Comparing Methodologies to Estimate Internal Trip Capture at Mixed-Use Developments

Benjamin R. Sperry

ABSTRACT

One of the unique aspects of mixed-land use developments is the potential for internal trip capture, defined by ITE as trips between two distinct on-site land uses without traveling on the roadway network external to the site. Although it is acknowledged that some internal trip capture occurs in the mixed-land use environment, there is not a universally accepted approach as to how to best estimate internal trip capture for trip generation estimates used in traffic impact analyses. Some reviewing agencies have adopted methods recommended by ITE; others publish their own methodologies, while others negotiate reductions on a case-by-case basis.

In this paper, three methodologies to account for internal trip capture at mixed-land use developments (a fixed-percentage reduction, the current ITE-recommended practice, and a new methodology based on forthcoming NCHRP research) are validated against observed trip generation counts at five mixed-use sites. For the five mixed-use development sites examined in this study, the proposed estimation methodology from the NCHRP research project was found to most accurately replicate the observed trip generation, with average error approximately one-fifth to one-third that of other methods currently in practice. The findings of this paper can be used by practitioners and reviewing agencies to guide the preparation of trip generation estimates for traffic impact analyses of proposed mixed-use developments.

INTRODUCTION

One of the key components of traffic impact analyses (TIAs) for proposed land developments is the estimation of the number of external trips that are expected to be generated by the site. For developments composed of a single land use, trip generation can be estimated using the Institute of Transportation Engineers' (ITE) *Trip Generation* informational report, or similar reference, based on certain characteristics of the proposed site (ITE 2008). For multi-use land developments, the process of estimating trip generation is slightly more complex due to the internalization of some trips between on-site land uses. ITE defines a "multi-use development" as a single real-estate project that consists of two or more ITE land-use classifications (LUC) between which trips can be made without using the off-site road system (ITE 2004a). One form of multi-use development, the mixed-use development (MXD), has emerged as a popular development style in both suburban greenfield and urban infill areas. MXD sites are developed in conformance with a single master plan, including fully integrated on-site land uses and deliberate layout and design of buildings and streets (Schwanke et al. 2003).

One of the unique transportation characteristics of MXD sites is that some trips have both origin and destination within the site. These trips, which are known as "internal" trips, do not impact

the external street network. As a result, estimating the portion of travel that is internal is generally part of the trip generation estimate for proposed MXD sites, usually resulting in an external trip generation estimate that is lower than if the on-site land uses are considered as stand-alone sites.

Accurate estimation of internal trip capture for MXDs benefits all parties involved with the development review process. Over-estimating internal trip capture could result in the traffic infrastructure around the site being inadequate for the real levels of traffic demand, with breakdowns in level of service and costly upgrades for the highway agency. Underestimating internal trip capture, on the other hand, could lead to excess roadway improvements and capacity around the site and the transportation agency or developer paying more than necessary to mitigate the traffic impacts of the proposed site.

METHODS IN PRACTICE

While it is acknowledged that some internal trip capture occurs in the mixed-land use environment, there is not a single, universally accepted approach as to how to best estimate internal trip capture for trip generation estimates used in TIAs. As a result, several methods exist in practice. All methods use an initial estimate of trip generation for the on-site land uses of the proposed MXD as single-site uses as a "base" then reduce these estimates to account for trip internalization. Reduction from the "base" estimate is dependent upon the methodology used by the analyst or prescribed by local development ordinance.

The ITE-recommended practice for estimating internal trip capture at mixed-use developments, outlined in Chapter 7 of the *Trip Generation Handbook*, 2nd edition (ITE 2004a), applies internal trip capture percentages to estimated vehicle-trips generated by each on-site land use (for which data are available) and distributes these trips among the other land uses at the site. After a balancing process, external travel is computed by subtracting the estimated internal trips between on-site land uses from the single-site trip generation estimates. The ITE-recommended methodology is based on the findings of a study sponsored by the Florida Department of Transportation (FDOT) in the early 1990s (ITE 2004a).

There are several limitations to the ITE methodology, including a lack of data for the AM peak hour, internal trip capture percentages for only three land uses, and a limited number of sites from which the percentages were drawn. Recognizing these drawbacks, the National Cooperative Highway Research Program (NCHRP) initiated a research project (NCHRP 8-51) to improve the estimation of internal trip capture for proposed MXD sites. The NCHRP 8-51 internal trip capture estimation methodology is expected to improve upon the ITE-recommended practice by adding data for the AM peak hour, three additional land uses, and updated internal trip capture percentages from additional MXD sites with designs that more closely-resembled current MXD design trends (Bochner et al. 2010). As of this writing, the NCHRP 8-51 project draft final report has been accepted by the project panel but not yet approved for formal publication by the National Research Council or the Transportation Research Board.

Other methods outside of the ITE-recommended methodology (or the expected updates provided by NCHRP 8-51) are also available. A fixed-percentage reduction, or "rule of thumb" reduction, is common. Using this approach, external trip generation for proposed MXDs is estimated by

reducing the aggregate single-use site estimates by a fixed percentage. This percentage is generally prescribed by the reviewing agency in its development code or similar regulation, or by policy or common practice. The fixed-percentage reduction approach can also be extended to allow for different levels of reduction for different land uses. An example of this approach is used in San Diego, California USA, which allows different reductions for residential, industrial, and commercial land uses (City of San Diego 1998).

In the absence of specific guidance from a local development code (or the absence of a code entirely), the developer and the reviewing agency negotiate appropriate reductions to account for internal trip capture at proposed MXD sites. These negotiations can delay the development approval process, which ultimately delays the opening of the development and can be costly for both the developer and the local jurisdiction.

In July 2004, ITE conducted a survey of transportation engineering and planning professionals to identify the current state-of-the-practice on the treatment of internal trip capture at proposed MXDs. The Internet-based survey gathered information from a total of 167 responses representing both preparers of TIAs (engineering and planning consultants) and reviewers of TIAs (municipal, regional, and state agency staff). One survey question asked the respondent to identify which method(s) he or she currently used to estimate internal trip capture rates for proposed MXDs. Table 1 summarizes these responses.

Table 1: Internal Trip Capture Methodologies Used in Practice

Methodology	Frequency[1]
ITE *Trip Generation Handbook* (2nd Edition, Chapter 7)	64%
ITE *Trip Generation* (7th Edition)[2]	52%
"Rule of Thumb" (Fixed-Percentage Reduction)	34%
"Other" Methodology	19%
Locally-Established Methodology	12%

[1]Respondents allowed to choose more than one methodology.
[2]Although respondents reported using *Trip Generation* as a reference to estimate internal trip capture at MXDs, the document does not contain any data on internal trip capture. The author speculates that the reference is likely used to develop preliminary trip generation estimates prior to applying reductions for internal trip capture.
Source: ITE (2004b)

The most frequently-cited methodology used to estimate internal trip capture was the ITE-recommended practice, with 64 percent of respondents indicating use of this method. One-third of respondents indicated the use of a fixed-percentage reduction while "other" methodologies or the use of a locally-established methodology were reported 19 and 12 percent of the time, respectively. Among the "other" methodologies described included engineering judgment, regional travel demand model forecasts, or results from travel surveys. While the ITE methodology was cited by a majority of respondents, the prevalence of other methods suggest that there is a lack of a unified approach to accounting for internal trips at MXDs.

RESEARCH PROBLEM

While the ITE-recommended practice (ITE 2004a) is a commonly-used methodology, many other methods are available and used in practice. This paper examines these methods by comparing the observed external trip generation at five MXD sites with the external trip generation estimated using several of these methods. Specifically, the following questions are considered:

- Which estimation method most accurately replicates the observed vehicle trip generation at the five MXD study sites?
- Does the use of data from ITE LUC 820 (Shopping Center), which implicitly incorporates internal trips between retail and restaurant land uses, result in a more accurate estimate as compared to estimating these land uses separately?
- Does the use of a more robust methodology to account for trip internalization among on-site land uses result in a more accurate estimate as compared to a simple fixed-percentage reduction from aggregated single-use site trip generation estimates?
- Do the improvements to the ITE-recommended practice proposed in the NCHRP 8-51 research project result in more accurate estimates of external trip generation as compared to the current ITE-recommended practice?
- What effect does emerging research on the proximity of on-site land uses at the proposed MXD site have on the estimation of external trip generation?

RESEARCH APPROACH

This paper will answer these questions by comparing estimated trip generation with observed traffic counts at five MXD sites. The metric for comparison is a simple percentage error between the observed and estimated trip generation, as given by the following equation:

$$\text{Percent Error} = \frac{\text{Estimated} - \text{Observed}}{\text{Observed}} \times 100$$

The percent error between the observed and estimated trip generation was estimated for a total of eight scenarios incorporating different approaches to estimating internal trip capture for mixed-use developments. Table 3 summarizes the eight trip generation analysis scenarios examined in this paper. The "base" case utilizes trip generation estimates as a sum of the component on-site land uses as single-use, free-standing sites. Two sub-cases of the base case, one with separate retail and restaurant estimates (Case 0a) and another with these land uses combined as a shopping center (Case 0b), are considered. The use of shopping center (LUC 820) is considered because in many cases, the exact distribution of retail and restaurant in a proposed development may not be identified with sufficient detail at the TIA stage. The use of LUC 820 overcomes this limitation, as the underlying data for LUC 820 include both components. Internal travel between these components of LUC 820 is implicit in the estimate.

Table 3: Description of Scenarios for Trip Generation Analysis

Analysis Scenario	Case #	Description
Base Case: No Reduction	0a	Separate Retail/Restaurant
	0b	Combined Retail/Restaurant (LUC 820)
Case 1: Fixed-Percentage Reduction	1	10 Percent Based on "Optimal" Base Case
Case 2: *Trip Generation Handbook* Chapter 7 Method (ITE 2004a)	2a	Combined Estimate; Assume Retail Capture
	2b	Separate Estimate; Retail Capture Only
	2c	Separate Estimate; Capture on Aggregate Estimate
Case 3: Proposed NCHRP 8-51 Method (Bochner et al. 2010)	3a	No Adjustment for Land Use Proximity
	3b	Adjustment for Land Use Proximity

Using the best or lowest base case, Case 1 considers a trip generation estimate based on a fixed-percentage reduction of 10 percent. This value was selected as it was the most frequently-cited fixed-percentage reduction used by reviewing agencies that used this approach (Bochner et al. 2010). Case 2 examines the current ITE-recommended practice (ITE 2004a), with three sub-cases considering the underlying estimate of retail and restaurant trip generation and the application of the "Retail" internal trip capture rates reported in Tables 7.1 and 7.2 of the *Trip Generation Handbook*. Case 2a considers the combined retail/restaurant estimate (LUC 820) and assumes this traffic has internal trip capture rates similar to the "Retail" land use. Case 2b considers the separate retail/restaurant estimate and assumes only the retail component is subject to internal trip capture. Case 2c considers the separate retail/restaurant trip generation estimate but aggregates these estimates and assumes the aggregate estimate has "Retail" internalization.

Case 3 estimates trip generation using the proposed methodology from NCHRP 8-51, which includes internal trip capture data for land use pair interaction among six land uses (as compared to three in the current ITE method) and uses source data from three additional sites. Another feature of the proposed NCHRP 8-51 methodology is an adjustment to the base internal trip capture rates to account for the proximity between certain on-site land use pairs (capture rates decrease with increasing distance between land uses). Two sub-cases of the NCHRP 8-51 method are considered: Case 3a, which does not adjust the internal trip capture rates for proximity, and Case 3b, which includes the proximity adjustment in the calculations.

Individual component trip generation estimates were obtained from the ITE *Trip Generation*, 8th Edition (ITE 2008). For the purpose of this paper, only traffic data for the PM peak hour (highest hour of traffic between 4:00 and 6:00 PM) were examined in this study, since the current ITE *Trip Generation Handbook* method does not cover the AM peak hour.

STUDY SITES

The trip generation of five mixed-use development sites was analyzed in this paper. Table 3 shows the location, size, and PM peak hour traffic information for these five sites. The sites are located either in Texas or the southeastern USA. The five study sites range in size from small (9 acres) to large (310 acres). Traffic counts for the five sites were obtained in the 2000s, and all sites were fairly new and representative of current trends in MXD design at the time of the count.

Although transit was not specifically examined in this paper, Sites 1 and 3 included transit as a major component of the overall site external access.

Table 3: Study Sites Examined in Trip Generation Analysis

Site	Location	Site Size[1]	PM Peak Hour Traffic[2]	Count Date
Site 1	Atlanta, Georgia USA	140	2,026	July 2006
Site 2	Plano, Texas USA	75	1,819	May 2007
Site 3	Dallas, Texas USA	9	728	May 2006
Site 4	Chapel Hill, North Carolina USA	310	1,336	March 2003
Site 5	Southlake, Texas USA	125	2,843	May 2008

[1]Acres

[2]Bi-Directional Peak Hour Total Vehicle Trips (Entering plus Exiting)

Table 4 summarizes development data for the five MXD sites in this paper. Development data are reported for six general categories of land use: office, retail, restaurant, cinema, residential, and hotel. The restaurant and residential land uses are further divided into three sub-categories each for the purposes of estimating trip generation for each sub-category. A generic "shopping center" category (corresponding to ITE LUC 820), is included in Table 4 as the sum of the square footage for the retail and restaurant land uses.

Table 4: Development Data for Study Sites

Land Use (ITE LUC)	Site 1	Site 2	Site 3	Site 4	Site 5
Office (710)[1]	510,000	310,764	114,600	95,000	238,924
Retail (814)[1]	437,723	196,264	156,100	8,000	504,272
Restaurant[1]					
Quality, Sit-Down (931)	13,360	29,451	20,759	4,500	--
High Turnover (932)	44,663	32,571	5,760	2,000	88,474
Fast-Food (933)	6,622	7,296	2,364	--	1,864
Shopping Center (820)[2]	502,368	265,582	184,983	14,500	594,610
% Retail in Shopping Center	87%	74%	84%	55%	85%
Cinema (444)[3]	16	5	8	4	14
Residential[4]					
Single-Family (210)	--	--	--	510	--
Apartments (220)	743	1,300	191	250	--
Townhomes (230)	55	60	--	335	41
Hotel (310)[5]	101	400	--	--	248

-- Indicates land use not present at site.

[1]Square Footage (Gross Floor Area/Gross Leasable Area)

[2]Sum of square footage for retail and restaurant

[3]Movie Screens

[4]Dwelling Units

[5]Occupied Rooms

All five sites examined in this paper included office, retail, restaurant, cinema, and residential land uses. Three of the five sites included an on-site hotel. Retail as a percentage of the total

shopping center component of the site ranged from 55 to 87 percent of the total shopping center square footage at the five sites, with three of the sites having approximately 85 percent retail. Sources of these development data are as follows: Sites 1-3, Bochner et al. (2010); Site 4, Khattak et al. (2004); and Site 5, Denholm et al. (2009). In addition to development data, these sources were used to identify cordon-line mode splits, vehicle occupancies, and distances between on-site land uses that were utilized in the analysis. Finally, some sites had additional land uses that were not subject to internal trip capture using current methods; trips for these land uses were estimated separately and added into the final external trip generation estimate.

TRIP GENERATION ANALYSIS

Table 5 reports the observed trip generation and the percent error for each of the eight estimated trip generation analysis scenarios for the five study sites. Positive values of percent error are the result of trip generation estimates that were higher than the observed traffic at the sites while negative values are underestimating actual trip generation. For each site, the most accurate estimate of the observed trip generation is reported in bold. Given the variation that occurs in the underlying trip generation estimates and the seasonal variations in observed traffic patterns, any percent error less than ±10 to 15 percent is considered acceptable for an accurate estimation.

Table 5: Comparison of Observed and Estimated Trip Generation (Percent Error)

Scenario[1]	Site 1	Site 2	Site 3	Site 4	Site 5
Observed Traffic	2,026	1,819	728	1,336	2,843
Case 0a (71%)	96%	84%	124%	17%	35%
Case 0b (49%)	66%	54%	100%	17%	6%
Case 1 (36%)	50%	39%	80%	5%	-5%
Case 2a (35%)	44%	36%	80%	13%	**2%**
Case 2b (59%)	75%	69%	105%	14%	31%
Case 2c (56%)	72%	59%	104%	13%	30%
Case 3a (12%)	**10%**	-3%	**29%**	-5%	-14%
Case 3b (13%)	16%	**1%**	30%	**-4%**	-14%

[1]Average of the absolute value percent error given in parenthesis.

At four of the five sites, the proposed NCHRP 8-51 estimation method (with and without the proximity adjustment) performed markedly better than the other scenarios. At Sites 1, 2, and 4, the NCHRP 8-51 method resulted in a percent error value within an acceptable range (10, 1, and -4 percent, respectively); this was not the case for Site 3 (29 percent). At Site 5, the most accurate estimation method was Case 2a, which replicated the observed trip generation at the site within 2 percent. Case 2a considered the retail and restaurant square footage at the sites as a "shopping center" and assumed retail internal trip capture characteristics for both components. The NCHRP 8-51 estimation method result at Site 5 underestimated the observed trip generation at the site, but within the acceptable error range.

Examining the percent error across the five sites for each scenario given in Table 5, several trends are apparent. The base case (Cases 0a and 0b) consistently overestimated the actual trip generation at the sites; this was not surprising, as it is expected that an MXD site would generate traffic levels below the sum of its components due to trip internalization. The current ITE-recommended practice for estimating internal trip capture also overestimated trip generation

within a range from 2 to over 100 percent, depending on the site and scenario. None of the eight scenarios consistently underestimated the observed trip generation at the five sites, suggesting that current methods produce conservative estimates of external trip generation at MXDs. This finding may be encouraging to reviewing agencies which may be hesitant to grant reductions for internal trip capture out of concern that some methods will overestimate internal trips, thus resulting in congestion and degraded traffic flow around the proposed MXD site.

Also given in Table 5 is the average of the absolute value of the five percent error values for each of the eight analysis scenarios. The absolute value was selected for this calculation as it only considers the magnitude of the error between the observed and estimated traffic, which is more useful than including the direction of the error when a comparison between methods is desired. This metric provides a starting point to examine the research questions initially presented in this paper – directly comparing various methods used to estimate internal trip capture. The "best" estimation method appears to be the proposed NCHRP 8-51 methodology (Case 3), which was computed to have an error rate of approximately 12 percent. This error rate was approximately one-fifth to one-third that of corresponding error rates computed for the current ITE method, examined in Case 2. It is not surprising that the proposed NCHRP 8-51 method is more accurate than the current ITE method, since the proposed method uses internal trip capture data for six land uses, while the current method only has data for three land uses. Including the proximity adjustment in the NCHRP 8-51 method (Case 3b) reduced the accuracy of the estimation method by an inconsequential amount (1 percentage point), as compared to the method without the proximity adjustment (Case 3a).

Results of the use of ITE LUC 820 in the initial trip generation estimate showed that a lower error rate was obtained when the retail and restaurant land uses were combined into a single estimate (Cases 0b and 2a) than when the components were estimated separately (Cases 0a and 2b). When the retail and restaurant components were estimated separately, but combined when applying internal trip capture rates (Case 2c), the error was slightly lower than assuming no internal capture for the restaurant component (Case 2b) but still poor overall. Surprisingly, the use of a 10 percent fixed-percentage reduction from the optimal base case (Case 1) resulted in a more accurate replication of external vehicle trip generation than if no internal capture was considered (Base Case) or two of the three cases of the ITE method (Case 2).

CONCLUSIONS

There are several methods that can be used to incorporate internal trip capture into the trip generation estimate in the preparation of traffic impact analyses for proposed mixed-use development sites. Using observed traffic data from five mixed-use developments in the USA, this paper examined the accuracy of two such methods – a fixed-percentage reduction and the ITE-recommended method – plus a proposed method from NCHRP 8-51. The NCHRP 8-51 method appears to replicate the observed counts most accurately, with average error one-fifth to one-third that of estimates based on the current ITE method. Therefore, it is recommended that the NCHRP 8-51 estimation method be adopted in practice when the final methodology is made available. However, it is noted that the findings from this independent analysis are limited to the PM street peak hour at five selected MXD sites where a complete development program and traffic counts were available – data for additional sites could be used to further determine the applicability of the proposed NCHRP 8-51 method for specific types and sizes of MXDs.

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Comparing Methodologies to Estimate Internal Trip Capture at Mixed-Use Developments

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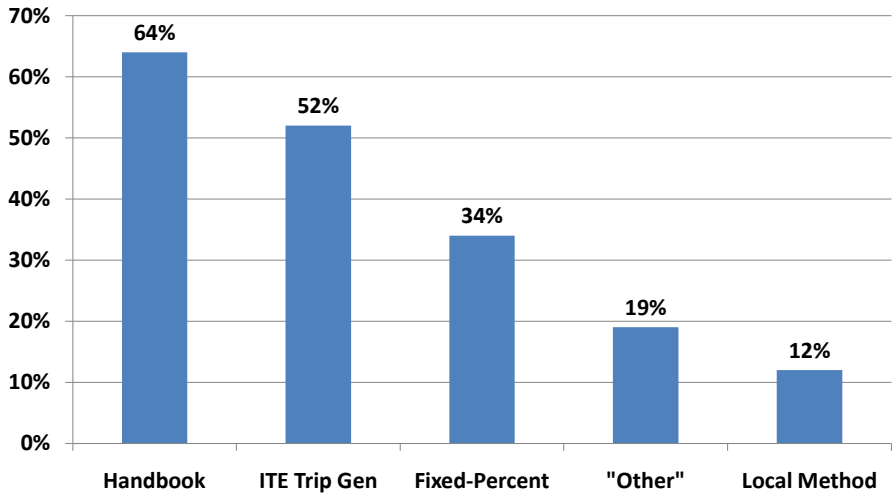
Introduction

- Mixed-Use Developments (MXD)
  - Multiple Land Uses On-Site
  - Popular Development Style
  - Often Pedestrian or Transit-Oriented
- Estimating Trip Generation @ MXD
  - Important Step in Preparing TIA Reports
  - Complex at Mixed-Use Developments
  - Internal Travel Results in Fewer Off-Site Trips
  - Accurate Estimation Benefits All Parties

Survey of Methods in Practice



Source: ITE July 2004 *Multiuse Trip Generation and Internal Capture Rates Questionnaire*

Proposed New Estimation Method

- Issues with *Trip Generation Handbook* Method:
  - Developed from FDOT Studies in Early 90s
  - Limited to PM/Daily, Three Land Uses
- Proposed NCHRP 8-51 Method:
  - Includes Capture Data for AM Peak Period
  - Adds Capture Data for Three New Uses
  - Data From Newer MXD Sites
  - Adjustment for Proximity Between Land Uses

Research Problems

- Several Methods Available in Practice
- New NCHRP 8-51 Method Forthcoming
- Research Questions:
    1. Which method accurately replicates actual trips?
    2. Use of LUC 820 Combined or Separate
    3. More Detailed Method Better Than Fixed Percentage?
    4. NCHRP 8-51 Method Improve Over Current ITE Method?
    5. Effects of Land-Use Proximity at Site?
- Compare to Actual Counts at Five MXD Sites

Analysis Scenarios

Analysis Scenario	Case #	Description
Base Case: No Reduction	0a	Separate Retail/Restaurant
	0b	Combined Retail/Restaurant (LUC 820)
Case 1: Fixed-Percent Reduction	1	10 Percent Based on "Optimal" Base Case
Case 2: *Trip Generation Handbook* Method	2a	Combined Estimate; Assume Retail Capture
	2b	Separate Estimate; Retail Capture Only
	2c	Separate Estimate; Capture on Aggregate Estimate
Case 3: Proposed NCHRP 8-51 Method	3a	No Adjustment for Land Use Proximity
	3b	Adjustment for Land Use Proximity

Study MXD Sites

Site	Location	Site Size[1]	PM Peak Hour Traffic[2]	Count Date
Site 1	Atlanta, Georgia USA	140	2,026	July 2006
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Site 5	Southlake, Texas USA	125	2,843	May 2008
[1]Acres				
[2]Bi-Directional Peak Hour Total Vehicle Trips (Entering plus Exiting)				

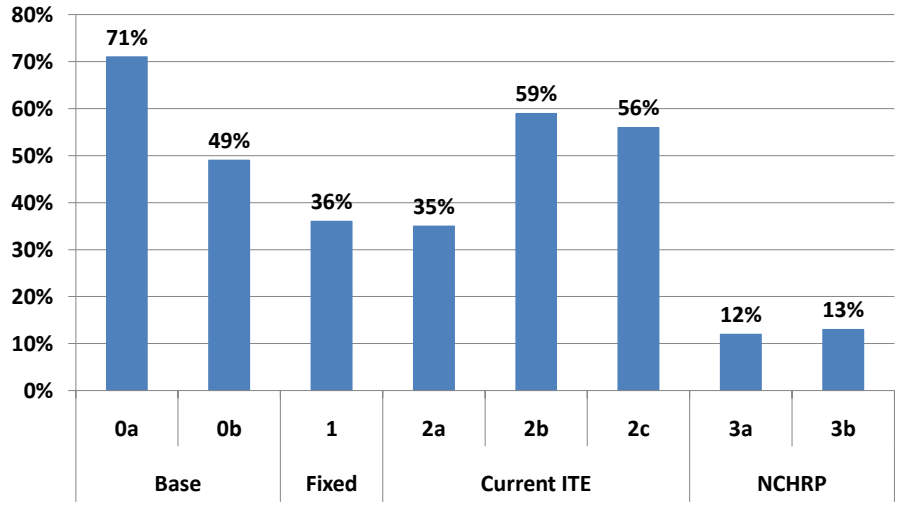
Methodology Details

- ITE *Trip Generation* 8th Edition
- PM Peak Period Only
- Adjustment for Transit, Vehicle Occupancy
- Land Uses Considered in Analysis:
  - Office
  - Retail
  - Restaurant
  - Residential
  - Cinema
  - Hotel

Analysis Results: Percent Error

Method	Case	Site 1	Site 2	Site 3	Site 4	Site 5
Observed Traffic	-	2,026	1,819	728	1,336	2,843
Base	0a	96%	84%	124%	17%	35%
	0b	66%	54%	100%	17%	6%
Fixed-Percent	1	50%	39%	80%	5%	-5%
Current ITE	2a	44%	36%	80%	13%	**2%**
	2b	75%	69%	105%	14%	31%
	2c	72%	59%	104%	13%	30%
NCHRP 8-51	3a	**10%**	-3%	**29%**	-5%	-14%
	3b	16%	**1%**	30%	**-4%**	-14%

Analysis Results: Average Absolute Error



Summary

- Base Case: Overestimated Traffic
- Current ITE Method Overestimated Traffic
- No Method Consistently Underestimated
- Most Accurate Method: NCHRP 8-51 Method
  - Average Absolute Error: 12 Percent
  - Error One-Fifth to One-Third of Other Methods
  - Proximity Adjustment Inconsequential

Conclusions

- Recommend Use of NCHRP 8-51 Method
- More Counts/Data Needed for Comparison