UrbanFootprint Technical Documentation
Transportation Analysis

Overview

The UrbanFootprint Transportation module is a high-level travel model that produces estimates of the following metrics for land use and transportation scenarios:

- Vehicle miles traveled (VMT)
- Trips taken, organized by mode
- Transportation costs
- Greenhouse gas (GHG) emissions and pollutant emissions

The UF transportation module estimates VMT and mode share with sensitivities to the effects of the built environment on travel behaviors. These effects are quantified within the UF transportation module according to the Mixed-Use Development (MXD) method, which consists of statistical models based on research of observed relationships between characteristics known as "D" factors and travel behavior in cities and regions across the US.

In turn, VMT estimates are used to calculate greenhouse gas (GHG) emissions, pollutant emissions, and household auto costs. Refer to the documentation for the Emissions and Household Costs modules for further information on those analyses.

Transportation analysis is run at the scale of the project canvas (generally parcels or census blocks), yielding a mapped spatial output layer and corresponding data table; both can be used within UrbanFootprint for mapping and data exploration, and exported. The module also reports individual and comparative scenario results via summary charts, and generates a spreadsheet summary in Excel format.

Module version 2.3.10
rev. 6/07/19

Methodology

The travel forecasting capabilities of UrbanFootprint are based on a comprehensive body of research on the observed relationships between trip generation and characteristics of the built environment[1].

The Ds

Among the findings of this research is that urban form, transportation supply, and management policies affect VMT, automobile travel, and transit in at least 8 different ways. These mechanisms are referred to as the "8 Ds."

The "8 Ds" include:

1. Density – residential and employment concentrations;
2. Diversity – jobs/housing, jobs mix, retail/housing;
3. Design – connectivity, walkability of local streets, and non-motorized circulation;
4. Destination – accessibility to regional activities;
5. Distance to Transit – proximity to high quality rail or bus service;
6. Development Scale – critical mass and magnitude of compatible uses;
7. Demographics – household size, income level, and auto ownership;
8. Demand Management – pricing and travel disincentives.

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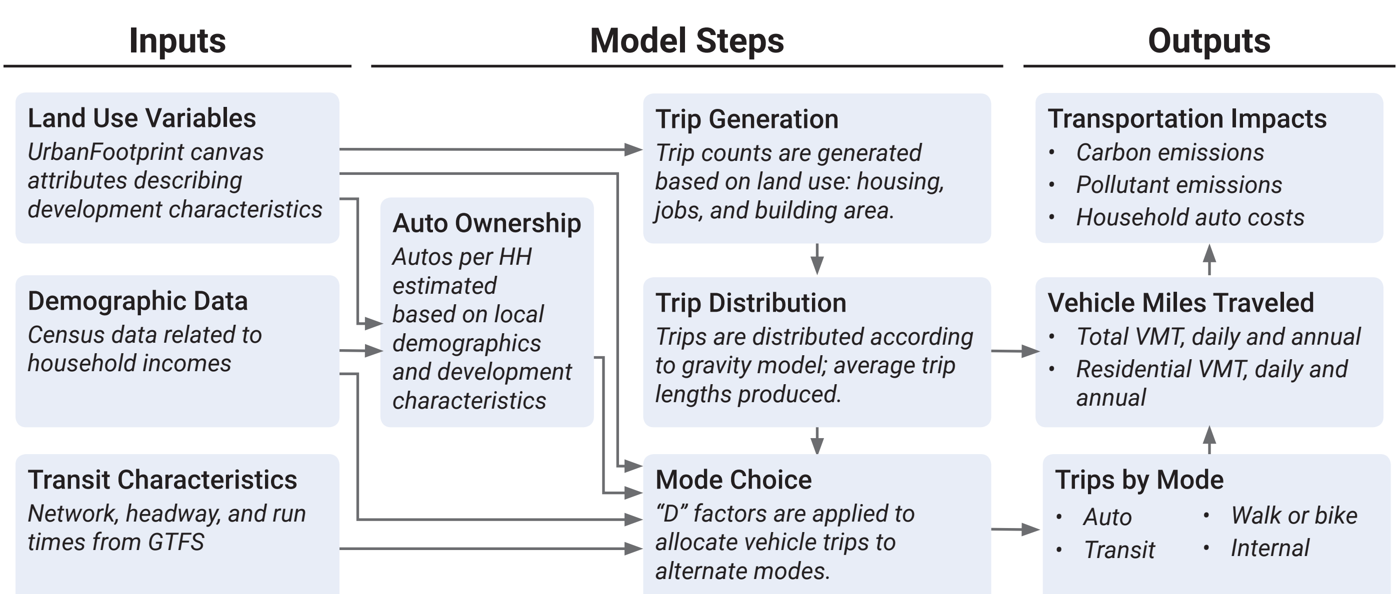
1 Referenced research includes:
- Ewing and Cervero. Travel and the Built Environment. 2010.
- Ewing and Walters, et al. Traffic Generated by Mixed-Use Developments—Six-Region Study. 2011.
- 2010 California Regional Transportation Plan Guidelines. California Transportation Commission. 2010.
- Caltrans, DKS. Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies. 2007.
- Ewing and Walters; et. al. Growing Cooler – The Evidence on Urban Development and Climate Change. 2008.
- California Air Pollution Control Officers Association. Guidelines for Quantifying the GHG Effects of Transportation Mitigation. 2010.

Figure 1. Transportation Analysis Flow



The relationships involving the first seven Ds are quantified within a segment of the core of UrbanFootprint's Transportation Module. This segment, named the Mixed-Use Trip Generation Model[2] (MXD), runs the measured attributes through a series of statistical models that are based on research[3] prepared for the United States Environmental Protection Agency and the American Society of Civil Engineers. The method for measuring effects of the "8D" travel engine, i.e., various demand management strategies, has been developed, but it has not been implemented in the current UrbanFootprint Transportation Module.

The study developed hierarchical models that capture the relationships between the identified "D" factors and the amount of travel generated by over 230 mixed-use developments in a wide variety of settings and sizes across the United States, including developments in the Sacramento and San Diego regions. The predictive accuracy of the methods was validated via traffic field surveys at almost 30 other development sites.

The use of "D" factors from the MXD model allows UrbanFootprint's Transportation Module to assess the comparative transportation impacts of scenario modifications to public transportation networks, urban land use, and contextual regional development patterns. With the MXD component of the Transportation Module, users are able to measure a range of factors, including

- The effects of transit development
- The impact of various densities and use mixes
- The impact of future employment location decisions

Model Overview

The core of the current Transportation Module, the MXD method, is based on a traditional four-step travel demand forecasting model. It has three key components[4]:

- Trip generation
- Trip distribution
- Mode choice modeling

Trip generation involves estimating the total number of trips associated with each of the different land uses in the project area with the standard ITE trip generation rates[5]. During trip distribution, these trips are allocated to likely origins or destinations. The allocation is determined via a gravity model (a description of the gravity model is provided in the Trip Distribution section overview).

Mode choice is then determined. In this step, trips are assigned a mode according to a series of observed proportional allocation rates that are determined via the "D" categories that were previously outlined. Specifically, this step involves estimating via a series of

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2 Mixed-Use Trip Generation Model. https://www.epa.gov/smartgrowth/mixed-use-trip-generation-model. Accessed 01/19/2018.

3 Ewing, Reid; Greenwald, Michael; Zhang, Ming; Walters, Jerry. Traffic Generated by Mixed-Use Developments—Six-Region Study Using Consistent Built Environmental Measures. Journal of Urban Planning and Development. Volume 137, Issue 3. September 2011.

4 The module does not currently support traffic assignment.

5 Institute of Transportation Engineers (ITE) Trip Generation Manual

statistical models the degree to which an area's external traffic generation[6] will be reduced due to:

- Walking or biking
- Transit use for off-site travel
- Trip internalization (a product of mixed use conditions, allowing a trip to remain "captured" within the site itself)[7]

This step enables estimation of the following:

- VMT per household (daily, annual)
- VMT per capita (daily, annual)
- Trips by mode

In addition, this step provides the base inputs that allow for GHG emissions and household costs. The following sections describe the default assumptions and calculations of each component.

Model Assumptions

While the typical assumptions that hold true for a traditional four-step travel demand forecasting model apply to the UrbanFootprint Transportation Module, the MXD component of the module requires some additional assumptions to be set. These assumptions are used to post-process auto trips and adjust the auto mode trip counts generated from the traditional mode choice model. Broadly, the MXD model performs the following steps:

1. It estimates vehicle trips during the trip generation step.
2. It then adjusts the number of vehicle trips to reflect the impacts of "D" variables. "D" variables are factors that contribute to the reduction of the number of vehicle trips. This is explored in more detail in the trip distribution step.

There are other assumptions underlying each step of the model, which are explained in the following sections.

Trip Generation

The trip generation step applies standard ITE manual trip generation rates and generates trips associated with land uses for the project area of each parcel or Census Block. The method categorizes each trip as one of the following:

- Home-based work (HBW) (production, attraction)
- Home-based other (HBO) (production, attraction)
- Non-home-based (NHB) (production, attraction)

For HBW and HBO trips, the method involves estimation of the number of external trips, which are trips that originate or end in areas external to the UrbanFootprint project area.

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6 External traffic in this context means vehicle trips ending or starting external to either the parcel or Census block, depending on the UrbanFootprint project canvas scale.

7 Trip internalization refers to trips that start and end in the same parcel or Census block. The default mode is walking.

Calculations

To estimate the number of vehicle trips either produced or attracted to a given parcel or Census Block, the standard ITE trip generation rates are used to generate initial vehicle trip counts. These rates differ according to the target parcel or block's household type and employment sector composition. They are discussed in more detail in the Input Parameters section (regarding the default rates used in the system).

For trips associated with residential land uses, trip generation accounts for three residential dwelling unit types:

- Single-family dwellings
- Multifamily dwellings with 2–4 units
- Multifamily dwellings with 5 or more

In the trip generation step, the number of trips produced by households is estimated by multiplying the number of occupied residential dwelling units of a given type by the corresponding stated trip generation rate. For example, the number of trips produced by households living in single-family dwelling units is given by the following equation:

$$Trips = OccupiedSingleFamilyDwellingUnits * SingleFamilyTripGenerationRate\ (trips/HH/day)$$

The logic for estimating trips associated with other land uses is similar. In the trip generation step, the number of trips associated with the following 8 non-residential land uses are calculated:

- Retail
- Restaurant
- Entertainment
- Office
- Public
- Industry
- School (K–12)
- School (College/University)

For typical employment, trips are calculated according to the following equation:

$$Trips = NumberOfJobs * TripGenerationRate\ (trips/job)$$

Trips associated with retail, entertainment, and restaurant destinations are handled differently than other trips are handled. Their numbers are calculated via the following equation (explained in detail after the equation):

$$Trips = NumberOfJobs\text{-}JobAreaConversionRate\ \left(\frac{jobs}{ksf}\right) * TripGenerationRate\ (trips/ksf)$$

For these particular trips (retail, entertainment, and restaurant), an alternate estimate of the number of jobs is used. This estimate is determined according to set job-area conversion rates that describe the average number of jobs per building area for various programming types. The default rate is two jobs for every 1,000 square feet of building area.

Total K-12 school trips are estimated as a percentage of total residential trips. The module uses a default rate of 0.097 (K–12 school trip per residential trip)[8].

Currently the number of college/university trips defaults to zero in the released version of the module in UrbanFootprint.

Trips are re-grouped into the following five categories:

- Retail (includes retail, restaurant, and entertainment)
- Office (including office and public)
- Industrial
- School (K–12 as well as higher education)
- Residential (including single-family and multifamily dwelling units)

These trips are further grouped by subcategory and direction (attraction or production). Currently the module considers three trip subcategories:

- Home-based work (HBW)
- Home-based other (HBO)
- Non-home-based (NHB)

The National Cooperative Highway Research Program (NCHRP) person trip rates[9] have been adapted for identification of the proportion of total trips that are allocated to each trip category. These proportions are used to weight the previously computed trip counts (which are based on ITE trip generation rates) into the trip categories.

For a better understanding of the application of the NCHRP person trip rates, an example focusing on residential trips is set out below.

First, assume there are N_r occupied residential dwelling units (DU) for a given parcel or block. Current default rates for the module are as follows:

- Production trips
  - 8.85 daily person trips are generated per residential dwelling unit[10]. The default distribution of production trips is as follows.
    - 21% are home-based work (HBW)
    - 56% are home-based other (HBO)
    - 23% are non-home-based (NHB)
- Attraction trips
    - No HBW attraction person trips are produced.[11]
    - 0.9 daily HBO person trips per residential dwelling unit are generated.
    - 0.5 daily NHB person trips per residential dwelling unit are generated.

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8 Default rate assessed through the Vision California project.

9 Refer to NCHRP Travel Demand Forecast - Parameters and Techniques Appendix C for more details.

10 The rate is the same regardless of dwelling unit type

11 The number of HBW production trips estimated according to occupied residential units includes both legs of the trip because both legs are 'produced' by the households. Therefore, there is no concept of 'attraction trips' associated with HBW trips estimated according to residential units.

These factors are represented in Table 1. In this table, each category represents a percentage of the total trips. The calculation in each cell illustrates the previously generated ITE residential trips.

Table 1. N_r is the number of residential dwelling units per parcel or Census Block.

Trip Type	Production Trips	Attraction Trips
Home-based work (HBW)	N_r * 8.85 * 21%	N_r * 0
Home-based other (HBO)	N_r * 8.85 * 56%	N_r * 0.9
Non-home-based (NHB)	N_r * 8.85 * 23%	N_r * 0.5

In the UrbanFootprint Transportation module, all residential NHB production trips[12] are, by default, external trips with both trip ends outside the project area. Specifically, it is assumed that:

- 0% of residential NHB production trips are internal-external trips, and
- 0% of residential NHB production trips are external-internal trips.

To accommodate this assumption, all residential production trips that are NHB are removed. Next, HBW and HBO other trips are scaled up proportionally to replace the removed NHB trip counts. In other words, residential NHB production trips and associated VMT are attributed to residents in the project area no matter if it is external or internal to the project area.

The same process is used for other non-residential trips. In each instance, proportions are calculated according to the paired NCHRP data for each trip type.

The last step of trip generation is categorizing the trips in each category as internal or external. By definition, both ends of internal trips lie within the project area. On the other hand, external trips either originate or end in areas outside of the project area.

Currently, the module only estimates external HBW trips, primarily because of the limited availability of datasets for building estimation models (to predict external percentages for HBO and NHB trips).

A percentage of HBW trips will be designated external trips, allowing for the balance of internal-internal production and attraction trips in the project area. For each project, the percentage of trips types where either the origin or the destination is external to the project site is estimated via a Decision Tree (DT). A DT is a non-parametric supervised learning method that we employ to develop a regression within the model.

The decision tree algorithm first finds similar projects, in a pool of representative project samples, as the target project. It does so by categorizing all projects based on a list of attributes, such as employment household ration, sum of dwelling units by type, and summary stats of intersection density[13]. The algorithm then predicts the external trip

12 See NHB Production trips cell in Table 1.

13 The full list of attributes used in the Decision Tree Regression model: occupancy rate, employment-household ratio, employment-population ratio, single-family dwelling unit percentage, total population, total households, total dwelling units, total dwelling units by type, total employment, total retail employment, and median of intersection densities in the project area.

percentage for the target project by taking a weighted average of external trip percentages of those similar projects.

The final output of trip generation is vehicle trip counts categorized according to whether they are internal or external, whether their purpose is HBW, HBO, or NHB, and whether they are production or attraction trips.

Trip Generation Input Parameters

Table 2 presents default trip generation rates used to estimate the number of residential and non-residential trips in each category.[14,15,16]

Table 2. Average trip generation rates by category

Dwelling Unit Type/ Employment Sector	Average Trip Generation Rate
Single Family Detached	9.57 vehicle trips per household
Single Family Attached	6.65 vehicle trips per household
Multifamily	4.18 vehicle trips per household
Retail	42.94 vehicle trips per thousand square feet
Restaurant	75 vehicle trips per thousand square feet
Entertainment	20 vehicle trips per thousand square feet
Office	3.32 vehicle trips per job
Public	3.32 vehicle trips per job
Industry	3.02 vehicle trips per job

Trip Distribution

While the trip generation step determines the number of trips that will occur in a given parcel or block, it does not specify the destination or origin of trips. The specification of trip destinations occurs during the trip distribution step.

The UrbanFootprint Transportation Module applies a gravity model to pair trip origins with destinations. This is the most common trip distribution method used in four-step travel demand forecasting models. The key assumption behind the gravity model is that people are more likely to travel to areas that feature more "attraction" and less "travel cost." There are alternative methods of generating trip aggregations for distributing trips in a travel demand forecast process, such as the growth factor method[17] and the disaggregate trip distribution method[18].

14 ITE trip generation manual. These are the initial rates to which the MXD trip reallocation process are applied.

15 ITE rate for units in multifamily buildings with two to four units used for Single Family Attached units.

16 ITE rate for units in multifamily buildings with five or more units used for Multifamily units

17 This method neglects travel costs, has a short-term planning horizon, and strongly depends on the quality of the base year data.

18 Because these alternative methods model decisions at the individual level, they require more and finer data than are currently reliably obtained at a national scale. As a result, we have opted away from using these to ensure consistent model performance across regions.

Destination “attraction” and “travel cost” can be calculated in several ways. Based on a gravity model, the following equation[19] provides an overview of the logic behind the trip distribution method as it is used in the Transportation Module.

$$T_{ij}^{p} = P_{i}^{p} * \frac{A_j^p * f(t_{ij}) * K_{ij}}{\sum_j A_j^p * f(t_{ij}) * K_{ij}}$$

Variable definitions (TAZ is an abbreviation for “traffic analysis zone”):

- T^p_{ij} is the number of trips of type p, from TAZ *i* to TAZ *j*.
- P^p_i is the number of trip origins of type p in TAZ *i*, generated during the trip generation step.
- A^p_j is the number of trip destinations of type *p* in TAZ *j*, which is generated during the trip generation step.
- $f(t_{ij})$is a function that outputs the cost of traveling between TAZ *i* and *j*; it is usually a function of travel time.
- K_{ij} represents adjustment factors for travel flow between TAZ *i* and *j*; they account for the possibility that factors not captured in the rest of the model influence destination choices.

In essence, this step allocates trips to traffic analysis zones (TAZs) according to two factors: zonal attraction strength and travel expenses. The following section provides more details about how these variables are calculated and the default parameters and equations used in the trip distribution step.

Calculations

Internal and external trips are distributed slightly differently. For internal trip distribution, all calculations are performed at the traffic analysis zones scale, which is a commonly used geography for travel demand forecasting. All evaluated blocks or parcels will be paired with their parent TAZ, and they will have descriptive attributes inherited from their parent TAZ.

During the trip generation step, the number of trip origins and destinations of smaller geometries, parcels or Census Blocks, is generated. These results are aggregated at the TAZ level. Each TAZ is paired with parcels or Census Blocks whose centroids lie within the area of the same TAZ. After these pairings, the parcel of block-level data and the associated trip counts are summed.

Next, a full distance matrix is computed. That is, the cost of travel between any two pairs of TAZs is calculated. Travel cost can be measured in various ways. It can be as simple as travel distance or as complex as a composite measure that includes various kinds of travel times (e.g., traffic data) and costs.[20]

By default, the module calculates a modified city grid distance between TAZ centroids and uses it as travel cost. City grid distance is based on the assumption that the relationship between an isosceles triangle’s hypotenuse and two other sides (adjacent and opposite) is roughly modeled by the average circuity of an “as the crow flies” direct line distance and the real path necessitated by the urban road network. Thus, to calculate the “real” distance

19 NCHRP Travel Demand Forecast - Parameters and Techniques Page 44, with slight modifications.

20 Mishra et al., Comparison between Gravity and Destination Choice Models for Trip Distribution in Maryland

between two centroids, one would multiply the straight point-to-point distance by the square root of 2 (approximately 1.4142). This value has been increased slightly because of a nationwide study of driving distance versus straight line distance to the nearest hospitals. That is, what was the distance more than the direct, straight line distance that a vehicle had to travel to reach its destination by traveling on available road networks. The study found an average percent difference (that is, a circuity factor) of 1.417.[21] This circuity factor will be available to users and adjustable for site optimization.

The output of this step is a matrix with the following composition:

- Rows represent the cost of a trip originating from a one TAZ to all others
- Columns represent the cost of a trip from each of the other TAZs to one TAZ

Costs are calculated via the (aforementioned) modified city-grid distance between an origin TAZ and a destination TAZ. Trips internal to TAZs are assigned an "average trip length." This value is calculated by measuring the radius of the smallest circle encompassing the largest single geometry of a given TAZ's composite geometries (polygons).

The travel distance matrix is then transformed into a travel impedance matrix via a deterrence function, a common method for representing the nonlinear impacts of travel cost changes on travel choices. The module uses an exponential deterrence function and a default initial β of 5. See Input Parameters for more details.

The next step is generating an initial trip matrix, assuming the K factors are equal to 1.[22] During this step, TAZ *i*, for example, is taken, which has a number of home-based work trip origins equal to P_i. P_i is allocated to all the TAZs (including itself) according to the equation:

$$\frac{A_j * f(t_{ij})}{\sum_j A_j * f(t_{ij})}$$

Note that the summation of the above for TAZ *j* should be equal to 1. In other words, more trips are allocated to TAZ *j* if it has more trip ends, indicating that it has a larger population and/or more employment (and therefore more "attraction") if it costs less to travel to, which in this case means being closer to TAZ *i*.

Depending on the scale of travel impedance values and initial deterrence function parameters, the resulting matrix may contain invalid values as a result of extremely small denominators. To account for this, the module automatically adjusts deterrence function parameters according to a simple decay function. Users can set minimum deterrence function parameters. Currently the module's minimum β value for the exponential deterrence function is 0.01.

The next step is balancing the matrix via an iterative proportional fitting (IPF) technique[23]. The initial trip matrix generated during the previous step is an unbalanced matrix because

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21 Boscoe, Francis P., Henry, Kevin A., and Zdeb, Michael S. A Nationwide Comparison of Driving Distance Versus Straight-Line Distance to Hospitals. The Professional geographer : the journal of the Association of American Geographers. 2012.

22 K factor adjustment comes into play during the calibration step and the step has not yet been implemented in the module.

23 In its current form, the Transportation Module's trip distribution step does not have an internal calibration step. Future module developments include using an average trip length table or a trip length frequency table to calibrate the trip matrix. It is a common validation/calibration practice to adjust deterrence function parameters and/or K factors so that the resulting trip length means or frequencies are equal to the observed trip length means or frequencies. Please refer to NCHRP Travel Demand Forecast - Parameters and Techniques for more details.

the sum of the allocated trips for each destination TAZ (that is, the sum of the values in each column) does not necessarily match the number of attraction trips estimated during the trip generation step.

Thus, the primary purpose of this step is to adjust trips proportionally until the resulting trip matrix matches the trip generation estimates. Therefore, at this stage the module calculates:

- The ratios of the sum of the trips allocated for destination TAZs to the estimated number of attraction trips for destination TAZs, and
- Scaled counts of trips that end in a given TAZ (using the corresponding ratio).

The consequence of this operation is that the number of trips allocated for each origin TAZ is not necessarily equal to the number of production trips estimated for each TAZ. That is, during the first pass, trip allocation does not necessarily match the pre-assessed production trip count for a given TAZ. As a result, each successive iteration scales up the production trips for each TAZ by each TAZ's corresponding ratio (that is, its ratio of allocated trips to the previously computed production trip count "source of truth"). It is this balancing operation that is "iterated" until convergence. For more information on the application of IPF to trip distribution, please refer to chapter 5 of "Modeling Transport" (Ortuzar, Juan de Dios and Willumsen, Luis G.).

In this model, the iterative balancing repeats until one of the following thresholds is met, the first two of which have parameters the user can control:

- The sum of the trip origins and destinations for each TAZ differs from the values estimated during the trip generation step (the degree to which this is allowed to be off is user-customizable by value from 0 to 1).
- A maximum of 5000 iterations has been reached (the iteration count being user-adjustable).
- The iteration step has run for longer than 5 minutes without successfully converging (that is, satisfying either threshold 1 or 2).

A simplified version of the method above is applied when assigning trips to areas that lie outside the project area. Because a 150-kilometer (user-adjustable) buffer area is used to pull a broader context area in around the project site, the number of parcels or blocks being evaluated may increase by several orders of magnitude.

The above approach to distributing external trips would require processing all geometries in the outlying context area. To reduce the computational expense, the context area is preprocessed to reduce the number of possible origins and destinations external to the project area to a limited series of representative points.

To create the context area's summary point, the module searches for likely origins and destinations according to employment and household densities in the context area[24]. Using these attributes, a kernel density estimation (KDE) algorithm smooths data to generate discrete peaks in the project's surrounding context area. Among these peaks, a limited set of external locations are identified, and all external trips starting or ending in the project area will be distributed (to or from) these locations.

24 Currently the context area is 150 km-buffered area around a given project boundary.

External trips are distributed to potential locations according to"

- The distance between two locations
  - The further a location is from the origin, the less likely a trip will be taken.
- How attractive or generative the external location is
  - Attraction is measured in terms of employment densities.
  - Generation is measured in terms of household densities.

The last step of the trip distribution component of the Transportation Module is calculating an average trip length for each trip category. Below is a walk through of this step with examples of home-based work production trips.

In this step, the weights are equal to the quotient of the number of trips from TAZ i to a given destination and the counts of the trip origins of TAZ i. The average production trip lengths from TAZ i are calculated next. These are equal to the product of the distances between each TAZ i and the other TAZs, and the corresponding weights, as shown in the following equation:

$$AverageTripLength_i^{hbw,\,production} = \sum_j Distance_{ij} * \frac{N_{ij}^{hbw,\,production}}{P_i^{hbw,\,production}}$$

Variable definitions:

- $AverageTripLength_i^{hbw,\ production}$ represents the average home-based work production trip length for location *i*.
- $Distance_{ij}$ is the distance between locations *i* and *j* (the centroid-to-centroid city-block distance by default).
- N_{ij}^{hbw} is the number of home-based work trips from location *i* to *j*.
- P_i^{hbw} *is* the number of home-based work trip origins produced by location *i*
  - Note that this count value comes from the trip generation step.

Trip Distribution Input Parameters

Table 3 presents the deterrence functions available to users. Users can also adjust the coefficient parameters used in each deterrence function available.

Table 3. Forms of Deterrence Functions

Deterrence Functions	Forms	Parameters	Default Values
exponential function	$f(c_{ij}) = exp(-\beta * c_{ij})$	β	5
power function	$f(c_{ij}) = c_{ij}^{-n}$	n	-
combined function	$f(c_{ij}) = c_{ij}^{n} * exp(-\beta * c_{ij})$	β, n	-
gamma function	$f(c_{ij}) = a * t_{ij}^{b} * exp(-\beta * c_{ij})$	a, b, β	-

c_{ij} is the raw cost of traveling between origin *i* and destination *j*. What it represents can be as simple as travel distance or as complex as a generalized cost that includes various other factors.

Mode Choice Modeling

The core of the MXD method is a series of logistic regression models, which are used to estimate the degree to which the traffic generation of a given development area will be reduced because of a variety of contextual factors, including:

- Development density
- Diversity
- Design
- Destination accessibility
- Distance to transit
- Demographics
- Development scale

These attributes (known as "D" factors) are all associated with the likelihood of walking, transit, or internalized trips associated with each parcel or Census Block.

This method enables the model to be sensitive to differences amongst a broad array of land use Place Types, which are one of the core building blocks of UrbanFootprint future scenarios. This sensitivity is achieved via calculation of the vehicle trip reductions resulting from the combination of "D" variables that characterize each Place Type.

"D" characteristics are combined with Place Type data to account for not only the "D" characteristics of the evaluated block or parcel itself, but also all the target blocks or parcels in the context area of the evaluated block or parcel's containing block or parcel. This contextual accounting for "D" factors facilitates computation when the place generates more or less than the regional average of vehicle travel.

Mode Choice Calculations

A logistic regression model predicts the probability of an event according to the variable attributes assigned to each geometry (block or parcel) in the broader area. In this context, the model is used to determine whether a trip is a vehicle trip or a walk, transit, or internal trip. This determination is based on a series of variables and the following equation:

$$P(walk/transit/internal) = \frac{1}{1 + exp(-t)}$$

The variable t is a linear function of one or more variables and is referred to as "log-odds"[25] and is described by the following equation:

$$Log - Odds\ of\ (Internal\ Capture,\ Walk,\ Transit) = Constant + \sum [Ln(VAR) * Coeff]$$

The operator *Ln* indicates the natural logarithm of each built environment "D" variable (*VAR* in the equation above). The result of this operation is multiplied by a variable-specific coefficient (*Coeff* in the equation above).

25 Log-odds is named as such because it is the sum of the logarithms of attribute values.

The results of the calculation for each variable VAR are summed and added to the variable Constant, which produces the logarithmic odds of travel being an internalized, pedestrian, or transit trip. The variables of the MXD equations are listed below.

Table 4. Explanatory and outcome variables in MXD equations

Variable	Explanation
Outcome Variables	
Internal	Trip remains within the parcel or Census Block (1=internal,
Walk	Travel mode of an external trip is walking (1=walk mode,
Transit	Travel mode of an external trip is bus or rail (1=transit, 0=other)
Explanatory Variables	
AREA	Gross land area within the parcel or Census Block
EMP	Employment within the parcel or Census Block
ACTDEN	Resident population plus employment per square mile of gross land over a quarter-mile buffer of the parcel or Census Block
JOBPOP	Average jobs/housing balance (index comparing the local ratio to the "ideal" regional average) over a quarter-mile buffer of the parcel or Census Block
INTDEN	Number of intersections per square mile of gross land within or within 400 meters of the parcel or the Census Block
EMPMILE	Total employment within 1 mile of the parcel or the Census
EMP30T	Total employment within a 30-minute transit trip from the parcel or the Census Block

The table above contains two sections, "Outcome Variables" and "Explanatory Variables." The second section, "Explanatory Variables," is often associated with the "D" variables that affect trip generation. These include development density, diversity, design, destination accessibility, distance from transit, development scale, and demographics. The output of the hierarchical modeling involved in the MXD model's research and development included the individual and combined effects of the seven types of "D" variables on the travel characteristics of 239 targeted mixed-use development areas. Via this research, the variables above were determined significant.

UrbanFootprint dynamically calculates these explanatory variables at the appropriate resolution using the current scenario's canvas data. In other words, these variables reflect different land use patterns and other built environment characteristics of each scenario that a user creates. To ensure that explanatory variables reflect "average" characteristics of a given parcel or Census Block and its surrounding, various sizes of buffers are applied to derive representative measures of each location. For example, a quarter-mile buffer is used to derive resident population and employment density that is representative of local activity level of a given parcel or Census Block.

However, such calculation can be computationally intensive, depending on its implementation, especially for large projects that contain hundreds of thousands of canvas shapes. To ensure that the Transportation Module can finish within a reasonable amount of time even for large parcel projects, data at parcels or Census Blocks are aggregated to standard grids. With that, efficient algorithms can be applied, which allows quick generation of explanatory variables for all canvas shapes in a project.

For internal capture, the dependent variable is the natural log of the odds of an individual making a trip whose origin and destination lie within the same parcel or Census Block. Depending on the trip-purpose, this probability is related to the development scale, a variety of mixed-use land variables, the measured urban design quality of the MXD, and several demographic variables. The log-odds probability of walking to external destinations is related to the MXD's size, density, development mix, urban design, demographics, and the number of jobs within a mile. The probability of a vehicle trip being shifted to a transit trips is a function of demographics and the accessibility of the site's transit to the rest of the region. This accessibility is expressed in terms of jobs within a 30-minute transit trip. The tables in the "Input Parameters" section present the values of parameters used in the log-odds equation.

Mode Choice Input Parameters

The following tables present the relationships used in the following equation:

$$Log - Odds\ of\ (Internal\ Capture,\ Walk,\ Transit)\ =\ Constant\ +\ \sum\left[Ln(VAR) * Coeff\right]$$

The constant term, variables (*VAR*), and coefficients (*Coeff*) are presented in Tables 5–7.

Table 5. Log-odds of internal capture (log-log form)

Variable	HBW			HBO			NHB		
	Coeff	t-stats	p-value	Coeff	t-stats	p-value	Coeff	t-stats	p-value
Constant	-1.75			-2.43			-5.32		
EMP	-	-	-	-	-	-	0.208	3.28	0.002
AREA	-	-	-	0.486	3.61	0.001	0.468	4.58	<0.001
JOBPOP	0.389	2.62	0.01	0.399	4.55	<0.001	-	-	-
INTDEN	-	-	-	0.385	1.92	0.055	0.638	4.95	<0.001
HHSIZE	-1.33	-6.03	<0.001	-0.867	-13.0	<0.001	-0.237	-4.54	<0.001
VEHCAP	-0.990	-4.15	<0.001	-0.59	-8.19	<0.001	-0.163	-3.0	0.003

Table 6. Log-odds of walking trips (log-log form)

Variable	HBW			HBO			NHB		
	Coeff	t-stats	p-value	Coeff	t-stats	p-value	Coeff	t-stats	p-value
Constant	-5.55			-10.96			-15.09		
AREA	-	-	-	-0.415	-4.27	<0.001	-	-	-
ACTDEN	-	-	-	0.37	2.74	0.007	0.377	3.12	0.003
JOBPOP	0.226	2.46	0.015	0.219	3.83	<0.001	-	-	-
INTDEN	-	-	-	-	-	-	0.803	5.05	<0.001
EMPMILE	0.385	3.12	0.002	0.45	5.05	<0.001	0.44	5.09	<0.001
HHSIZE	-1.57	-6.29	<0.001	-0.486	-5.05	<0.001	-0.281	-2.59	0.01
VEHCAP	-1.84	-7.00	<0.001	-0.768	-7.62	<0.001	-0.242	-2.13	0.033

Table 7. Log-odds of transit trips (log-log form)

Variable	HBW			HBO			NHB		
	Coeff	t-stats	p-value	Coeff	t-stats	p-value	Coeff	t-stats	p-value
Constant	-8.05			-6.08			-2.69		
ACTDEN	-	-	-	0.324	2.89	0.005	-	-	-
INTDEN	1.12	4.44	<0.001	-	-	-	-	-	-
EMP30T	0.209	2.98	0.004	-	-	-	0.134	3.29	0.002
HHSIZE	-1.14	-6.31	<0.001	-0.958	-8.48	<0.001	-	-	-
VEHCAP	-1.68	-8.56	<0.001	-1.09	-8.91	<0.001	-0.34	-3.74	<0.001

The logistic regression model, shown below, transforms log-odds (t) into probabilities. This transformation is represented by the following equation:

$$P(walk/transit/internal) = \frac{1}{1 + exp(-t)}$$

For each trip category of all internal trips (i.e. trips with both trip ends inside the project area), the probability of each trip being internal captured, or a walking or transit trip is calculated. The probability is then used to calculate the number of non-vehicle trips (internal capture, transit, and walk) in each of the three trip categories (HBW, HBO, and NHB).

For example, let's say that the probabilities of internal capture, walking, and transit trips for internal HBW trips in a parcel or Census Block are 5%, 10%, and 15% respectively. Given that the total number of internal HBW trips is 10000, the probabilities would result in the following trip distribution:

- 500 internal capture trips, or 5% of all internal HBW trips
- 1,000 walking trips, or 10% of all internal HBW trips excluding internal capture trips
- 1,500 transit trips, or 15% of all internal HBW trips excluding internal capture trips

If the examined trips are external trips, we only consider the probability of it being transit trip, not walk or internal capture trip.

VMT is then calculated according to adjusted vehicle trip counts and the corresponding estimated trip lengths. Vehicle trips are first categorized as production or attraction trips according to the production and attraction trip ratio derived in the trip generation step. Take internal HBW production trip as an example. It is calculated via the following equation:

$$Internal\ HBW\ production\ vehicle\ trips\ =\ Number\ of\ internal\ HBW\ vehicle\ trips\ *\ (ITE\ production\ trips\ /\ total\ ITE\ trips)$$

After the number of trips and the corresponding trip length have been computed, the module can calculate VMT.

The module produces a set of MXD vehicle trip variables and a set of VMT variables as the main spatial outputs. The remainder of this section of the documentation will cover how different VMT variables are derived. It will also cover how the results of these operations are summarized for project-wide outputs. These summary operations are applied both to the processed VMT outputs and MXD vehicle trip outputs in a similar fashion.

The module produces both total VMT and VMT per capita (or per household). For the estimation of VMT per capita or per household (at both the parcel and Census Block level), only HBW and HBO production trips are considered because they are trips produced by individuals or households in that given parcel or Census Block. The VMT associated with trips that are attributed to a retail shop in this geometry or a visitor to the area, for example, is not part of this measure.

Let's take HBW vehicle trips as an example. HBW VMT per household at the parcel or Census Block level is calculated in two steps. First, the HBW VMT is calculated via the following equation:

$$VMT_{HBW}\ = Number\ of\ HBW\ production\ vehicle\ trips\ *\ HBW\ production\ trip\ length$$

Note that HBW attraction vehicle trips are not included in the equation above because they are not taken by households or individuals living in the given parcel or Census Block.

Second, VMT per household (or capita) is determined via the following equation:

$$VMT_{HBW}\ per\ Household = VMT_{HBW}\ /\ NumberOfHouseholds\ (NumberOfPop)$$

The same logic applies to calculating the per capita and per household VMT associated with HBO vehicle trips. Since residential NHB trips are assumed to be zero in the trip generation step, there is no NHB VMT associated with households[26]. As a result, VMT per household is the sum of HBW VMT per household and HBO VMT per household only:

$$VMT\ per\ Household = VMT_{HBW}\ per\ Household + VMT_{HBO}\ per\ Household$$

When it comes to total VMT at the parcel or Census Block level, the calculation is slightly different. Total VMT for a given parcel or Census Block includes the VMT associated with not only trips generated from the geometry but also trips attracted to the area.

Again, let us take HBW vehicle trips as an example. To get the total daily VMT associated with internal HBW vehicle trips for a given parcel or Census Block, the following equation is used:

$$\begin{aligned} VMT_{HBW,\ internal} &= (Number\ of\ internal\ HBW\ production\ trips * internal\ HBW\ production\ trip\ length) \\ &+ (Number\ of\ internal\ HBW\ attraction\ trips * internal\ HBW\ attraction\ trip\ length) \end{aligned}$$

VMT associated with HBO and NHB, internal or external, are derived using the same functions. Last, total daily VMT, for each parcel or Census Block, includes VMT of all trip types:

$$\begin{aligned} Total\ Daily\ VMT &= VMT_{HBW,\ internal} + VMT_{HBW,\ external} + VMT_{HBO,\ internal} + VMT_{HBO,\ external} \\ &+ VMT_{NHB,\ internal} + VMT_{NHB,\ external} \end{aligned}$$

Total annual VMT is derived by applying an annual factor and users can modify this factor:

$$Total\ Annual\ VMT = Total\ Daily\ VMT * AnnualFactor$$

The module also estimates total daily and annual VMT for the entire project area. Note that it is not the sum of previously derived total daily/annual VMT for each parcel or Census Block because some trips will be double counted in the process of simply summing all parcels' or Census Blocks' total daily/annual VMT.

The reason for this double counting is that half of internal HBW or HBO production trips (per parcel or Census Block) are trips from home to work/other destinations. As a result, these trips are considered internal HBW or HBO attraction trips in another geometry and will be counted as part of total VMT for that geometry as well. Similarly, one parcel or Census Block's internal NHB production trip can be another parcel or Census Block's internal NHB attraction trip. Essentially, variables at each parcel or Census Block capture attributes of trip ends whereas project-level variables capture attributes of trips.

The following equation is used to handle the aforementioned double counting issue:

$$\begin{aligned} AdjustedTotalDailyVMT = Total\ Daily\ VMT & \\ - VMT_{HBW,\ prod,\ internal}\ /\ 2 & \\ - VMT_{HBO,\ prod,\ internal}\ /\ 2 & \\ - VMT_{NHB,\ prod,\ internal}\ /\ 2 & \\ - VMT_{NHB,\ prod,\ internal}\ /\ 2 & \end{aligned}$$

26 Please see "Calculations" subsection of Trip Generation section for more details.

The sum of *AdjustedTotalDailyVMT* of all parcels or census blocks is used as the project-level total daily VMT.

Note that double counting is not an issue in the external VMT calculation because the origins/destinations of external trips are outside the project area. In addition, external HBW attraction trips and associated VMT are not typically included in total VMT because they are produced by residents living outside the project area.

The module also estimates the VMT of heavy trucks by applying a truck adjustment factor. Users can modify this factor.

Output Metrics

The Transportation module generates two mapped spatial output layers and corresponding data tables; all can be used within UrbanFootprint for mapping and data exploration, and exported. The spatial layers summarize trip counts for each mode and type, and daily and annual VMT in total, per capita, and per household.

The module also reports individual and comparative scenario results via summary charts, and generates a spreadsheet summary in Excel format. The attributes of the spatial output/data tables are summarized in Table 8.

Table 8: Transportation Module Outputs: Vehicle Miles Traveled

Vehicle Miles Traveled Outputs

Attribute(s)	Description
Population, Dwelling Units, Households, Employment	Demographic variables as depicted in base or scenario canvas.
Autos per Household	Number of autos per household, as estimated by the model.
VMT Annual	Vehicle miles traveled (VMT) annually in a parcel or Census Block, including all passenger vehicle VMT attributed to residents, workers, and visitors in the given area. The relationship between daily and annual VMT is dependent on the “annualization factor” parameter (a default value is 350).
VMT Annual with Heavy Trucks	VMT Annual with the addition of VMT by heavy trucks in a parcel or Census Block. VMT by heavy trucks can be estimated optionally as a factor relative to passenger VMT.
Residential VMT Annual	Annual passenger vehicle VMT attributed to residents in a parcel or Census Block. Residential VMT is lower than total VMT, and will be zero in parcels or census blocks without households.
Residential VMT Annual per Household	Average annual residential VMT per household in a parcel or census block.
Residential VMT Annual per Capita	Average annual residential VMT per capita in a parcel or census block.
VMT Daily	Vehicle miles traveled (VMT) daily in a parcel or Census Block, including all passenger vehicle VMT attributed to residents, workers, and visitors in the given area.
VMT Daily with Heavy Trucks	VMT Daily with the addition of VMT by heavy trucks in a parcel or Census Block. VMT by heavy trucks can be estimated optionally as a factor relative to passenger VMT.

Vehicle Miles Traveled Outputs

Attribute(s)	Description
Residential VMT Daily	Daily passenger vehicle VMT attributed to residents in a parcel or Census Block. Residential VMT is lower than total VMT, and will be zero in parcels or census blocks without households.
Residential VMT Daily per Household	Average daily residential VMT per household in a parcel or census block.
Residential VMT Daily per Capita	Average daily residential VMT per capita in a parcel or census block.
Summary Chart Outputs	
Annual total VMT	Total annual vehicle miles traveled in the project area
Average Annual VMT per Capita	Average annual per capita home-based passenger vehicle miles traveled in the project area
Average Annual VMT per Household	Average annual home-based passenger vehicle miles per household traveled in the project area
Average Annual VMT per Capita by Land Development Category	Average annual home-based passenger vehicle miles per capita traveled in urban, compact, standard, and rural areas, in the project area
Average Annual VMT per Household by Land Development Category	Average annual home-based passenger vehicle miles per household traveled in urban, compact, standard, and rural areas, in the project area

Table 9: Transportation Module Outputs: Vehicle Trip Counts by Type

Vehicle Trip Counts by Type Outputs

Attribute(s)	Description
Population, Dwelling Units, Households, Employment	Demographic variables as depicted in base or scenario canvas.
Autos per Household	Number of autos per household, as estimated by the model.
Internal Trips Daily	Daily "internal" trips that take place within a local mixed-use area and attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
Walk (or Bike) Trips Daily	Daily walk, bike or other active trips shifted away from autos, and attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
Transit Trips Daily	Daily transit trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
MXD Vehicle Trips Daily	Daily vehicle trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
MXD Vehicle Trips Daily per Capita	Daily vehicle trips per capita attributed by the MXD model to residents in the given parcel or census block.
MXD Vehicle Trips Daily per Household	Daily vehicle trips per household attributed by the MXD model to residents in the given parcel or census block.
MXD Home-based Work Trips	Daily home-based work vehicle trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
MXD Home-based Other Trips	Daily home-based other vehicle trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
MXD Non-home-based Trips	Daily non-home-based work vehicle trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.

Vehicle Trip Counts by Type Outputs

Attribute(s)	Description
ITE Vehicle Trips Daily	Daily vehicle trips attributable to residents, workers, and visitors in the given parcel or census block, as estimated by ITE vehicle trip generation rates.
ITE Home-based Work Vehicle Trips Daily	Daily home-based work trips attributable to residents, workers, and visitors in the given parcel or census block, as estimated by ITE vehicle trip generation rates.
ITE Home-based Other Vehicle Trips	Daily home-based other trips attributable to residents, workers, and visitors in the given parcel or census block, as estimated by ITE vehicle trip generation rates.
ITE Non-home-based Vehicle Trips	Daily non-home-based trips attributable to residents, workers, and visitors in the given parcel or census block, as estimated by ITE vehicle trip generation rates.
Walk (or Bike) Mode Share	Walk or bike mode share of all trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block. Walk or bike share includes all internal trips.
Transit Mode Share	Transit mode share of all trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
Auto Mode Share	Auto mode share of all trips attributed by the MXD model to residents, workers, and visitors in the given parcel or census block.
Percent Vehicle Trips Reduction	Percentage reduction of vehicle trips via the MXD model as compared to estimates based on ITE trip generation rates. This variable considers all trips attributed to residents, workers, and visitors in the given parcel or census block. Higher values indicate greater reductions in auto travel due to the effects of mixed-use development.
Summary Chart Outputs	
Walk or Bike Mode Share	Travel mode share by walk or bike in the project area
Transit Mode Share	Travel mode share by transit in the project area
Auto Mode Share	Travel mode share by driving in the project area
MXD Total Vehicle Trips	Number of daily and annual vehicle trips in the project area, estimated by the MXD model
ITE Total Vehicle Trips	Number of daily and annual vehicle trips in the project area based on ITE vehicle trip generation rates
MXD Total Vehicle Trips per Capita	Average number of daily and annual per capita vehicle trips in the project area, estimated by the MXD model
MXD Total Vehicle Trips per Household	Average number of daily and annual vehicle trips per household in the project area, estimated by the MXD model

Summary of Updates since Version 2.3.9

Since the last version, major changes to UrbanFootprint's Transportation Anywhere Module include:

- Improved accounting of Mixed-Use Trip Generation Model (MXD) vehicle trips and vehicle miles traveled (VMT) variables for each parcel or Census Block.
  - Daily (annual) MXD vehicle trips include all trips attributed to residents, workers, and visitors in the parcel or Census Block and MXD vehicle trips per capita and per household only include trips attributed to residents;
  - Daily (annual) VMT include all VMT attributed to residents, workers, and visitors in the parcel or Census Block and VMT per capita and per household only include VMT attributed to residents.
- Improved accounting of MXD vehicle trips and VMT variables for the project area.
  - Both variables capture unique trips and associated VMT for the entire project area.
- Improved handling of external residential Non-home-based (NHB) trips.
  - Residential NHB trips and associated VMT that occur outside the project area are accounted for in module outputs.