM estimate).
- Method operationalized in a spreadsheet.
- Tested at two sites in Texas & one in Georgia.
- Requires data on mode split and vehicle occupancy, ideally in peak hours and by inbound/outbound.
- For this report, mode split data from the 2000 MTC Travel Survey was used for all the Multi-use sites (the only daily, two-way modal data available). For the Infill sites, intercept survey data was used (that was collected for the California Infill Trip Generation Rates study*).

*Kimley-Horn & Associates, et.al., *Trip-Generation Rates for Urban Infill Land Uses in California, Final Report*, June, 2009.

MTC Survey-based method

- A travel survey-based method was suggested by a panel member. Based on detailed analysis of the Metropolitan Transportation Commission's (MTC) 2000 Travel Survey of the SF Bay Area*
- Adjusts ITE vehicle trip rates based on urban environment (density) and proximity to rail/ferry transit.

* Station Area Residents Survey (StaRS), 2006: http://www.mtc.ca.gov/planning/smart_growth/stars/

URBEMIS* ("Urban Emissions")

- Air quality analysis tool for estimating daily vehicle trips and emissions of land use projects in CA.
- Uses ITE trip rates (7^{th} Edition of Trip Generation; not yet updated to the 8^{th}).
- "Mobile Source Mitigation Component" includes some context variables (density, mixed-use, transit, street connectivity, bicycle and pedestrian facilities, transportation-demand management).
- Does not predict peak hour trips; some consultants estimate for peak hours based on ITE Trip Generation data (this method was also used for this report).

* URBEMIS 2007 (version 9.2.4) http://urbemis.com/

3. Evaluation of Candidate Methods on Operational Criteria using Survey Rankings

This section evaluates each of the five candidate methods using a number of key operational criteria identified by a panel of transportation practitioners with experience in traffic impact analysis (Practitioners Panel). During several conference calls, the panelists discussed the qualities – in addition to accuracy – that they most require in a smart growth trip generation rates estimation methodology. From these discussions, we compiled a list of operational criteria and reviewed them with the panelists. Based on our experience in applying each method (as described in Section 4 and Appendix A), we rated the methods regarding each criterion.

We then invited panelists to rate the criteria regarding their relative importance via an on-line survey. Eight members of the Practitioners Panel responded to the on-line survey (see full results in Appendix C). Respondents were asked to rate each criterion from one to six with one being "least important" and six being "most important." The average of all responses for each criterion is shown in the right column of Tables 3 through 7. The criteria are arranged according to the average ratings from highest-rated to lowest-rated in each category.

The Practitioners Panel's operational criteria are grouped into the following categories: 1) Ease of use; 2) Sensitivity to key smart growth elements; 3) Input requirements; 4) Output features; and 5) Usability of a methodology or tool in helping to define smart growth projects based on their performance. Definitions of subjective criteria (terms such as "Low," "Moderate," "High," and "User-friendliness") that are used in the evaluations of operational criteria are shown in Table 2.

Table 2: Subjective Criteria Definitions

Criteria	Low	Moderate	High
User-friendliness	Basic understanding of the method requires more than a day	Basic understanding of the method requires more than an hour but under a day	Basic understanding of the method requires under an hour
Transparency	Source and magnitude of effects of adjustments to trip rate not readily apparent	Source and magnitude of effects of adjustments to trip rate somewhat apparent	Source and magnitude of effects of adjustments to trip rate readily apparent
Data needs	Little or no data needed beyond that required to use ITE trip rates	Some data needed beyond that required to use ITE trip rates	Substantial data needed beyond that required to use ITE trip rates
Difficulty of obtaining required data	All relevant data readily obtainable from public sources	Most relevant data readily obtainable from public sources	Unpublished data needed, or extensive data collection by analyst required
Effort to use available data	Little interpretation or judgments about data required	Up to three interpretations or judgments about data required	More than three interpretations or judgments about data required
Sensitivity of output to inputs	Many inputs reduce the effect of any single factor	Several inputs have a moderate effect on outputs	One or two inputs greatly affect output

3.1 Evaluation Results

The first set of criteria identified by the Practitioners Panel addresses the relative difficulty or ease of using each of the methods. Table 3 compares each of the candidate methods against specific components of ease of use. (Note that for the last criterion - "time to analyze a project composed of three land uses" - it was assumed that the user starts with a site plan with land uses, quantities, and site area.)

Table 3: Ease of Use Criteria*

Criterion	ITE Multi-use	EPA MXD	NCHRP 8-51	MTC Survey	URBEMIS	Average Survey Rating
1. **User-friendliness**	Moderate	Moderate	Moderate	High	Moderate	4.8
2. **Difficulty of obtaining required data**	Low	High	High	Low	Low	4.8
3. **Transparency**	High	Moderate	High	High	Low	4.1
4. **Data needs**	Low	Moderate	High	Low	High	4.1
5. **Time to analyze a Project** (with three land uses)	<30 minutes	30-60 min. *(if required data is readily available)*	30 min. *(note: including land use interchange distance data & mode split survey adds one day)*	<30 minutes	2 hours	3.4
6. **Use voluntary**	Yes	Yes	Yes	Yes	Yes	2.3

Elaboration of Criteria in Table 3 (based on Practitioners Panel input):

1. Is the tool user-friendly? (i.e., Can architects, planners, and junior engineers with little/no experience use it?)
2. Is needed input data readily available?
3. Is the methodology transparent?
4. How much data needs to be input to use the methodology?
5. How much time is required to run the methodology (using available data)?
6. Will use of the methodology be voluntary?

Based on all the criteria in Table 3, the ITE Multi-use and MTC Survey methods emerge as the easiest to use, while URBEMIS, the EPA MXD, and NCHRP 8-51 methods are more challenging, each for slightly different reasons. URBEMIS' data needs are high in terms of the number of items an analyst must enter; however sources for this data are easily found. The number of data items required for the EPA MXD method is fewer, but one required item – the number of jobs accessible within 30 minutes by transit – is difficult to calculate manually without a regional model, and analysts in some regions may not have easy access to such regional modeling data. The NCHRP 8-51 method has fewer inputs than either URBEMIS or MXD, but detailed data on mode of access to a project site is not readily available, and collecting such data at sites comparable to the project site would be labor intensive.

Responding practitioners rated user-friendliness and ease in obtaining data as their most important criteria regarding ease of use, reaffirming the favorable status of the ITE Multi-use and MTC Survey methods in this category. Respondents did not consider the voluntary use of the methodology to be an important criterion, and the time required to analyze a project did not rate highly.

The second set of criteria identified by the Practitioners Panel addresses how sensitive each method or tool is to important factors that affect project trip generation, especially factors that define projects as smart growth. Table 4 compares the methods against specific sensitivities that practitioners identified as important. As in Table 3, the criteria are shown as rated by the respondents to the on-line survey, with the highest-rated criteria listed first.

Table 4: Method Sensitivities Criteria*

Criterion	ITE Multi-use	EPA MXD	NCHRP 8-51	MTC Survey	URBEMIS	Average Survey Rating
1. LU context variables	No	Yes	No, except via mode split	Yes	Yes	5.1
2. Project-level Variables	Yes (land use mix only)	Yes	Yes (land use mix only)	No	Yes	5.0
3. Transport Variables	No	Yes	Via mode split	Yes	Yes	4.9
4. Transit headways/ Change in service	No	Indirectly, via employment within 30 minutes	No, except via mode split	No	Yes	4.3
5. Urban design variables	No	Intersection density	No, except via mode split	No	Yes – several	4.0
6. Parking supply/pricing	No	No	No	No	Yes	3.9
7. Pedestrian/ Bicycle Connectivity	No	Indirectly, via number of intersections and employment within 1 mile	Yes	No	Yes	3.7
8. Use of 7Ds	1 D	6 Ds	2 Ds	2 Ds	5 Ds	3.4
9. Starts with person trips, then allocates to modes	No	No	No; estimates person trips	No	No	2.4
10. Gas Prices	No	No	No	No	No	2.0

Elaboration of Criteria in Table 4 (based on Practitioner Panel input):

- Is the method or tool sensitive to:
    1. Land use/context-sensitive variables? Density and mix of surrounding uses.
    2. Project level variables? (Especially spatial distribution) – e.g. density and mixed use.
    3. Transportation variables? e.g., proximity to transit, nearby pedestrian & bike facilities.
    4. Transit headways/Changes in Transit service?
    5. Urban design variables? Pedestrian friendliness, traffic calming.
    6. Parking supply and pricing?
    7. Pedestrian connectivity? e.g. density of walkways.
    8. Does it use the 7Ds methodology? Can it prioritize Ds by estimated sensitivity?
    9. Does it start with person trips, then allocate to modes? (Considered ideal).
    10. Gas prices?

Examination of all Table 4 criteria indicates that URBEMIS and the EPA MXD method are the most sensitive to key smart growth variables regarding this category. The NCHRP 8-51 method is sensitive to some of these variables, while the ITE Multi-use and MTC Survey method are the least sensitive.

In reviewing the highest-rated sensitivity criteria (over 4.0), URBEMIS and EPA MXD are again the preferred methods, along with NCHRP 8-51 with mode split applied. Respondents favored sensitivity to the surrounding land-use variables as the most important criterion, followed closely by project-specific and multi-modal sensitivity. It is interesting to see that based on this rating, sensitivity regarding the surrounding environment scored slightly higher than sensitivity to the actual project and mode data. It is also interesting to note that "sensitivity to gas prices" and "starting with person trips" were rated as not important in this context.

The third set of criteria identified by the Practitioners Panel concerns the mechanics of preparing the input data. Table 5 compares each of the candidate methods against specific criteria regarding input data requirements and characteristics. The average rating from panelists via the on-line survey is shown in the column on the right.

Table 5: Input Data Mechanics Criteria*

Criterion	ITE Multi-use	EPA MXD	NCHRP 8-51	MTC Survey	URBEMIS	Average Survey Ratings
1. Sensitivity of output to inputs	High, since few inputs	Moderate, several inputs	High, since few inputs	High, since few inputs	Moderate, several inputs	6.0
2. Uses local information	No	Yes	Via mode split	Yes	Yes	4.6
3. Difficulty of obtaining required data	Low	High	High	Low	Low	4.6
4. Amount of data needed about the proposed project	Land use quantities (LUQ)	LUQ plus HH size & Vehicle Ownership	LUQ plus mode split data	LUQ	LUQ plus mitigation data	4.6
5. Can it work without regional or local travel models?	Yes	Yes; more effort if no model	Yes	Yes	Yes	4.5
6. 2-tiered data inputs for data-poor/-rich areas	No	No	No	No	No	4.5
7. Borrowed data OK	No	No	No	To be determined	No	4.3
8. Amount of data needed about the project's context &/or area nearby	None	Two data items	None	One item	Several data items	4.3
9. Relates Smart Growth indicators to inputs	No	Yes Intersection density	No, except via mode split data	No	Yes	4.1
10. Effort to use available data	Low	Moderate	Moderate	Low	High	3.6

Elaboration of Criteria in Table 5 (based on Practitioner Panel input):

1. How sensitive is the final result to the data input?
2. Does method require some local information?
3. How easy is it to access/find input data? (Ideally method uses data that is available.)
4. How much input data is project-level?
5. Can method work without regional or local travel models?
6. Is it two-tiered for more and less sophisticated data environments? (Is there a process for areas without good data or models? e.g., possibly "lookup" tables in lieu of regional or modeling data.)
7. If input data is lacking, does method allow for borrowing from other, similar sources?
8. How much input data is larger contextual data?
9. Does a tool relate smart growth indicators to inputs?
10. How difficult is it to operate the methodology using available data?

The evaluation summarized in Table 5 indicates that the EPA MXD method and the NCHRP 8-51 method are the most demanding with respect to input data availability. URBEMIS is the most demanding in terms of the amount data that needs to be input. The ITE Multi-use and MTC survey-based methods are the least demanding in terms of data availability and input.

Overall, survey respondents gave input mechanics criteria high importance ratings, with sensitivity of outputs to inputs receiving the highest possible score (6) from every respondent. Respondents' ratings show that input mechanics are a priority and that the availability of local data is of high importance in evaluating a preferred methodology. URBEMIS scores well in the prioritized criteria for its use of local data and the ease of acquiring these data; it also has the most demanding data requirements, but respondents gave relatively low importance to this criterion.

The fourth set of criteria identified by the Practitioners Panel concerns the outputs that are calculated and reported by each of the methods. Table 6 compares the methods against specific criteria related to outputs and shows the on-line Panel survey results.

Table 6: Method Output Criteria*

Criterion	ITE Multi-use	EPA MXD	NCHRP 8-51	MTC Survey	URBEMIS	Average Survey Ratings
1. **Results replicable by other analysts?**	Yes	Yes	Yes	Yes	Yes	5.8
2. **AM / PM / daily / other time frames reported?**	PM / Daily	AM/PM/ Daily	AM/PM	AM/PM/ Daily	Daily only	5.4
3. **Auto vs. "other" trip generation rates**	Auto only	Auto, Transit, Non-motor	Auto, Transit, Non-motor	Auto, Transit, Non-motor	Auto only	5.3
4. **"Internal capture" shown?**	Yes	Yes	Yes	No	Yes	5.0
5. **Project description by land use(s) and size?**	Yes	Yes	Yes	Yes	Yes	4.9
6. **Input assumption?**	Yes	Yes	Yes	Yes	Yes	4.6
7. **Analyst can adjust model?**	No	Yes	Yes	No	Yes	4.5
8. **Include and distinguish between future traffic volumes and a project's trip generation rate?**	No non-project trips	No non-project trips	No non-project trips	No non-project trips	No non-project trips	4.0
9. **Effect of bike and pedestrian facilities on travel?**	No	Yes	No	No	Yes	3.9
10. **Graphical representation of raw vs. final trip gen. data?**	No	No	No	No	No	3.8
11. **Link reduced trips to a reduction in vehicle-miles traveled (VMT)?**	No	Possible with more data	No	No	Yes	3.4

12. **Effect of transit service on travel?**	No	Yes	Yes	Yes	Yes	3.3

The data in Table 6 indicate that most methods produce and report a significant number of the outputs desired by practitioners. None of the methods produce all desired outputs. In particular, all the methods lack graphical display of outputs.

URBEMIS stands out as the one method that does not produce peak hour results because it was designed to estimate air quality effects, not for traffic impact studies. While this shortcoming has been addressed by practitioners and in our assessment (through the application of peak hour factors from ITE Trip Generation data, as described in Appendix A), it adds another layer of complexity to this method.

Survey respondents gave high ratings to many of the output criteria, as they did for the input criteria. Most importantly, results need to be replicable, a criterion satisfied by all methodologies. Respondents also wanted multi-modal reports on multiple time frames. This criterion favors the EPA MXD, NCHRP 8-51 and MTC Survey methods, although the latter does not show internal capture, another highly-rated criterion. Consistent with ratings in Tables 4 and 5, respondents favor local, project-specific information both as an input and an output. Respondents were only somewhat concerned with linking reduced trips to a reduction in vehicle-miles traveled or knowing how transit availability affected travel.

The Practitioners Panel also identified several other criteria and topics, shown in Table 7 in the order of importance as rated by respondents in the survey.

Table 7: Additional Criteria

Criterion	ITE Multi-use	EPA MXD	NCHRP 8-51	MTC Survey	URBEMIS	Average Survey Ratings
1. **Results should not fluctuate excessively**	See Section 4 (Evaluation of Accuracy)					5.6
2. **Can the method measure the performance of different kinds of land use projects?**	Theoretically, each method could potentially be used to do this, if it is sufficiently accurate based on adequate traffic count data for a sufficiently broad range of sites					5.6
3. **Can the method be used to define a range of reductions in ITE rates?**	Theoretically, each method could potentially be used to do this, if it is sufficiently accurate based on adequate traffic count data for a sufficiently broad range of sites					4.3
4. **Does the method identify a context for a development that qualifies it as smart growth?**	Theoretically, each method could potentially be used to do this, if it is sufficiently accurate based on adequate traffic count data for a sufficiently broad range of sites					3.6

5. **Can the method define different categories of smart growth based on size, urban area, etc?**	Theoretically, each method could potentially be used to do this, if it is sufficiently accurate based on adequate traffic count data for a sufficiently broad range of sites	3.6
6. **Complex equations should be converted to simpler graphs and/or tables**	Although this analysis has not been done for any of the methods, converting equations to graphs or tables would appear to be a straightforward procedure, especially for methods implemented as spreadsheets.	3.6
7. **Can the method group certain types of smart growth within parameters to comprehend complex development mixes?**	Theoretically, each method could potentially be used to do this, if it is sufficiently accurate based on adequate traffic count data for a sufficiently broad range of sites	3.4

Many of these additional criteria relate to whether the method can be used to measure and define different types and levels of smart growth based on performance as estimated by the method. As noted, any of the methodologies should be able to meet these objectives, depending on the data and the range of sites. Section 4 of this report presents evidence regarding the fluctuation of results, a highly-rated criterion in this category. The emphasis practitioners placed on repeatability and flexibility in general over specific relationships to "smart growth" is particularly interesting.

In addition to the above listed criteria, the Practitioners Panel highlighted the ability to encourage and facilitate the use of a preferred method as important for any chosen methodology.

3.3 Conclusions

No clear "winner" emerges among currently available methodologies based on the Practitioners Panel operational criteria. However, survey respondents prioritized a number of criteria that could be focal points in considering the merits of both existing methodologies and a final preferred methodology. However, survey results should be considered in light of the small initial respondent pool. It could be useful to survey a broader sample of practitioners as well as additional constituencies such as policymakers and regulators.

With respect to the operational criteria described above, the methods all both meet and fall short of desired goals:

- The current ITE Multi-use method has modest data needs, but does not consider any land use and transportation contextual factors beyond the project boundaries. It also does not predict AM peak hour trip generation, which is necessary for most traffic impact analyses.

- The EPA MXD method is fairly sensitive to smart growth characteristics and has moderate data needs. However, the availability of required input data can be challenging, particularly regarding employment within a 30-minute transit trip. This data need can be met by a fairly simple exercise of a regional travel demand model, <u>if</u> one is available, accessible, and models transit. However, such models are not universally accessible in California at this time.

- The NCHRP 8-51 method is less data intensive than either URBEMIS or the EPA MXD methods. However, one data requirement – directional mode split information for comparable projects in the AM and PM peak periods – is not readily available and has proved challenging to collect via surveys. The method does not make explicit consideration of land use and transportation contextual factors beyond the project boundaries, although if accurate mode split data can be obtained, such data would be reflective of the project's context.

- The MTC Survey method has very modest data needs, but it does not consider on-site characteristics (e.g. the mix of land uses, density, connectivity, etc.). The method's basis (the MTC 2000 Bay Area Travel Survey) may not be applicable to other regions in California, although it would potentially be possible to analyze travel survey data from other regions to produce more localized adjustment factors.

- URBEMIS is very comprehensive with respect to its sensitivity to smart growth factors. Required input data is readily available for URBEMIS, but it takes the most time to operate due to the need to analyze census and other available input data. Also, URBEMIS does not currently provide peak hour estimations, which must therefore be obtained from other sources for use in traffic impact analyses (if available).

The results of the initial Practitioners Panel survey on operational criteria provide guidance for the selection of an existing methodology or development of new methodologies. The top-rated criteria across all categories, as shown in Table 8, suggest that respondents favored specific output criteria (five of the 11 highest-rated) followed by method sensitivity (three of the 11) as most important. Interestingly, no "ease of use" criterion scored higher than a 4.8, suggesting that the practitioners who responded to our on-line survey favor results from an input-sensitive methodology over one that is easier to use. They also prefer a method that works for various land types, not only smart growth development, and has results that are not analyst-dependent. Respondents consistently noted the importance of a method using local context-sensitive data from both the project as well as the surrounding environment.

Table 8: Top-Rated Criteria

Criterion	Criteria Type	Average Rating
12. Sensitivity of output to inputs	Input Data Mechanics	6.0
13. Results replicable by other analysts	Output	5.8
14. Results should not fluctuate excessively.	Additional Criteria	5.6
15. Method measures the performance of different kinds of land use projects	Additional Criteria	5.6
16. AM / PM / daily / Other time frames reported	Output	5.4
17. Auto vs. "other" trip generation rates	Output	5.3
18. LU context variables	Sensitivity	5.1
19. "Internal capture" shown?	Output	5.0
20. Project-level Variables	Sensitivity	5.0
21. Transport Variables	Sensitivity	4.9
22. Project description by land use(s) and size?	Output	4.9

Because the survey results are based on a limited number of responses (8) and a select group of respondents (Practitioners Panel members), they may not be generalizable. Other practitioners, city council members, agency regulators, or interest-based policy groups could have different perspectives on desired sensitivities, outputs, and other "operational criteria" for trip generation methodologies. It is important to consider what different user groups would prefer in a new trip generation methodology, both to ensure its wide acceptance and broad usefulness.

4. Evaluation of the Accuracy of Candidate Methodologies

The Practitioners Panel identified the ability to accurately predict trip generation for projects as the most important criterion against which each method should be measured. To assess the relative accuracy of each of the five candidate methods, we compared available cordon counts at ten multi-use sites and twelve infill sites in California against estimates from the five candidate methodologies. These methods were also compared to the industry standard ITE trip generation rates for single land uses (referred to as **ITE rates**).[4]

Traffic count data used to evaluate the accuracy of the candidate methodologies come from two sources: 1) daily and peak-hour traffic counts at 10 sites in California originally collected for validation of the EPA/SANDAG MXD method[5] (referred to hereafter as the "**Multi-Use sites**"); and 2) peak hours cordon count and intercept survey data for 12 infill sites that was gathered for Caltrans' *Trip-Generation Rates for Urban Infill Land Uses in California* study[6] (referred to hereafter as the "**Infill sites**"). Most of the Multi-Use sites are medium to large-scale developments (5 to 200+ acres) located outside urban cores. By contrast, the Infill sites are single uses located in urban cores close to high-quality transit. Appendix B provides information about each of the sites.

Three summary tables present the results of the evaluation of the five candidate methodologies. Table 9 summarizes results for daily counts, for the multi-use sites only (daily counts were not available for the infill sites). Table 10 summarizes results for AM peak hour counts, for both multi-use and infill sites. Table 11 summarizes results for PM peak hour counts, for both multi-use and infill sites. Figures associated with each table help to illuminate the comparisons.

The summary tables show the error for each method, calculated as the percentage deviation between the actual traffic count and the estimate.[7] Two summary statistics were also computed for each method: the average error, calculated as the sum of the errors for all sites divided by the number of sites; and the average absolute error, calculated as the sum of the absolute values of the errors for all sites divided by

[4] Institute of Transportation Engineers, *Trip Generation*, 8th Edition.

[5] Although 12 of the validation sites are in California, we chose to exclude two sites, South Davis and Moraga because these areas are too large for appropriate use of trip-generation rates. See the draft documentation (EPA Mixed Use Trip Gen Research 05 09.pdf); and *Trip Generation for Smart Growth: Planning Tools for the San Diego Region*, SANDAG, June 2010 (*http://www.sandag.org/tripgeneration).*

[6] Kimley-Horn & Associates, et.al, *Trip-Generation Rates for Urban Infill Land Uses in California*, *Final Report* for Caltrans, June, 2009. *http://www.dot.ca.gov/research/researchreports/reports/2009/final_summary_report-calif._infill_trip-generation_rates_study_july_2009.pdf*

[7] Several entries in the tables are missing, for various reasons. The NCHRP method does not produce daily estimates. The EPA/SANDAG method estimates are missing for five infill sites because of the unavailability of a key input, employment accessible within 30 minutes by transit. The ITE Multi-use method does not produce AM peak hour estimates and is not applicable to infill sites. AM and PM peak hour counts were not available for Gateway Oaks, a multi-use site in Sacramento.

the number of sites. A positive average error indicates that the method, on average, overestimates vehicle trips, while a negative average error indicates that the method underestimates vehicle trips. The absolute average error corrects for the fact that a method that overestimates in half the cases and underestimates by the same amount in the other half would have a misleading average error of 0%.

It is important to note that the results presented here depend on the assumptions used in applying the methods, as described in Table 1 and in Appendix A, and on the assumptions used in preparing the input data. Repeating the analysis with different assumptions could produce different results and lead to different conclusions about the performance of each methodology with respect to accuracy.

4.1 Daily Counts

Estimated daily counts and error rates are shown in Table 9. Note that the NCHRP 8-51 method does not produce estimates of daily counts. As shown in the table, the ITE Multi-use method and the EPA MXD method tied for the lowest average error (6%) for the Multi-use sites, while the EPA MXD method had the lowest average absolute error (11%). This result is perhaps not surprising, given that the multi-use sites were chosen because they are similar in scale and composition to the sites used to calibrate the EPA MXD method. Average and absolute errors for the other methods are generally comparable to or greater than those for ITE rates (average error of 9% and average absolute error of 19%). The fact that ITE rates are as accurate as most of the methods may suggest that the multi-use sites in the EPA study are not all full-fledged examples of smart growth regarding location, density, and site design. In particular, the Gateway Oaks site (in Sacramento) and the three Irvine sites are larger (and hence more spread out) than the others and do not appear particularly walkable (see site descriptions in Appendix B).

Figure 1a shows estimated counts plotted against observed counts for each method for each site. The points mostly cluster around the diagonal line representing estimated counts equal to observed counts. Estimates for the three largest sites for the SANDAG trip rates stand out as significantly higher than the observed counts. Error rates, calculated as the difference between estimated and observed counts divided by observed counts, for the SANDAG Rates method are substantially higher than for other methods, as seen in Figure 1b, particularly for the Park Place site in Irvine. As shown in Table 9, all of the methods are more accurate than using unadjusted SANDAG trip generation rates at these sites. On average, SANDAG rates overestimate vehicle trip generation at the 10 multi-use sites by 40%.

4.2 AM Peak Hour

Estimated counts and error rates for the AM peak hour are shown in Table 10, first for the multi-use sites, then for the infill sites. Note that the ITE Multi-use method does not produce estimates for the AM peak hour, and key input data were missing for the EPA MXD method for several of the sites. Again, the EPA MXD method produced the lowest average error and absolute average error for the multi-use sites, at 14% and 27%, respectively. All methods, however, had significantly lower errors than the ITE rate. Note that the errors were generally greater for the AM peak than for daily counts, as can be seen in Figures 2a and 2b.

For the infill sites, URBEMIS produced the lowest average error, at 8%, and the lowest average absolute error, at 51%. Again, all methods had significantly lower errors than the ITE rate. However, the errors for the infill sites were generally much higher than for the multi-use sites, as can be seen in

Figures 3a and 3b. The error rates, shown in Figure 3b, are higher for the smaller infill sites, and mostly reflect over-estimates of AM counts.

4.3 PM Peak Hour

Estimated counts and error rates for the PM peak hour are shown in Table 11, first for the multi-use sites, then for the infill sites. Note that input data were missing for the EPA MXD method for several of the sites and that the ITE Multi-use method cannot (without modification) be applied to the infill sites. PM peak hour counts were also not available for one MXD site.

For the PM peak hour, the MTC Survey method produces the lowest average error, at 5%, but the EPA MXD method produces the lowest average absolute error, at 22%. As before, this result is not surprising, given that the multi-use sites were selected to resemble the multi-use sites used in calibrating the EPA MXD method. All methods but the ITE Multi-use method produce lower average errors than the ITE rates. As shown in Figures 4a and 4b, the methods tend to err in the same direction and to similar degrees for each site. For example, the errors are all quite high for Park Place and for Jamboree, both in Irvine.

For the infill sites, URBEMIS produced the lowest average error, at -4%, and the second lowest average absolute error, at 29%. Again, all methods had significantly lower errors than the ITE rate. The ITE rate error was especially high for one of the residential sites in San Francisco. In contrast to the AM peak hour errors, the PM peak hour errors were generally about the same for the infill sites and for the multi-use sites. However, as can be seen in 5a, 5b, and 5c, the variation in errors for any particular site was much greater than for the multi-use sites. As was the case for AM peak hour estimates, the error rates for the smaller infill sites tend to reflect over-estimates of PM counts. Errors for some of the larger sites are comparable to the errors for the smaller sites. The MTC survey method and the NCHRP 8-51 method produce errors over 100% for some sites.

Table 9. Daily Trip Estimates vs Counts

Mixed-Use Site and Location	Daily Count	Trip Generation Rates				Candidate Methods							
		ITE Rate Estimate	ITE Rate Error	SANDAG Rates Estimate	SANDAG Rates Error	ITE Multi-Use Estimate	ITE Multi-Use Error	EPA MXD Estimate	EPA MXD Error	MTC Survey Estimate	MTC Survey Error	URBEMIS Estimate	URBEMIS Error
Gateway Oaks, Sacramento	**23,280**	23,984	3%	33,593	44%	23,333	0%	21,274	-9%	20,960	-10%	19,897	-15%
Jamboree Center, Irvine	**36,569**	36,918	1%	54,133	48%	35,529	-3%	31,996	-13%	32,263	-12%	33,142	-9%
Park Place, Irvine	**19,064**	25,157	32%	41,356	117%	24,501	29%	22,008	15%	21,985	15%	23,334	22%
The Villages, Irvine	**7,128**	8,808	24%	8,435	18%	8,790	23%	7,886	11%	7,697	8%	6,623	-7%
Rio Vista Station Village, San Diego*	**5,307**	7,216	36%	6,689	26%	7,101	34%	5,538	4%	3,991	-25%	4,324	-19%
La Mesa Village Plaza, San Diego*	**4,280**	4,146	-3%	5,681	33%	4,057	-5%	4,539	6%	2,293	-46%	3,024	-29%
Uptown Center, San Diego*	**16,886**	11,376	-33%	20,214	20%	10,786	-36%	17,097	1%	9,942	-41%	8,487	-50%
The Village at Morena Linda Vista, San Diego*	**4,712**	5,438	15%	6,375	35%	5,367	14%	5,251	11%	3,007	-36%	3,909	-17%
Hazard Center, San Diego*	**11,644**	14,703	26%	15,051	29%	14,427	24%	13,214	13%	8,131	-30%	11,890	2%
Heritage Center at Otay Ranch, Chula Vista*	**7,935**	6,870	-13%	10,505	32%	6,383	-20%	9,730	23%	6,004	-24%	11,007	39%
Average error			**9%**		**40%**		**6%**		**6%**		**-20%**		**-8%**
Average absolute error			**19%**		**40%**		**19%**		**11%**		**25%**		**21%**

*San Diego and Chula Vista sites use SANDAG rates in their MXD estimates

Note: NCHRP method does not produce daily estimates.

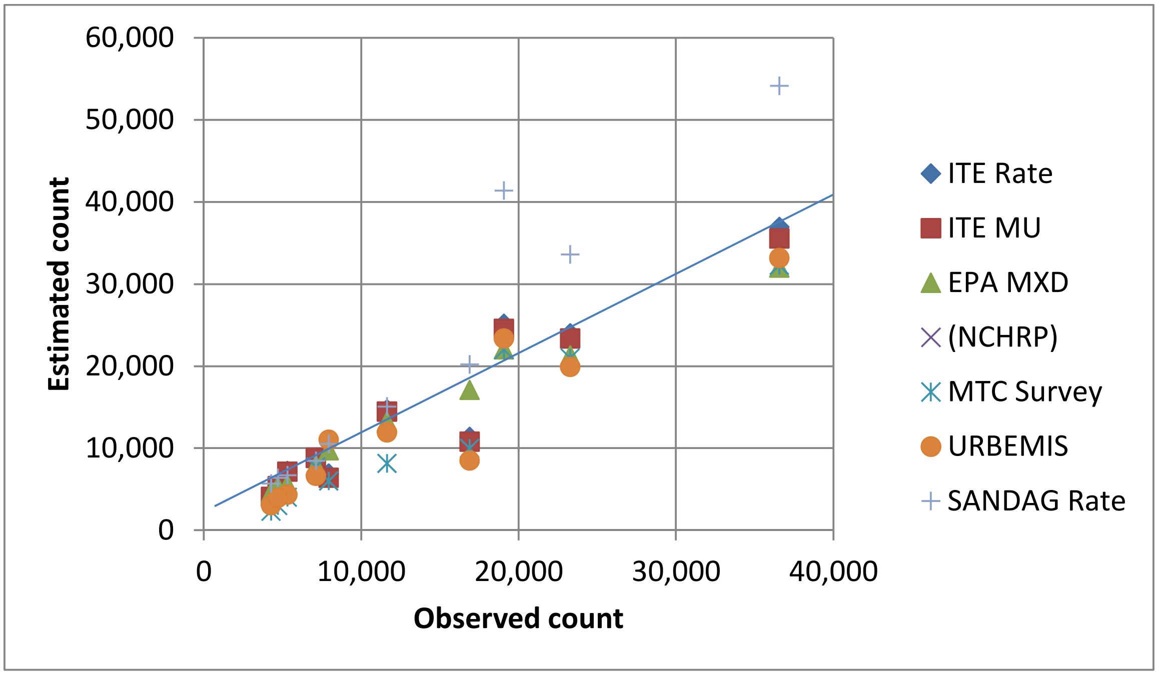

Figure 1a. Estimated versus Observed Count – **Daily for Multi-Use Sites**

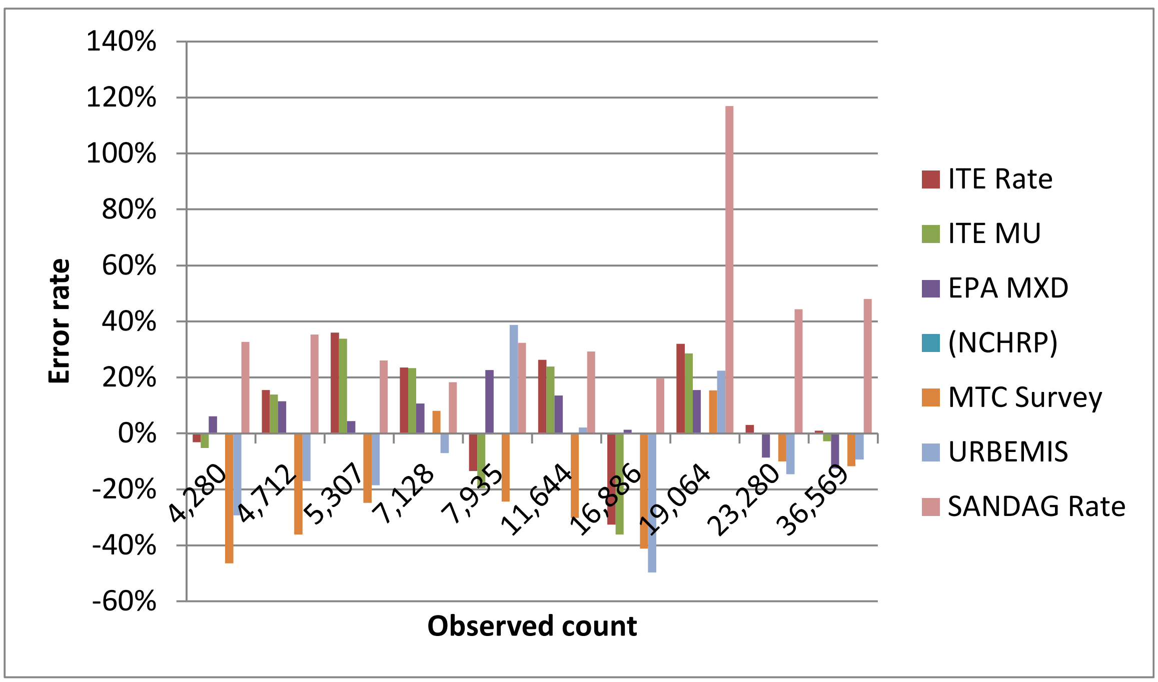

Figure 1b. Error Rate versus Observed Count – **Daily for Multi-Use Sites**

Table 10. AM Peak Hour Trip Estimates vs Counts

		Trip Gen Rates		Candidate Methods									
Mixed-Use Site and Location	**AM Peak Hour Count**	**ITE Rate Estimate**	**ITE Rate Error**	**ITE Multi-Use Estimate**	**ITE Multi-Use Error**	**EPA MXD Estimate**	**EPA MXD Error**	**NCHRP 8-51 Estimate**	**NCHRP 8-51 Error**	**MTC Survey Estimate**	**MTC Survey Error**	**URBEMIS Estimate**	**URBEMIS Error**
Gateway Oaks, Sacramento	missing	2,684	**na**	**A**	**na**	1,555	**na**	2,185	**na**	2,346	**na**	2,235	**na**
Jamboree Center, Irvine	3,125	3,893	25%	**A**	**na**	2,393	-23%	3,847	23%	3,402	9%	3,512	12%
Park Place, Irvine	1,295	3,068	137%	**A**	**na**	1,594	23%	2,454	89%	2,681	107%	2,841	119%
The Villages, Irvine	664	757	14%	**A**	**na**	565	-15%	652	-2%	662	0%	584	-12%
Rio Vista Station Village, San Diego	280	650	132%	**A**	**na**	431	54%	391	40%	359	28%	400	43%
La Mesa Village Plaza, San Diego	302	456	51%	**A**	**na**	331	9.8%	273	-9.6%	252	-16%	333	10.3%
Uptown Center, San Diego	638	882	38%	**A**	**na**	770	21%	776	22%	771	21%	658	3%
The Village at Morena Linda Vista, San Diego	315	693	120%	**A**	**na**	391	24%	419	33%	383	22%	511	62%
Hazard Center, San Diego	614	1,575	157%	**A**	**na**	938	53%	679	11%	871	42%	1,273	107%
Heritage Center at Otay Ranch, Chula Vista	667	485	-27%	**A**	**na**	553	-17%	882	32%	424	-36%	737	10%
Average error			**72%**				**14%**		**26%**		**19%**		**40%**
Average absolute error			**78%**				**27%**		**29%**		**31%**		**42%**

A = Method does not produce AM peak hour estimates and is not applicable to infill sites

B = Missing input data (Employment within 30 min. by transit)

Table 10 AM Peak Hour Trip Estimates vs Counts - continued

Infill Site and Location	AM Peak Hour Count	Trip Gen Rates		Candidate Methods									
		ITE Rate Estimate	ITE Rate Error	ITE Multi-Use Estimate	ITE Multi-Use Error	EPA MXD Estimate	EPA MXD Error	NCHRP 8-51 Estimate	NCHRP 8-51 Error	MTC Survey Estimate	MTC Survey Error	URBEMIS Estimate	URBEMIS Error
Retail, Oakland	133	11	-92%	**A**	**na**	10	-92%	6	-95%	6	-95%	4	-97%
Office, San Francisco	145	186	28%	**A**	**na**	120	-17%	114	-21%	109	-25%	92	-37%
Office, Los Angeles	110	210	92%	**A**	**na**	**B**	**na**	200	82%	160	46%	84	-23%
Residential, San Diego	21	72	241%	**A**	**na**	45	113%	56	165%	42	101%	45	113%
Residential, San Diego	132	212	61%	**A**	**na**	75	-43%	113	-14%	125	-6%	145	10%
Office, Los Angeles	28	140	393%	**A**	**na**	**B**	**na**	128	350%	82	190%	51	79%
Office, Los Angeles	63	131	110%	**A**	**na**	**B**	**na**	123	97%	100	59%	47	-25%
Residential, San Diego	33	37	11%	**A**	**na**	**B**	**na**	31	-7%	28	-15%	29	-13%
Residential, Pasadena	39	34	-12%	**A**	**na**	**B**	**na**	29	-25%	26	-33%	29	-25%
Residential, San Francisco	21	126	499%	**A**	**na**	42	100%	18	-14%	74	252%	40	90%
Restaurant, San Francisco	14	17	24%	**A**	**na**	15	12%	6	-56%	10	-27%	8	-42%
Restaurant, San Francisco	11	33	214%	**A**	**na**	30	186%	13	24%	19	85%	17	62%
Average error			**131%**				**37%**		**40%**		**44%**		**8%**
Average absolute error			**148%**				**80%**		**79%**		**78%**		**51%**

A = Method does not produce AM peak hour estimates and is not applicable to infill sites

B = Missing input data (Employment within 30 min. by transit)

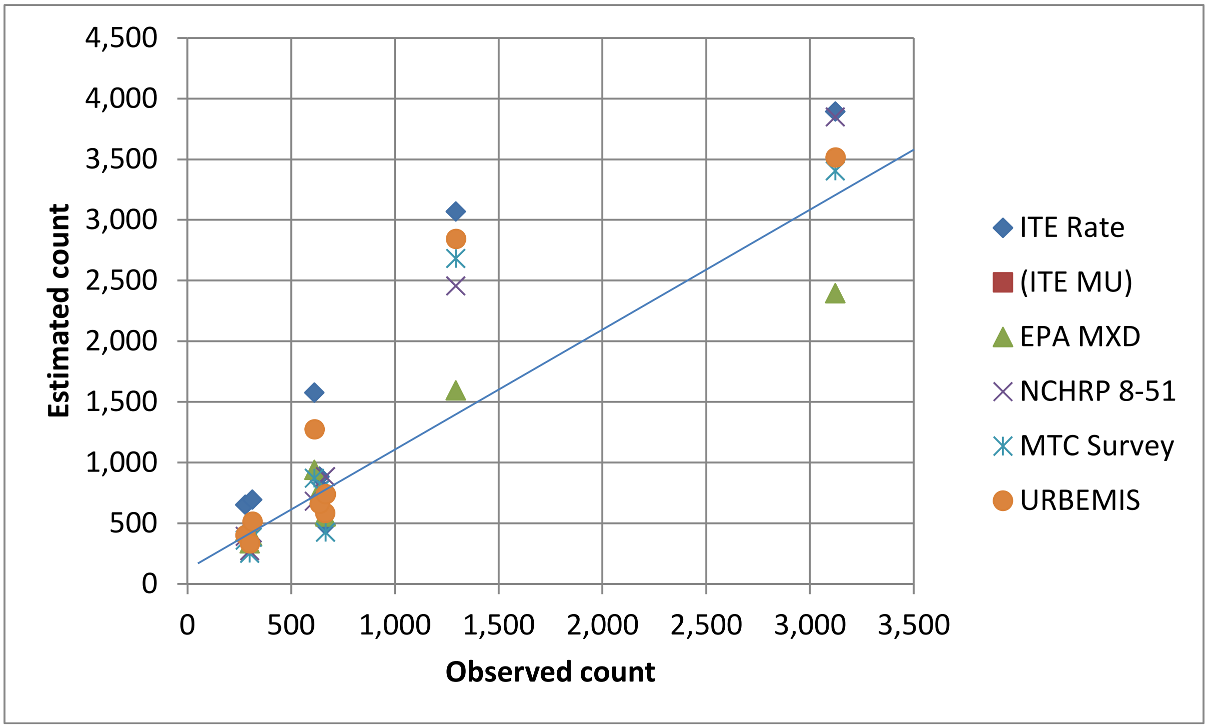

Figure 2a. Estimated versus Observed Count – **AM Peak Hour for Multi-Use Sites**

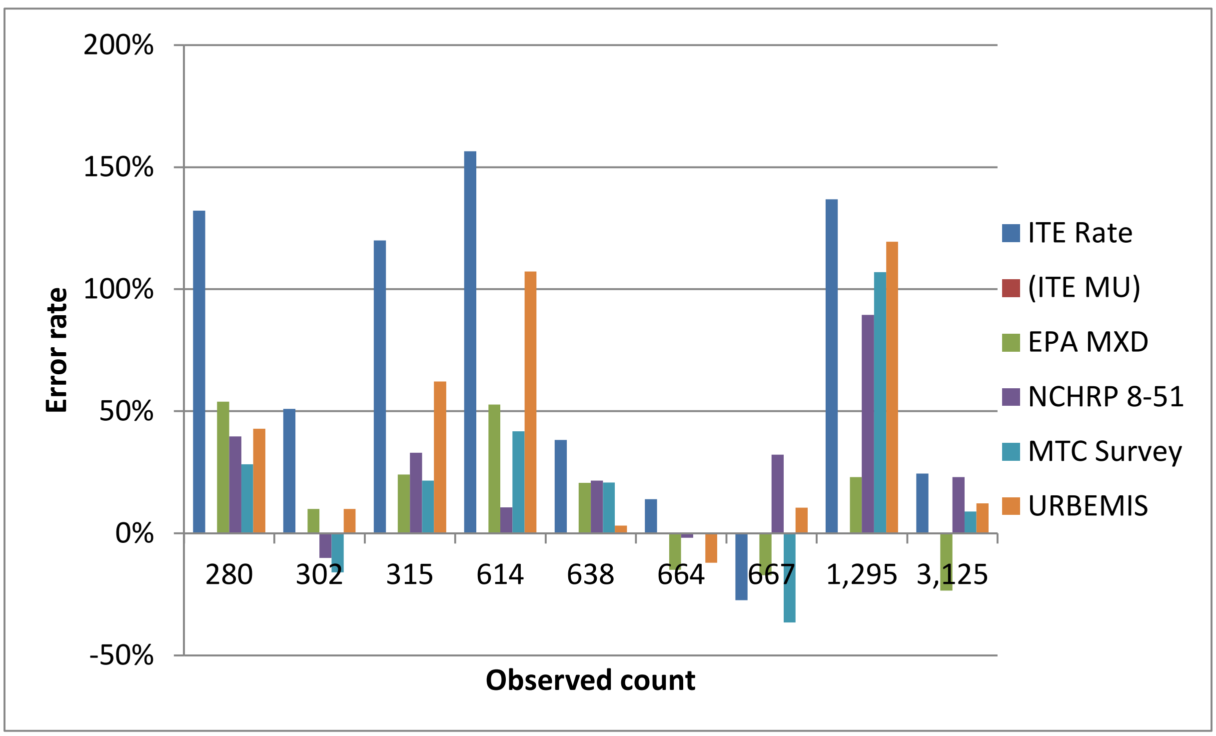

Figure 2b. Error Rate versus Observed Count – **AM Peak Hour for Multi-Use Sites**

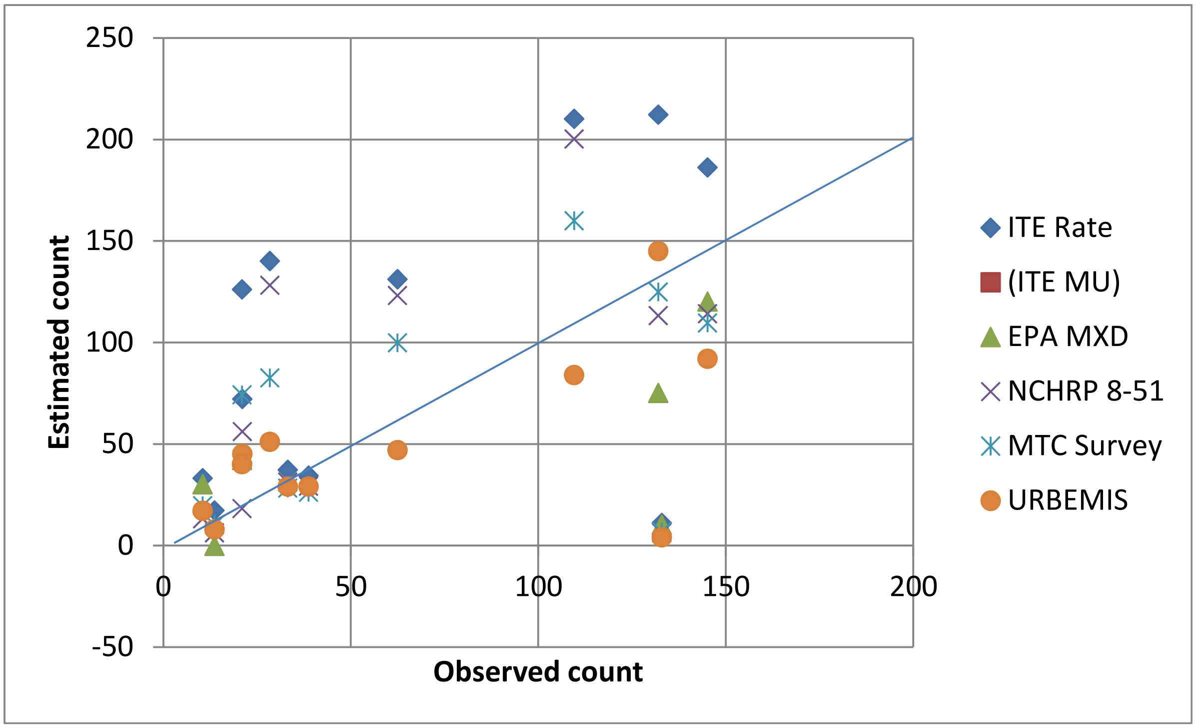

Figure 3a. Estimated versus Observed Count – **AM Peak Hour for Infill Sites**

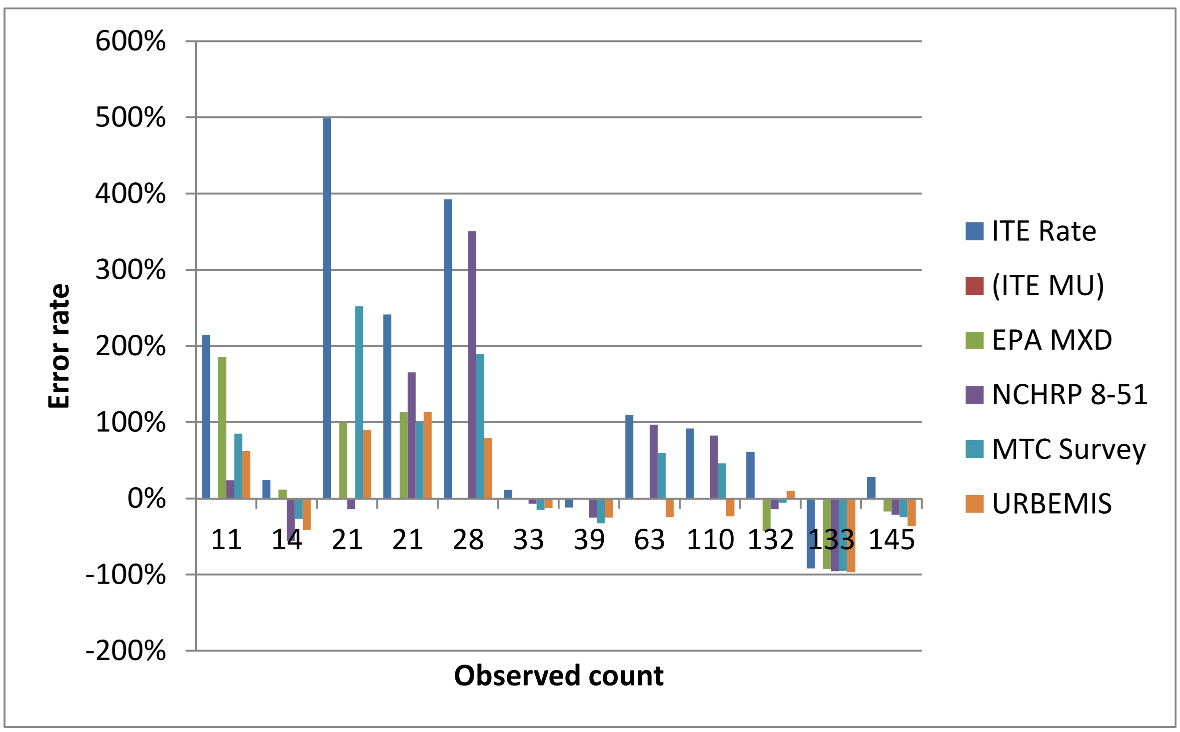

Figure 3b. Error Rate versus Observed Count – **AM Peak Hour for Infill Sites**

Table 11. PM Peak Hour Trip Estimates vs Counts

Mixed-Use Site and Location	PM Peak Hour Count	Trip Gen Rates		Candidate Methods									
		ITE Rate Estimate	ITE Rate Error	ITE Multi-Use Estimate	ITE Multi-Use Error	EPA MXD Estimate	EPA MXD Error	NCHRP 8-51 Estimate	NCHRP 8-51 Error	MTC Survey Estimate	MTC Survey Error	URBEMIS Estimate	URBEMIS Error
Gateway Oaks, Sacramento	missing	2,858	**na**	2,779	**na**	1,891	**na**	2,379	**na**	2,498	**na**	2,377	**na**
Jamboree Center, Irvine	3,513	4,212	20%	4,096	17%	2,329	-34%	4,283	22%	3,681	5%	3,775	7%
Park Place, Irvine	1,676	3,289	96%	3,230	93%	2,016	20%	2,659	59%	2,874	71%	3,046	82%
The Villages, Irvine	605	877	45%	875	45%	665	10%	750	24%	766	27%	655	8%
Rio Vista Station Village, San Diego	452	757	67%	744	65%	500	11%	432	-4%	419	-7%	459	2%
La Mesa Village Plaza, San Diego	434	518	19%	508	17%	381	-12%	294	-32%	286	-34%	380	-12%
Uptown Center, San Diego	1,560	1,203	-23%	1,148	-26%	1,722	10%	968	-38%	1,051	-33%	899	-42%
The Village at Morena Linda Vista, San Diego	361	774	114%	766	112%	456	26%	445	23%	428	19%	568	57%
Hazard Center, San Diego	978	1,891	93%	1,869	91%	1,231	26%	819	-16%	1,046	7%	1,530	56%
Heritage Center at Otay Ranch, Chula Vista	673	697	4%	656	-3%	980	46%	1,136	69%	609	-9%	1,024	5%
Average error			48%		46%		11%		12%		5%		18%
Average absolute error			54%		54%		22%		32%		24%		30%

Table 11. PM Peak Hour Trip Estimates vs Counts - continued

Infill Site and Location	PM Peak Hour Count	Trip Gen Rates: ITE Rate Estimate	Trip Gen Rates: ITE Rate Error	Candidate Methods: ITE Multi-Use Estimate	ITE Multi-Use Error	EPA MXD Estimate	EPA MXD Error	NCHRP 8-51 Estimate	NCHRP 8-51 Error	MTC Survey Estimate	MTC Survey Error	URBEMIS Estimate	URBEMIS Error
Retail, Oakland	44	41	-7%	**A**	**na**	36	-18%	26	-41%	24	-45%	16	-64%
Office, San Francisco	110	178	61%	**A**	**na**	104	-6%	108	-2%	105	-5%	88	-20%
Office, Los Angeles	84	201	140%	**A**	**na**	**B**	**na**	201	140%	153	82%	81	-3%
Residential, San Diego	36	81	126%	**A**	**na**	47	31%	59	64%	48	33%	50	39%
Residential, San Diego	72	127	76%	**A**	**na**	68	-6%	53	-26%	75	4%	98	36%
Office, Los Angeles	51	135	166%	**A**	**na**	**B**	**na**	127	150%	79	56%	49	-3%
Office, Los Angeles	99	126	28%	**A**	**na**	**B**	**na**	118	20%	96	-3%	45	-54%
Residential, San Diego	33	49	47%	**A**	**na**	**B**	**na**	30	-10%	37	12%	34	2%
Residential, Pasadena	36	44	22%	**A**	**na**	**B**	**na**	37	1%	34	-7%	34	-7%
Residential, San Francisco	29	147	399%	**A**	**na**	47	60%	25	-15%	86	193%	47	60%
Restaurant, San Francisco	13	22	75%	**A**	**na**	20	55%	13	3%	13	3%	14	11%
Restaurant, San Francisco	50	45	-10%	**A**	**na**	40	-20%	26	-47%	26	-47%	27	-46%
Average error			94%				14%		20%		23%		-4%
Average absolute error			96%				28%		43%		41%		29%

A = Method is not applicable to infill sites

B = Missing input data (Employment within 30 min. by transit)

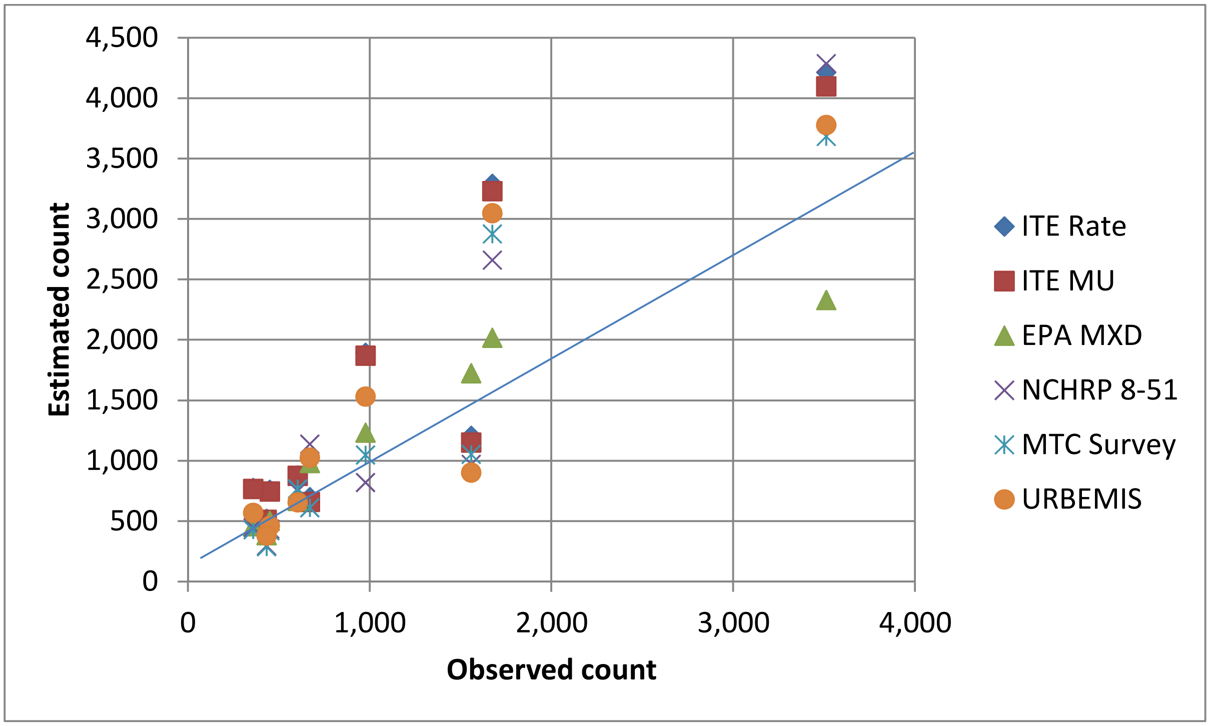

Figure 4a. Estimated versus Observed Count – **PM Peak Hour for Multi-Use Sites**

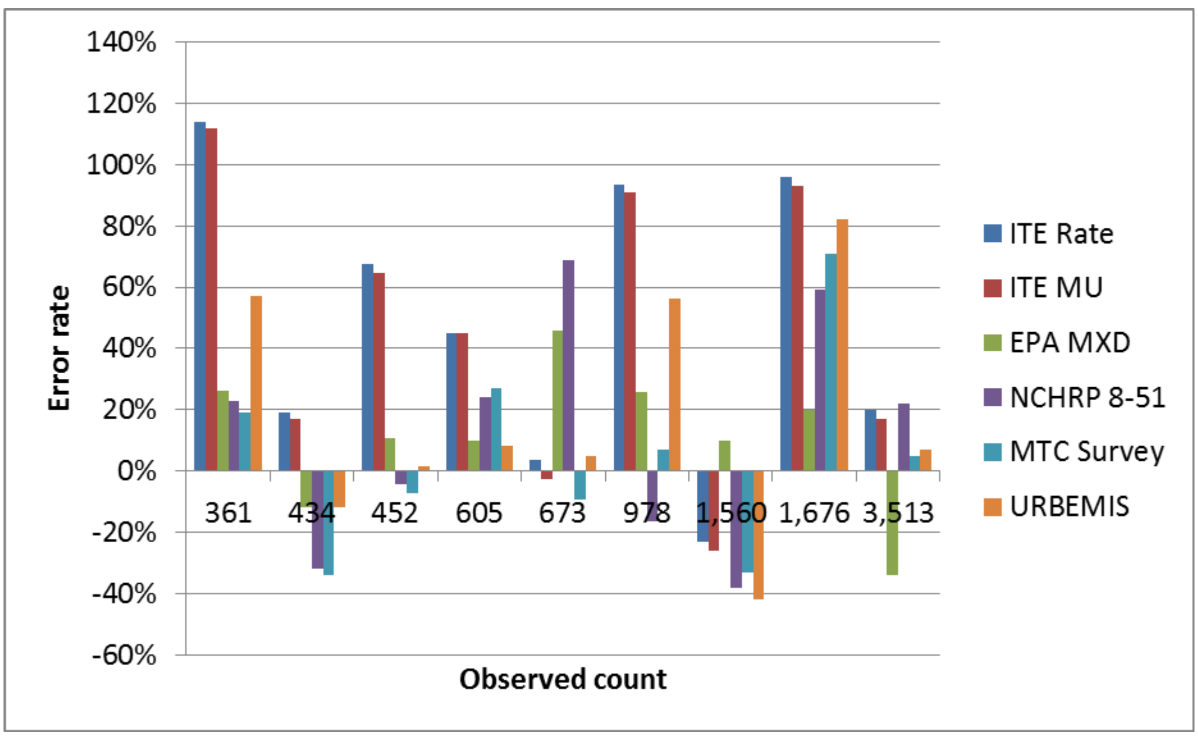

Figure 4b. Error Rate versus Observed Count – **PM Peak Hour for Multi-Use Sites**

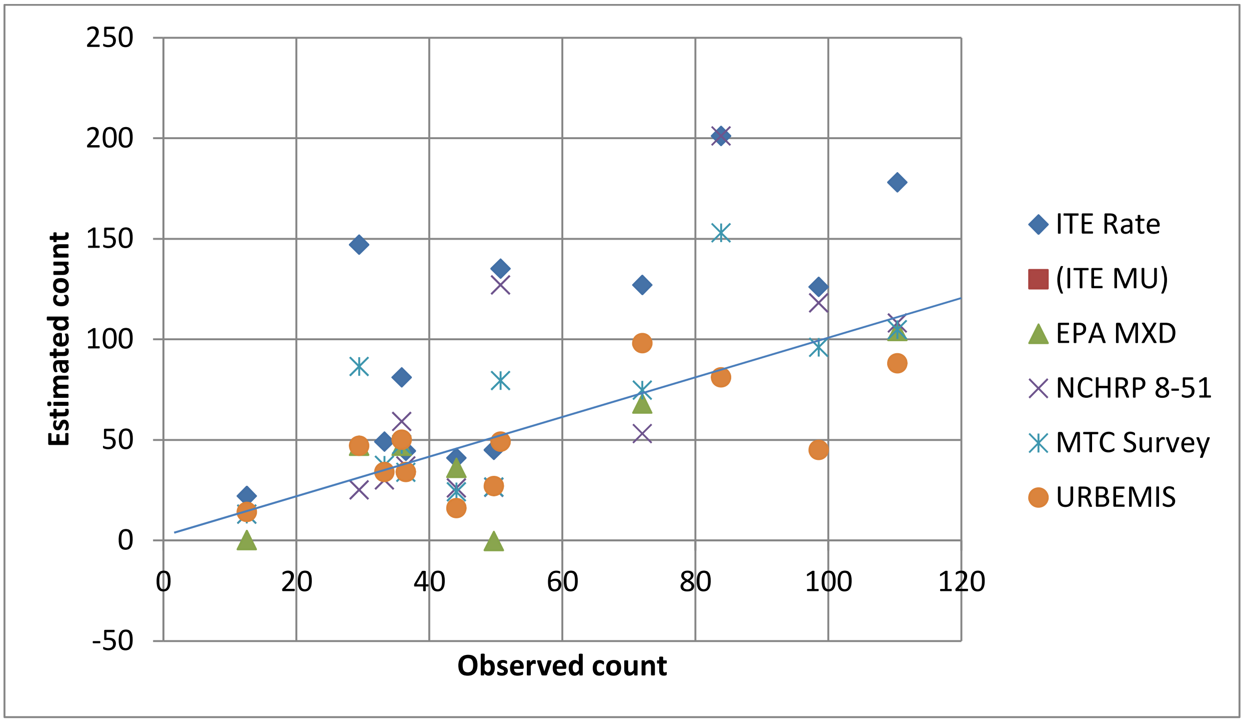

Figure 5a. Estimated versus Observed Count – **PM Peak Hour for Infill Sites**

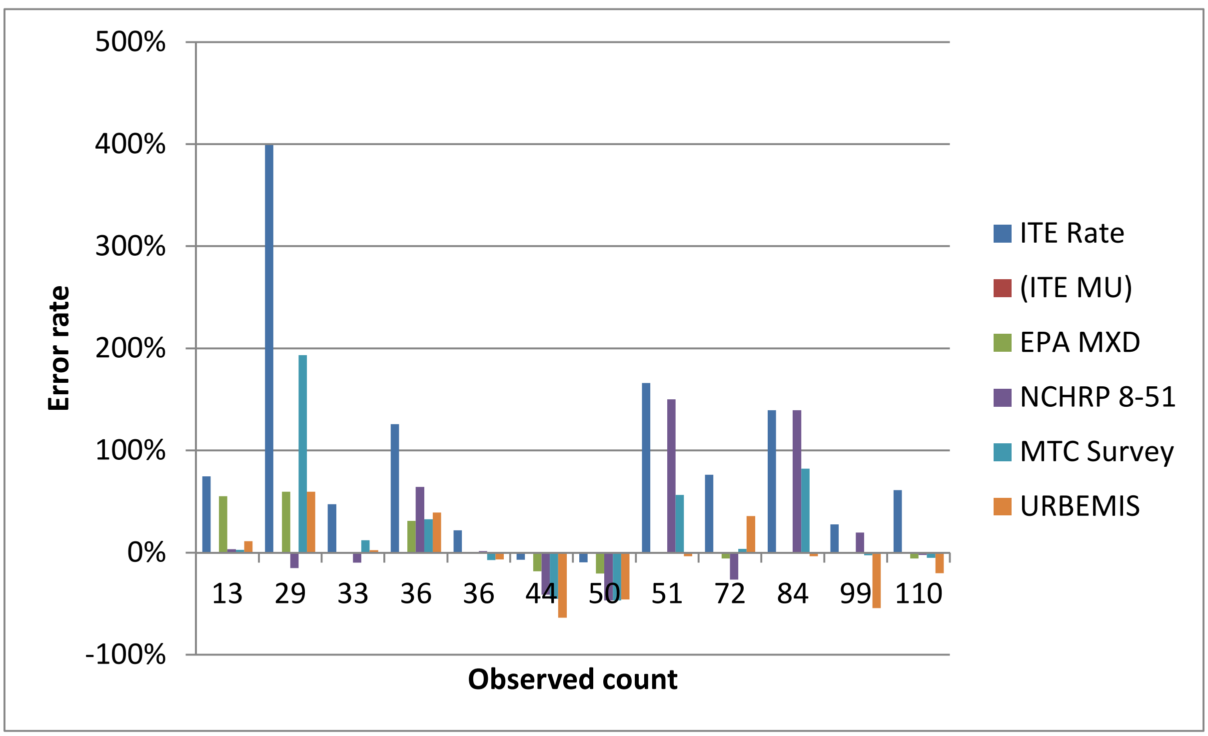

Figure 5b. Error Rate versus Observed Count – **PM Peak Hour for Infill Sites**

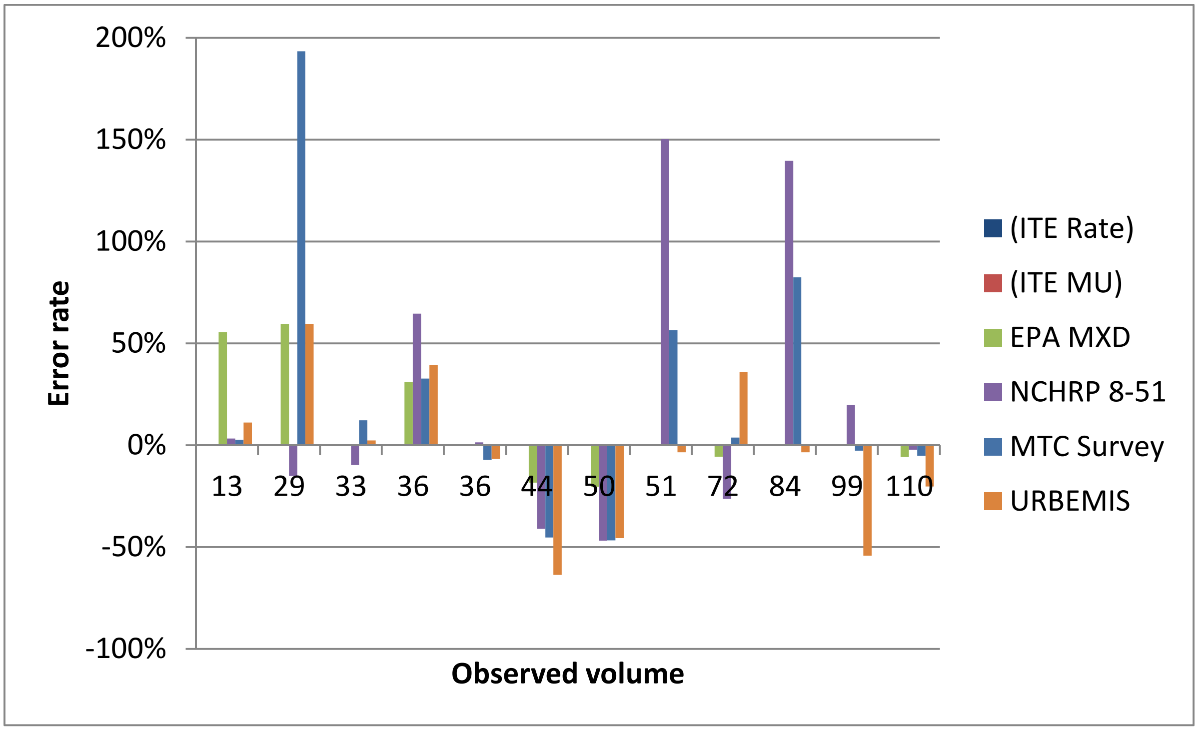

Figure 5c. Error Rate versus Observed Count – **PM Peak Hour for Infill Sites – without ITE Rate Estimates**

4.4 Summary

Table 12 indicates *for each site* the method that most accurately matches the observed traffic counts for the two sets of land use sites. For sites where the raw ITE rate is the best match, the candidate method that mostly closely matches the observed count is also shown.

For the multi-use sites, all of which are large-scale projects not located in the central business district, the EPA MXD method produces the most accurate estimate in the greatest number of sites. For daily counts, the EPA MXD method is most accurate for seven of the sites. Its performance drops to two sites for AM peak hour and four sites for PM peak hour. As noted earlier, it is not surprising that the EPA MXD method is most accurate for the multi-use sites, given that these sites were chosen based on their similarity to the sites used to calibrate the method. The MTC Survey method is most accurate for four multi-use sites for the AM peak hour and three sites for the PM peak hour. URBEMIS is most accurate for two sites for daily counts, two for AM peak hour, and three for PM peak hour. The ITE Multi-use method was most accurate for daily counts for one site and for PM peak hour for one site. The NCHRP 8-51 method was the most accurate for two sites in the AM peak hour (note that this method does not produce estimates of daily counts). ITE trip rates were more accurate than the candidate methods for daily counts for three of the sites.

For the single-use urban infill sites, a clearly best method does not emerge. For the AM peak hour, the methods were most accurate for relatively equal numbers of sites: the EPA/MXD method was most accurate for three sites, the MTC Survey method for two, URBEMIS for four, and the NCHRP method for four. For the PM peak hour, the numbers are roughly equal: the EPA/MXD method was most accurate for three sites, the MTC Survey method for three, URBEMIS for three, and the NCHRP method for four. Across both the AM and PM peak hours, the NCHRP method is most accurate for the greatest number of sites, followed by URBEMIS, the EPA/MXD method, and the MTC Survey method. Note that the ITE Multi-use method was not applied to the infill sites because it requires at least two land uses. ITE trip rates were as or more accurate than the candidate methods in three cases, but were much higher for the other sites.

Table 12. Most Accurate Method for Each Evaluation Site (Showing Method with Lowest Error Rate)							
Multi-Use Site and Location	**Daily**	**% Error**	**AM Peak Hour**	**% Error**	**PM Peak Hour**	**% Error**	**Notes on Site**
Gateway Oaks, Sacramento	ITE Multi-Use	0%	na		na		Large site, little use mix
Jamboree Center, Irvine	EPA MXD	-3%	MTC survey	9%	MTC survey	5%	Large site, little use mix
	ITE Rate	*1%*					
Park Place, Irvine	EPA MXD	15%	EPA MXD	23%	EPA MXD	20%	Mulit-use, low-density
	MTC Survey	15%					
The Villages, Irvine	URBEMIS	-7%	MTC survey	0%	URBEMIS	8%	Higher density, lowest WalkScore (40)
Rio Vista Station Village, San Diego	EPA MXD	4%	MTC survey	28%	URBEMIS	2%	Multi-use suburban, LRT
La Mesa Village Plaza, San Diego	EPA MXD	-5%	EPA MXD	10%	EPA MXD	-12%	Multi-use suburban, LRT
	ITE Rate	*-3%*	NCHRP 8-51	-10%	URBEMIS	-12%	
Uptown Center, San Diego	EPA MXD	1%	URBEMIS	3%	EPA MXD	10%	Multi-use urban; no rail
The Village @Morena Linda Vista, San Diego	EPA MXD	11%	MTC survey	22%	MTC survey	19%	Multi-use suburban, LRT
Hazard Center, San Diego	URBEMIS	2%	NCHRP 8-51	11%	MTC survey	7%	Office+retail, LRT no res'l
Heritage Center @ Otay Ranch, Chula Vista	EPA MXD	-20%	URBEMIS	10%	ITE Multi-	-3%	Suburban, no LRT
	ITE Rate	*-13%*					
Infill Study Site and Location							
Retail, Oakland	na		EPA MXD	-92%	EPA MXD	-18%	Retail only, Oakland
			ITE Rate	*-92%*	*ITE Rate*	*-7%*	
Office, San Francisco	na		EPA MXD	-17%	NCHRP 8-51	-2%	Office Only, CBD
Office, Los Angeles	na		URBEMIS	-23%	URBEMIS	-3%	Office Only, CBD
Residential, San Diego	na		MTC Survey	101%	EPA MXD	31%	High–rise res'l, CBD
Residential, San Diego	na		MTC Survey	-6%	MTC Survey	4%	Res'l + coffee shop, CBD
Office, Los Angeles	na		URBEMIS	79%	URBEMIS	-3%	Office Only, CBD
Office, Los Angeles	na		URBEMIS	-25%	MTC Survey	-3%	Office Only, CBD
Residential, San Diego	na		NCHRP 8-51	-7%	URBEMIS	2%	Mid–rise res'l Only, CBD
Residential, Pasadena	na		NCHRP 8-51	-25%	NCHRP 8-51	1%	High–rise res'l Only,
			URBEMIS	-25%			
			ITE Rate	*-12%*			
Residential, San Francisco	na		NCHRP 8-51	-14%	NCHRP 8-51	-15%	High–rise res'l Only, CBD
Restaurant, San Francisco	na		EPA MXD	12%	NCHRP 8-51	3%	Quality restaurant only
					MTC Survey	3%	
Restaurant, San Francisco	na		NCHRP 8-51	24%	EPA MXD	-20%	Quality restaurant only
					ITE Rate	*-10%*	

Finally, a summary of the average percent error across all sites for each method is shown in Table 13 below. This table represents the percent error for each site averaged across all sites and indicates that all five methods are more accurate than ITE rates. At the 10 multi-use sites, EPA MXD was most accurate but it was developed for this purpose (i.e. multi-use sites). At the 12 infill sites, no clear winner exists, but URBEMIS and EPA MXD methods are the most accurate of the five. At the 12 infill sites, the percent standard error is significantly higher compared to the 10 multi-use sites, which were more suburban.

Table 13. Summary Table of Average Percent Error Averaged Across All Sites by Method

Method	10 Multi-Use Sites			12 Infill Sites	
	Daily	AM	PM	AM	PM
ITE Rate	19%	78%	54%	148%	96%
ITE Multi-Use	19%	NA	54%	NA	NA
EPA MXD	11%	27%	22%	80%	28%
NCHRP 8-51	?	29%	32%	79%	43%
MTC Survey	25%	31%	24%	78%	41%
URBEMIS	21%	42%	30%	51%	29%

5. Conclusions

This report provides an assessment of five candidate smart growth trip generation methodologies with respect to their performance regarding operational criteria and their accuracy. The results show that all of the candidate methodologies performed better than the ITE rates, but they do not point to a clear "winner" – one methodology that is clearly superior to the others. Nevertheless, this assessment generated many insights that could guide the selection or development of a recommended methodology. Four options seem feasible:

1. The selection of one of the candidate methods as the recommended method, despite its limitations.
2. The development of a "decision-tree" that would guide the analyst as to what method is most appropriately used for what kinds of development projects in what situations.
3. The modification of one or more of the candidate methods to increase its sensitivity to smart growth qualities and to the California context.
4. The development of an entirely new method using available data sources.

A combination of the second and third options might also be considered. The fourth option is limited by the quantity and quality of available data; given the limited trip generation data collected for smart growth development projects, travel survey data offer the most promise but are generally too sparse spatially to be of much use for this purpose. It would be unfeasible in the near term to develop a method for the U.S. comparable to the UK's TRICs or the New Zealand Trips and Parking Database. These methods require a substantial investment in data collection and considerable time to build a sufficient database of multimodal trip generation data from a large and diverse set of development sites. In the long-term, such an approach would be desirable.

These initial results also point to the critical need for further collection of trip generation data at smart growth sites. Based on only 22 sites, the evaluation presented here is not adequate to fully assess the performance of the available methods. In addition, the validation sites do not reflect the full spectrum of smart growth development projects but instead cluster around two extremes – large multi-use suburban sites, and individual urban infill projects. Data from more sites of more types are needed to better understand the performance of the available methods. Such data, if sufficient in quantity and quality, could be used to modify one of the existing methods or calibrate an entirely new method. In addition, development of an acceptable methodology for obtaining such data potentially could form the basis for a long-term effort to build a multimodal trip generation database for the U.S., similar to those in the U.K. and New Zealand.

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