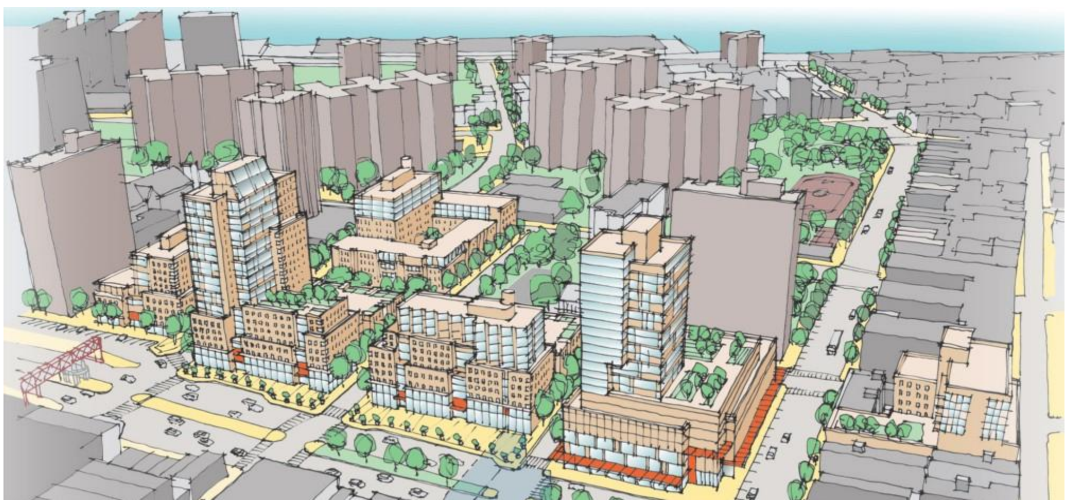
MIXED-USE DEVELOPMENT TRIP GENERATION MODEL



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Abstract

The Mixed-Use Development Trip Generation model provides a mechanism for estimating vehicle, walking, and transit trips for a mixed-use development (MXD). The model applies trip modifications to standard single-use trip generation estimates developed by the Institute of Transportation Engineers (ITE). MXDs with diverse internal activities have been shown to capture internal trips at a rate higher than conventional suburban developments; therefore, the MXD Trip Generation model accounts for the internal capture of MXD sites by reducing the external trips produced and estimating the number of walking and transit trips that would typically be conducted by automobile. In addition, MXDs located in central areas have been shown to generate shorter vehicle trips, which has been accounted for in the model as internal and external vehicle miles traveled (VMT) are estimated based on published travel characteristics of MXDs.

The MXD Trip Generation model provides a straightforward method of testing transportation-related metrics of MXDs. The model uses ratios from a leading research-based MXD model to reduce ITE vehicle trip estimates and presents a summary of results that show the effects on VMT, internal capture, and mode split as a result of enhanced activity density and diversity of land uses within the MXD. The MXD trip reductions are based on the methodology described in Ewing et al. (2011), which analyzed datasets for MXDs in six large and diverse metropolitan regions. Benefits of locally-calibrated vehicle ownership characteristics are also included in the mode split of the trip estimates of the MXD Trip Generation model.

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Introduction

The Mixed-Use Development Trip Generation model estimates the daily vehicle, walking, and transit trips by purpose for a proposed development with a mix of land uses. The model, which has been developed to be incorporated as a component of the Envision Tomorrow Plus (ET+) planning tool, estimates a unique trip generation for planning scenarios and is based on land use amounts by type: residential, retail, office, and industrial. Daily trip generation is estimated based on rates and equations in *Trip Generation, 8th Edition* from the Institute of Transportation Engineers (ITE), the nationally recognized source that is commonly used by traffic engineers and transportation planners across the United States (1). Trip reduction factors, based on mixed-use development (MXD) research, estimate reductions and trip distribution of a mixed-use area and are applied to the initial ITE trip estimates to determine MXD trip generation of internal and external travel.

Singular land use variables, such as square feet of gross leasable area for retail, office, and industrial uses, have been used to develop trip generation estimates of stand-alone developments. Internal trips and a mode split which includes walking and transit trips can be expected when a combination of development types occur in a relatively small area. Therefore, trip estimates from ITE have been factored, based on the best research available in MXD applications, and local input variables to develop estimates of the walk, transit, and vehicle trips for travel that is both internal and external to the site. Estimates of the vehicle miles traveled (VMT) for the internal and external vehicle trips are also produced.

Envision Tomorrow Plus

Land use and transportation scenario planning allows users to preview impacts of development, rather than accept the trends frequently embodied in existing plans. Scenario planning is an approach that allows decision-makers, stakeholders, and the public to consider a wider range of possible futures than present in most traditional planning approaches. Scenario planning usually includes a technical component that utilizes a sketch planning tool that enables scenarios to be drawn and quantified. Envision Tomorrow (ET), developed by Fregonese Associates, is being used for scenario planning in several locations throughout the US.

ET creates a scenario via a "Prototype Builder" that tests the physical and financial feasibility of development. The tool allows users to examine land use regulations in relation to the current development market and to consider the impact of parking, height requirements, construction costs, rents, and subsidies. The tool can be used to examine if a development “pencils.” For example, it can assess how preferred forms of development, such as mixed-use retail with housing above, might become more financially feasible within an existing code.

The subsequent part of ET is "Scenario Builder", which adds scenario-building functionality to ArcGIS. From prototypes generated in Prototype Builder, development types combinations are fed into Scenario Builder to “paint the landscape” by allocating different development types across a study area to create a land use scenario. Unlimited scenarios can be built to test against each other. The tool allows real-time evaluation of the impact of each scenario on land use, housing, sustainability, and economic conditions.

In 2011, the University of Utah Metropolitan Research Center received funding as part of the Housing and Urban Development Sustainable Communities Program grant. In part, the grant included a joint effort with the Metropolitan Research Center and Fregonese Associates to expand ET tools using new research-based methods, resulting in ET+. The expansion includes 23 new models that range from energy and water consumption to transportation. The MXD Trip Generation model is one of the components of ET+ and outputs of the model are essential to the overall tool as many indicators for other models are dependent on its outputs.

The authors have established procedures to generate variables to model trip generation, internal capture, VMT, and mode share of internal and external trips based on existing and proposed conditions. This report provides an overview of the research guidance and operations contained in the MXD Trip Generation model as well as a guide to the operation of the component within ET+.

Literature Review

Vehicle-based trip generation is a traffic engineering method that is used extensively across the US to analyze impacts of proposed developments on the surrounding transportation network. While no standard of trip estimation is universally agreed upon, the most common practice for traffic impact studies in the US is to rely upon the procedures from trip generation rates and adjustments published by ITE in its two reports: *Trip Generation, 8th Edition* (ITE, 2008) and the *Trip Generation Handbook, 2nd Edition* (ITE, 2004) (2). Limitations have been raised regarding the ITE MXD lookup tables in the *Trip Generation Handbook*. The ITE MXD analysis is based on data from a limited number of surveys; three multi-use sites in Florida (2). Accuracy of future forecasts is thus dependent on how closely the site and context being analyzed matches the three suburban Florida mixed-use sites. Therefore, in addition to ITE standard trip generation rates and equations, the MXD Trip Generation model of ET+ references studies that address the trip estimation characteristics of MXDs with respect to vehicular, transit, and pedestrian travel.

To determine the most appropriate MXD trip generating method for the model and ET+, a literature review of MXD trip generation methods was conducted. After completion of the literature review, it was apparent that a combination of the two most applicable methodologies would be used for the MXD Trip Generation model: *Trip Generation, 8th Edition* (ITE, 2008) and "Traffic Generated by Mixed-Use Developments – Six-Region Study Using Consistent Built Environmental Measures" (Ewing et al., 2011) (3). The findings of the literature review are presented in this section, along with a detailed description of the methodologies selected for use.

Evaluation of the Operation and Accuracy of Available Smart Growth Trip Generation Methodologies for Use in California

A review of eight standard methods of MXD trip generation by Shafizadeh et al. (2011) found all to be more accurate than ITE procedures (4). The review found that in estimating trip generation for multi-use sites, all of which are large-scale projects located outside the central business district, the most accurate estimate for the greatest number of sites was produced by Ewing et al. (2011) (4). For daily counts, the Ewing et al. (2011) study methodology produces the best estimate for seven of the 22 sites used for validation (4). Therefore, the Ewing et al. (2011) study methodology is the basis for MXD Trip Generation estimation in ET+.

The study compared five of the trip generation methods by modeling a variety of hypothetical characteristics as well as a real-world assessment at 22 sites in California. Three additional methods were reviewed in the study but were not tested due to their methodology having been developed for site-specific locations. The five methodologies selected for comparison by Shafizadeh et al. (2011) are included in the literature review in this section.

National Cooperative Highway Research Program Report 684

One of the latest MXD trip generation studies is the National Cooperative Highway Research Program Report (NHCRP) 684, which summarizes the multi-year research effort of the NCHRP 8-51 project (5). The report studied the trip making characteristics of six MXD sites. The result was the determination of an amount of expected level of interactivity between land uses within a site, during both the morning and evening peak periods (5). The sites in the study contained the following land uses: office, retail, restaurant, residential, movie theater, and hotel.

The report is intended to improve the MXD methodology presented in the ITE *Trip Generation Handbook* (at the time of publication of this paper, ITE has announced the release of *Trip Generation, 9th Edition* and an updated *Trip Generation Handbook*; however, information in this paper is based on the *Trip Generation, 8th Edition*.)

Station Area Residents Survey

The Metropolitan Transportation Commission, in the San Francisco Bay Area, conducted a demographic and travel characteristics survey of residents living within close proximity to rail/ferry terminals in the area. The study produced many travel-related findings, including "those living (and working) close to rail/ferry transit use transit, walk and bike much more than people living farther from a rail/ferry stop" (6). The finding indicates that the presence of transit is related to the walking and bicycling mode choice.

The extensive data collection effort led to an MXD trip generating method that factors ITE *Trip Generation* rates based on location to rail/ferry terminals in urban areas (4). The method appears to only be applicable in urban areas with rail/ferry connection to the development site and its limited database (the San Francisco Bay Area) may be prohibitive for national use.

Emissions Estimation for Land Use Development Projects (URBEMIS2007)

The "Emissions Estimation for Land Use Development Projects" is a software package that estimates air emissions from land use sources and includes MXD trip generation estimations (7). The URBEMIS2007 is a stand-alone software package and was deemed incompatible with the ET+ tool being developed by Fregonese Associates.

The findings by Shafizadeh et al. (2011) related to the accuracy of the URBEMIS2007 software with respect to trip generation did not indicate that the product was superior to the other, more ET+ tool-friendly, methodologies (4).

Traffic Generated by Mixed-Use Developments – Six-Region Study Using Consistent Built Environmental Measures

The analysis in Ewing et al. (2011) was based on travel data from 239 MXD sites in six diverse regions. In each region, consultations with local planners and traffic engineers were conducted to identify MXDs that met the ITE definition of MXD: "A mixed-use development or district consists of two or more land uses between which trips can be made using local streets, without having to use major streets. The uses may include residential, retail, office, and/or entertainment. There may be walk trips between the uses" (3). The 239 identified MXDs ranged from compact infill sites near the region's core to low-rise freeway-oriented developments. The sites varied in population and employment densities, mix of jobs and housing, presence or absence of transit, and location within the region. The sites ranged in size from less than five acres to over 2,000 acres, with some sites containing over 15,000 residents and employees.

Quantifiable relationships between a development site's external traffic generation and the following seven "D" characteristics; density, diversity, design, destination accessibility, distance from transit, development scale, and demographics were established. The statistical analysis found that several "D" factors influence internal trip capture, and that the effects vary by trip purpose. For home-based work trips, internal capture is related to two "D" variables, diversity and demographics. The odds of an internal trip occurring decline with household size and vehicle ownership per capita, and increase with a job-population balance in the MXD. Larger households have more complex activity patterns, which are more likely to take them beyond the bounds of an MXD. Households with higher vehicle ownership have fewer constraints on the use of household vehicles for long trips. A high job-population balance value translates into more opportunities to live and work on site. For home-based trips conducted for purposes other than commuting, the odds of internal capture decline with household size and vehicle ownership per capita and increase with the land area, job-population balance, and intersection density of an MXD.

The model produced in this study enables a traffic analysis to account for the differences in trip generation that arise from infill developments within or adjacent to traditional downtowns or central business districts, implicitly accounting for the factors that differentiate downtown areas from conventional suburbs, including the presence or absence of rail and bus service, and the degree to which external trip generation is affected by the number of jobs in the area surrounding the development site. The model also reflects the extent to which the internal, walking, and transit trip generation of the site is affected by: the mixture of uses, the pedestrian interaction related to the scale of the area, the ease of access and proximity to a variety of activities, parking constraints, as well as higher automobile occupancy and more convenient transit service.

Trip Generation, 8th Edition

Trip Generation, 8th Edition (ITE, 2008 and referred to as *Trip Generation* in this document) is the standard for vehicle-based single-use trip generation estimates and is used by engineers and planners across the US (1). *Trip Generation* is developed by ITE and, at the time of development of ET+, is in its eighth edition.

ITE compiles trip generation studies for various sites and isolated land uses, groups these studies into categories, and then develops rates and equations which can be applied to similar projects. The trip generation studies are summarized in ITE's *Trip Generation* with additional information provided in the *Trip Generation Handbook, 2nd Edition* (ITE, 2004).

Trip Generation Handbook, 2nd Edition

ITE produces a trip generation handbook to accompany the *Trip Generation* manual. The *Trip Generation Handbook, 2nd Edition* (ITE, 2004 and referred to as *Trip Generation Handbook* in this document) provides guidance on proper application of the data summarized in the *Trip Generation* manual. Engineering and planning topics presented in the *Trip Generation Handbook* include guidelines for estimating project site trip generation, collection of local trip generation data, and development of local trip generation rates, among other traffic engineering-specific applications.

The *Trip Generation Handbook* details a method for developing vehicle trip generation estimates for mixed-use developments. However, the methodology has several shortcomings, including: being based on a limited number of sites, providing only three land use types, and disregarding the scale of the development. Therefore, the methodology used in the ET+ model follows the trip estimation procedures described in the Ewing et al. (2011) study, primarily due to its ability to estimate walk trips and transit trips estimated at an MXD, thus reducing VMT.

Definition of Mixed-Use Development

The study area boundary created for ET+ project sites **should include only mixed-use type development**. The boundary should be established as close to the proposed scenario as possible;

however, it should also include any immediately adjacent existing land use that would be considered part of the MXD. Mixed-use is defined as **development consisting of two or more land uses between which trips can be made using local streets** (including walk trips), without having to use major streets. The uses may include residential, retail, office, and/or entertainment.

Identification of "local" streets may use Census Feature Class Code (CFCC) local street criteria. However, streets that may not be classified as local by the CFCC may be included if exchanging trips as part of a contiguous development. For example, a main street in a smaller town may legally be classified as a US Highway but may function as a local street.

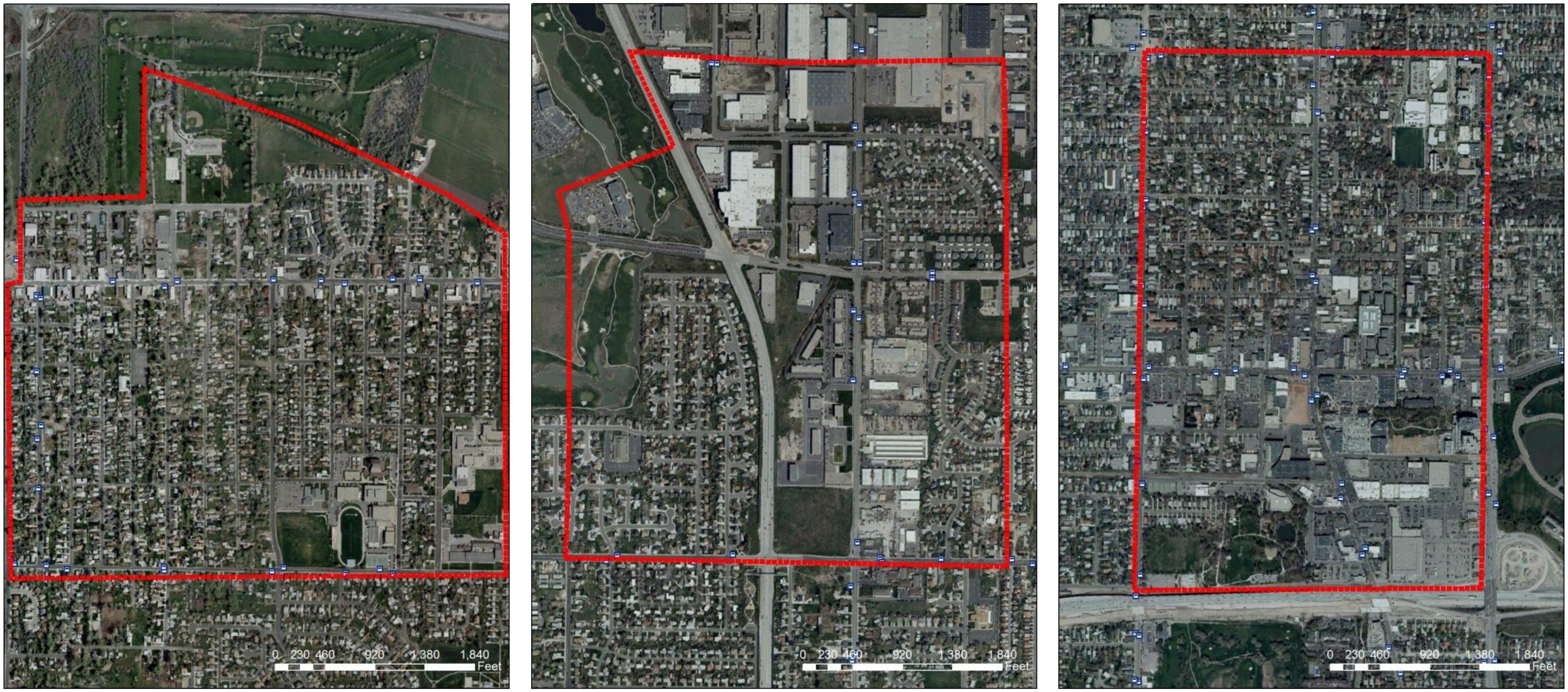
Figure 1 provides aerial illustrations of several types of development areas and their applicability to the MXD definition: a) the type and scale of a typical MXD tested in ET+, b) an area that does not follow the MXD definition as it is divided by an arterial and has a distinct separation of land use, and c) a mixed-use district that meets the MXD definition but contains a larger traffic volume collector roadway which continues to function as a local street.

A planning professional should be involved in the development of the study area boundary to ensure that only MXDs are included and that land uses are exchanging trips on local streets. A study area boundary and scenario planning effort may include existing uses; however, the amount of existing uses should be carefully considered. Every effort should be made by the planning professional to develop the MXD study area boundary so that it encompasses only the mixed-use type development that follows the MXD definition. In addition, constraints with respect to scale have been established due to bounds of study locations and destination access of walk trips.

An ET+ MXD study area boundary should be **no larger than 960 acres** (approximately 1.5 square miles). The area limit for the MXD was determined based on the areas used in the Ewing et al. (2011) study and by considering the upper bounds of a typical walking distance for pedestrians (0.5 mile) between land uses that may exchange trips. (The Federal Transit Administration has officially established the walkable catchment area around transit stops as 0.5 mile. In addition, a 2009 study commissioned by the Victoria Department of Transport found that the average walk trip in the US was 1.2 miles but that 50 percent of all walk trips were less than 0.5 mile.)

Important Considerations

- All applications of the MXD Trip Generation model should meet the definition of an MXD.
- An MXD should contain local streets and not major streets (in most cases).
- The MXD should be 960 acres or less; results computed for sites larger are out of the bounds of the MXD Trip Generation model.



Example of an area that follows the MXD definition.

Example of an area that does not follow the MXD definition due to its large internal roadways.

Example of an area that follows the MXD definition despite the presence of larger roadways within the site.

FIGURE 1 Examples of development areas and their applicability to the MXD definition.

Inputs

Inputs for MXD scenarios in ET+ are comprised of both manually collected inputs and GIS tool based auto-populated fields. Summary square footage by land use from scenarios and existing conditions are pushed to the model and generate variables used in model calculations. A general overview of the development of variables is provided in Table 1.

TABLE 1 MXD Model Inputs

Variable Inputs for MXD Trip Generation Estimates	Description
MXD Area	Gross land area in square miles and acres within the user-defined MXD boundary
Non-Residential Land Use	Existing and scenario lot area of retail, office, and industrial uses in MXD boundary plus one mile buffer (in square feet)
Residential Units	Sum of single family dwelling units and “other” (multi-family) dwelling units from land use units in MXD (existing plus scenario)
Intersections	Number of intersections within the MXD boundary and in a one mile buffer
Employment in Region	Number of jobs in region from Metropolitan Planning Organization model
Employment in One Mile	Employment within a one mile buffer of the MXD boundary derived from non-residential land use (excluding the MXD study area)
Median Household Income	Median household income from the US Census American Community Survey five year estimates by MXD centroid tract converted to the 1982 Consumer Price Index
Employment in 20 Minute Automobile Commute	Proportion of total employment in the region that is within a 20 minute automobile commute from the MXD
Employment in 30 Minute Automobile Commute	Proportion of total employment in the region that is within a 30 minute automobile commute from the MXD
Employment in 30 Minute Transit Commute	Proportion of total employment in the region that is within a 30 minute transit commute from the MXD
Household Income	Derived from separate models contained in ET+
Transit Stops	Stops within MXD, stops within 0.25 mile buffer of MXD and proportion of area within 0.25 mile buffer that has stop coverage in MXD

Equations

The MXD Trip Generation model requires a number of equations and inputs to produce a mixed-use trip generation estimate. Equations are based on research and are summarized in the literature review, with required inputs identified. Many of the inputs to the MXD Trip Generation model are outputs from ET and selected ET+ models, while others are regional outputs from large-scale travel estimates, such as a travel demand forecasting model.

The equations are presented in four sections: 1) those required to determine an ITE *Trip Generation* calculation, 2) those inputs required for the 7D Household Vehicle Ownership model, 3) the separation of trips by purpose, and 4) those inputs required to apply the MXD trip reduction procedures to the initial trip estimates.

1. ITE Trip Generation

The land use inputs required for the ITE *Trip Generation* estimates are provided by the scenario planning component of ET+ and existing geographic data. An estimate of the number of vehicle trips based on ITE *Trip Generation* rates and equations requires the following land use information:

- Existing and scenario square feet of retail, office, and industrial (if present)
- Existing and scenario dwelling units of single family residential, townhomes, multi-family residential, and mobile home park (if present)

Equations and rates utilized in the MXD Trip Generation model are presented in Table 2 for single family residential, townhomes, multi-family residential, mobile home park, retail, office, and industrial.

TABLE 2 ITE Equations Utilized in the MXD Trip Generation Model

Land Use Type	Equation	Variables
Single Family Residential (ITE Code 210)	Ln (T) = 0.92 * Ln (X) + 2.71	T = number of daily vehicle trips X = number of dwelling units in MXD
Townhomes (ITE Code 230)	Ln (T) = 0.87 * Ln (X) + 2.46	T = number of daily vehicle trips X = number of dwelling units in MXD
Multi-Family Residential (ITE Code 220)	T = 6.06 * X + 123.56	T = number of daily vehicle trips X = number of dwelling units in MXD
Mobile Home (ITE Code 240)	T = 3.52 * X + 277.51	T = number of daily vehicle trips X = number of dwelling units in MXD
Retail (ITE Code 820)	Ln (T) = 0.65 * Ln (X) + 5.83	T = number of daily vehicle trips X = 1,000 square feet of gross leasable area in MXD
Office (ITE Code 710)	Ln (T) = 0.77 * Ln (X) + 3.65	T = number of daily vehicle trips X = 1,000 square feet of gross leasable area in MXD
Industrial (ITE Code 130)	T = 6.96 * X	T = number of daily vehicle trips X = 1,000 square feet of gross leasable area in MXD

For additional information on ITE trip generation estimating equations, rates, and procedures, refer to *Trip Generation Handbook* and *Trip Generation*.

Important Considerations

Development scenarios that include land use amounts greater than the following upper limits are not applicable to these trip generation estimates:

- Retail greater than 1,500,000 square feet
- Office greater than 1,300,000 square feet
- Industrial greater than 2,300,000 square feet
- Single family residential greater than 3,000 dwelling units
- Townhomes greater than 1,250 dwelling units
- Multi-family residential greater than 1,000 dwelling units
- Mobile home park greater than 810 dwelling units

2. 7D Household Vehicle Ownership Model

The 7D Household Vehicle Ownership model was developed to estimate the number of vehicles owned by households and is based on local land use and geographic characteristics. The MXD Trip Generation model utilizes inputs which are generated by the 7D Household Vehicle Ownership model.

Single family households and multi-family households (referred to as "Other Households" in the model) have distinct vehicle ownership characteristics and are represented by separate models. Each vehicle ownership model is presented in this section with inputs identified. Several of the vehicle ownership model inputs require sources outside of the ET+ package.

Single Family Households

$$\ln(V) = -1.42478 + [0.33331 * \ln(HHSIZE)] + [0.220001 * \ln(SFINCOME)] + [-0.09165 * \ln(INTDEN)] + [-0.01382 * \ln(EMP30T)]$$

V = vehicles

HHSIZE = single family household size

SFINCOME = single family median household income (modified to 1982 consumer price index)

INTDEN = intersection density within the MXD

EMP30T = employment within a 30 minute transit commute

Other Households

$$\ln(V) = -2.27444 + [0.390903 * \ln(OHHSIZE)] + [0.315116 * \ln(OINCOME)] + [-0.1513 * \ln(INTDEN1)] + [-0.02201 * \ln(TMILE)]$$

V = vehicles

OHHSIZE = "other" household size

OINCOME = "other" median household income (modified to 1982 consumer price index)

INTDEN1 = intersection density within a one mile buffer from every separate "other" household

TMILE = transit stops within a quarter mile buffer from every separate "other" household

Important Considerations

- All income should be converted to the 1982 Consumer Price Index. ET+ produces income in current dollars.
- The variable TMILE represents an aggregate of the number of transit stops within a one mile buffer of every household. Although this value is often impractical to obtain in practice, the model requires this input for proper functionality. As a substitute, the number of transit stops within a one mile buffer from the edge of the MXD study area can be used to provide an approximate result.
- Household vehicle ownership estimates for MXDs may be higher than generally accepted and national household vehicle ownership rates due to local land use and income distributions which may be higher in the MXD.

3. Trips by Purpose

Information from the Nationwide Personal Transportation Survey and the National Highway Cooperative Research Program 365 report was used to determine the percentage of trips based on purpose for each land use type used in the MXD Trip Generation model of ET+ (8, 9). Vehicle trips estimated by the ITE *Trip Generation* rates and equations are separated by purpose prior to the application of MXD reduction factors.

To separate the vehicle trip estimates into home-based work (HBW), home-based other (HBO), and non-home-based (NHB) trips, a unique set of trips by purpose percentages were used. A distinct trip percentage is provided for each land use type as the trip making characteristics differ. The following unique percentages were used in the MXD Trip Generation model of ET+:

TABLE 3 Trips by Purpose (8, 9)

Land Use	HBW	HBO	NHB
Residential	25%	75%	0%
Retail	5%	45%	50%
Office / Industrial	65%	5%	30%

Data in Table 3 is used to assign trips by purpose to land use types. As an example, residential trips generated by a development are assumed to the following purposes: 25 percent will travel between the home and work, 75 percent will travel between the home and an “other” destination, and zero percent are non-home-based.

For additional information on MXD trip generation estimating equations, rates, and procedures, refer to Ewing et al. (2011).

4. Mixed-Use Development Model

An estimation of trips associated with an MXD requires a separate set of equations with distinct inputs, based on Ewing et al. (2011). The MXD equations predict the internal and external trips generated by a mix of land use based on the vehicle trip estimation. Internal and external trips are further divided into walk trips, transit trips, and MXD-related vehicle trips.

The specific indicators calculated by the model are: internal share of total trips, internal automobile trip length, external automobile trip length, internal walk trips, external walk trips, and external transit trips. For each trip type, there is a separate equation for HBW, HBO, and NHB trips.

An example of the equations and rates utilized in the MXD model portion of the MXD Trip Generation model are presented in this section. The following set of equations detail the probability that a trip will be an internal trip.

Internal Share of Total Trips - HBW

$$\mathrm{Ln}\,(P) / [1 + \mathrm{Ln}\,(P)] = -1.75 + [0.389 * \mathrm{Ln}\,(JOBPOP)] - [1.33 * \mathrm{Ln}\,(HHSIZE)] - [0.99 * \mathrm{Ln}\,(VEHCAP)]$$

P = percentage of HBW internal share of total trips

JOBPOP = proportion of employees in study are to population of study area
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

Internal Share of Total Trips - HBO

Ln (P) / [1 + Ln (P)] = -2.43 + [0.486 * Ln (AREA)] + [0.399 * Ln (JOBPOP)] + [0.385 * Ln (INTDEN)] – [0.867 * Ln (HHSIZE)] – [0.59 * Ln (VEHCAP)]

P = percentage of HBO internal share of total trips
AREA = area in square miles of the MXD
JOBPOP = proportion of employees in study area to population of study area
INTDEN = intersection density in the MXD
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

Internal Share of Total Trips - NHB

Ln (P) / [1 + Ln (P)] = -5.32 + [0.208 * Ln (EMP)] + [0.468 * Ln (AREA)] + [0.638 * Ln (INTDEN)] – [0.237 * Ln (HHSIZE)] – [0.163 * Ln (VEHCAP)]

P = percentage of NHB internal share of total trips
EMP = employees in study area
AREA = area in square miles of the MXD
INTDEN = intersection density in the MXD
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

The following set of equations is an example of trip length calculations for external vehicle trips.

External Automobile Trip Length - HBW

L = 6.54 + [1.07 * Ln (AREA)] – [0.298 * Ln (JOBPOP)] – [1.19 * Ln (EMP30A)] + [2.76 * Ln (HHSIZE)] + [2.76 * Ln (VPC)]

L = external automobile trip length for HBW trips of the MXD
AREA = area in square miles of the MXD
JOBPOP = proportion of employees in study area to population of study area
EMP30A = employees within a 30 minute automobile commute as a portion of the employees in the region
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

External Automobile Trip Length - HBO

L = 4.33 – [0.356 * Ln (JOBPOP)] – [0.697 * Ln (EMP20A)] + [0.772 * Ln (HHSIZE)] + [1.48 * Ln (VEHCAP)]

L = external automobile trip length for HBO trips of the MXD
JOBPOP = proportion of employees in study area to population of study area
EMP20A = employees within a 20 minute automobile commute as a portion of the employees in the region
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

External Automobile Trip Length - NHB

L = 8.99 – [0.282 * Ln (JOBPOP)] – [0.832 * Ln (INTDEN)] – [0.823 * Ln (EMP20A)] + [0.52 * Ln (HHSIZE)] + [1.06 * Ln (VEHCAP)]

L = external automobile trip length for NHB trips of the MXD
JOBPOP = proportion of employees in study area to population of study area
INTDEN = intersection density in the MXD
EMP20A = employees within a 20 minute automobile commute as a portion of the employees in the region
HHSIZE = single family household size in the MXD
VEHCAP = vehicles per capita in the MXD

Additional equations are used in the MXD Trip Generation model to determine the trip characteristics for the following types of trips: internal walk trips, external walk trips, and external transit trips. Internal automobile trip length is also determined by a separate equation. For additional information on MXD trip generation estimating equations, rates, and procedures, refer to the Ewing et al. (2011) study.

Important Considerations

Acquiring variables for modeling a complete MXD model analysis requires several data collection and processing techniques. Accuracy of the model and ITE trip modification may not be considered valid without proper inputs. MXD boundaries must be defined according to the definition of the MXD section and the following variable details must be considered:

- Developed land ratio considers scenario totals as built, and is combined with existing land use totals.
- Intersections must include existing and any proposed intersections.
- Employment information is estimated by square feet of non-residential use per employee according to ET estimates.

Process

The trip generation estimates are developed through a combination of ET+ scenario and user inputs, empirically based coefficients, and standard transportation rates and equations. An overview of the process for developing MXD trip generation estimates is presented in the following, in which steps are summarized in the order they are completed in the ET+ MXD Trip Generation model:

1. Calculate an ITE *Trip Generation* estimate of total vehicle trips to be generated by the development types.
2. Separate the vehicle trips by purpose (HBW, HBO, and NHB) based on land use type.
3. Employ the 7D Household Vehicle Ownership model to predict the number of vehicles per household, to be used in the MXD equations.
4. Apply the MXD equations to factor the estimated vehicle trips into internal and external vehicle trips.
5. Apply the MXD equations to factor the estimated internal and external vehicle trips into walking trips, transit trips, and vehicle trips (for both internal and external situations).
6. Apply the MXD equations to factor the estimated internal and external vehicle trips into VMT (for both internal and external situations).

Each step of the process is described in greater detail in this section. The intent of describing each individual process is to provide the user insight into the general operations of the MXD Trip Generation model. The model has been developed to operate transparently, allowing the user to examine and follow each step, if desired.

Land use amounts from ET are input into the MXD Trip Generation model and ITE *Trip Generation* rates and equations are used to estimate the number of vehicle trips expected to be generated if the land uses were stand-alone developments. The trip generation estimates are produced according to standard traffic engineering protocol.

A significant portion of the process involves separating trips into trip types: HBW, HBO, and NHB. The division of vehicle trips by purpose has significant effects on the ultimate MXD trip generation of the development; each of the vehicle trip generation estimates from ITE are factored by the nationwide HBW, HBO, and NHB percentages before being factored by the site-specific MXD ratios.

One of the inputs for the MXD equations, vehicle ownership, requires a separate set of models with unique inputs. The 7D Household Vehicle Ownership model predicts the number of vehicles per household and is embedded within the MXD Trip Generation model. The model operates as part of the module and predicts the number of vehicles owned by single family and “other” households (multi-family households) based on local land use and economic conditions.

The next step of the MXD Trip Generation model uses site-specific ratios from the MXD equations to transform the vehicle trips estimated by ITE into internal and external trips. The site-specific ratios factor the total vehicle trips into internal trips and external trips.

The internal vehicle trip estimates are separated into the HBW, HBO, and NHB purpose categories by land use type to determine the amount of internalization of vehicle trips. For example, all office vehicle trips are separated into HBW, HBO, and NHB vehicle trips. The vehicle trips are then grouped by purpose and the land use productions and attractions are compared. The smaller of the two, production or attraction, is used as the governing internalization maximum amount and the internal trip generation of the associated land uses are set at that amount.

Once the internal trips are set for each land use type, the site-specific MXD ratios are applied to factor the trips into internal walking and vehicle trips. The internal trips are subtracted from the total vehicle trips to arrive at the estimated number of total external trips.

Additional equations from the MXD models are used to factor the trip estimates into walking trips, transit trips, and vehicle trips. Separate equations from the MXD models are used for both the internal and external trips. The resulting estimates are walk trips and vehicles trips that are internal and external to the study area. In addition, transit trips are estimated and are entirely external and are represented in person-trips.

The final step summarizes trip type by mode to produce the total trips estimated to be generated by the MXD. The MXD Trip Generation model uses ratios from the MXD models to reduce the ITE vehicle trip estimates. Therefore, the resulting vehicle trips estimated by the described process will always produce a trip generation estimate less than ITE.

An MXD ratio is applied to the vehicle trips to estimate the VMT for those internal and external vehicle trips. The site-specific VMT ratio is developed from the MXD models and is dependent on external data, as previously described. Total internal and external VMT is summarized for the study area.

Results

The MXD Trip Generation model of ET+ produces a results table that summarizes the following types of trip generation estimates for the MXD: walk trips, transit trips, vehicle trips, and VMT. The resulting walk and vehicle trips are also summarized into internal and external trips. Interim results within the model can be used to identify numerous additional metrics, as desired by the user, such as the totals per dwelling unit, totals per capita, totals per employee, or the difference in trip estimates when compared to a stand-alone development approach.

Estimates for walk trips and vehicle trips are listed for both those trips internal and external to the site. Internal trips are those that are expected to remain entirely within the MXD boundary while external trips would be expected to travel to/from the MXD. Internal and external modal split is also summarized by percentage of trips generated. Users will find summations side by side for each scenario. Transportation benefits of higher density and mix of uses become readily apparent when viewing summary results.

The MXD Trip Generation model of ET+ is intended to be transparent with source and rate information found throughout the spreadsheet model. The probability of trips by purpose, percentage of trips by purpose, and ITE rates are readily available as lookup tables and within the appropriate formulas.

Important Considerations

The MXD Trip Generation model produces trip estimates and is not intended to predict the exact number of MXD trips. In addition, the MXD Trip Generation model does not assess the impacts of the MXD on the surrounding transportation network. A detailed traffic impact study should be conducted by a licensed traffic engineer to fully evaluate the effect the MXD would have on the transportation network.

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