How-to: Improve Non-Home-Based Trips

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Better Methods. Better Outcomes.

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16. Abstract

This How-to guide presents new incremental improvements to trip-based models to enhance the representation of non-home-based trips. These techniques are designed to be inexpensive enhancements to existing trip-based models that can be implemented quickly in a straightforward manner as part of a model update without requiring the development of a whole new model. There are many problems related to non-home-based trips in traditional trip-based models arising from the fact that they are disconnected from the home-based trips with which they comprise complete tours. The fundamental approach presented in this guide addresses these problems with a simple change to the structure of trip-based models, running non-home-based model components after and conditional on the home-based model components instead of in parallel and independently of them. This relatively simple structural change appears to significantly improve the trip-based model's ability to represent non-home-based trips and their response to land use changes and transportation infrastructure investments.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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April 2018

Federal Highway Administration

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List of Abbreviations

CBD	Central Business District
DR	Drive Alone
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HB	Home-Based
HBC	Home Based College
HBNW	Home Based Non-work
HBO	Home Based Other
HBW	Home Based Work
HH	Household
MPO	Metropolitan Planning Organization
NHB	Non-Home-Based
NHBNW	Non-Home-Based-Non-Work
NHBW	Non-Home-Based-Work
NHTS	National Household Travel Survey
NM	Non-Motorized
NTD	National Transit Database
OD	Origin and Destination
PA	Production and Attraction
SB	School Bus
SOV	Single Occupancy Vehicle
TAZ	Traffic Analysis Zone
TMIP	Travel Model Improvement Program
TR	Transit
WFRC	Wasatch Front Regional Council

Special Note

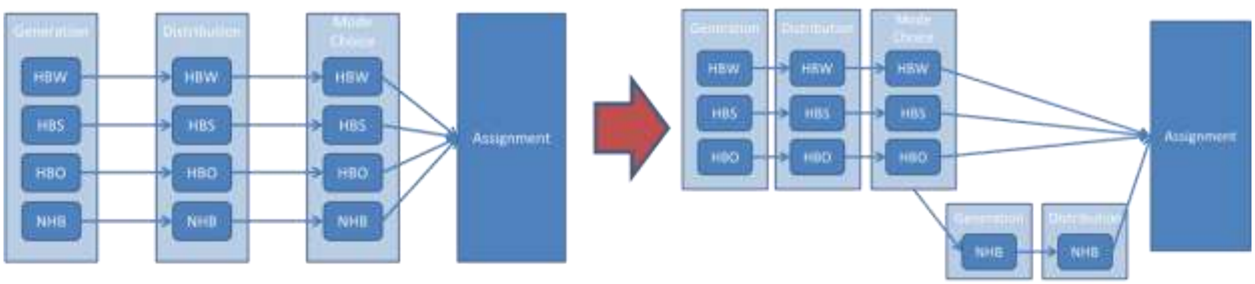
The views and opinions expressed in this paper belong to the authors and do not constitute nor should they be construed as an endorsement, recommendation, or official guidance by FHWA. Although initial testing appears to bear out the hypotheses of this report for the test pilot region, this only provides an initial indication of their validity and these results may not be generalizable to all regions.

1.0 Executive Summary

TMIP presents in this How-To guide new incremental improvements to trip-based models to enhance the representation of non-home-based trips. The techniques presented here are designed to be inexpensive enhancements to existing trip-based models that can be implemented quickly in a straightforward manner as part of a model update without requiring the development of a whole new model. In fact, three methods, each successively more complex, are presented to offer agencies a range of options to suit their particular needs, available time and scripting skill.

The How-to guide begins with a review of the problematic issues related to non-home-based trips in trip-based models which motivate the enhanced methods presented here. Next, an overview of each of these methods is presented. Finally, the guide demonstrates the enhanced methods as they were implemented using the model of the Wasatch Front Regional Council (WFRC), the MPO for Salt Lake City, UT, and surrounding areas and presents the results of testing that indicates that at least for this pilot case, the enhanced methods performed as well or better as traditional methods.

There are many problems related to non-home-based trips in traditional trip-based models arising from the fact that they are disconnected from the home-based trips with which they comprise complete tours. The fundamental approach presented in this guide addresses these problems with a simple change to the structure of trip-based models, running non-home-based model components after and conditional on the home-based model components instead of in parallel and independently of them.



Source: FHWA

Figure 1. Simple change in model structure.

Tests using the Salt Lake City pilot case reveal that this relatively simple structural change is able to address several key problems with non-home-based trips. The enhanced methods are better able to replicate observed NHB trip rates, mode shares and OD patterns with less calibration. They make clearer, more intuitive and reasonable connections between NHB and HB modes, and the new methods produce much more reasonable responses to hypothetical new residential growth and more plausible mode shifts in response to hypothetical enhanced transit service.

Further empirical studies in other metropolitan areas and with actual before and after data would be desirable and necessary for drawing an ultimate conclusion on the superiority of the proposed methods over traditional ones. However, this study provides good preliminary evidence for the conclusion that these enhanced methods may be more accurate and realistic than traditional ones. Moreover, given the very low marginal effort to implement the enhanced methods, it may be reasonable to consider them even if some uncertainty remains about their superiority.

While some adjustments or adaptation may be required for models with different trip purposes or modes, by following the details of the proof of concept implementation for Salt Lake City, this guide is intended to function as a How-to reference and allow others interested in the enhanced methods to implement them in their own trip-based model.

Several other states and MPOs have now implemented the methods presented here or are in the process of doing so. Other MPOs now using the method include those for Anchorage, Alaska; Anderson, Indiana; Fredericksburg, Harrisonburg and Charlottesville, Virginia; and Charleston, South Carolina. Three DOTs have also used the methods in their statewide models including Iowa, Tennessee, and Michigan.

2.0 Introduction

In this installment of its How To series as part of its Travel Analysis Toolbox, TMIP presents new incremental improvements to trip-based models to improve their handling of non-home-based trips. The techniques presented here are designed to be inexpensive enhancements to existing trip-based models that can be implemented quickly in a straightforward manner as part of a model update without requiring the development of a whole new model. In fact, three methods, each successively more complex, are presented to offer agencies a range of options to suit their particular needs, available time and scripting skill. To validate and demonstrate the ability of these techniques to improve trip-based models' representation of non-home-based trips, each of the three methods was tested and compared using the model of the Wasatch Front Regional Council (WFRC), the MPO for Salt Lake City, UT, and surrounding areas. Even though this initial testing largely bears out the hypothesized advantages of these methods for the WFRC region, it only provides an initial indication of the validity of these methods and results may not be generalizable to all regions.

While activity-based models offer one existing alternative to trip-based models with improved handling of non-home-based trips, for a variety of reasons from costs to staff skills, many agencies are unable or uninterested in replacing their trip-based models with activity-based models. The methods presented in this manual are meant to offer agencies another option for addressing issues related to non-home-based trips in traditional models. It is important to acknowledge, on the one hand, that activity-based models offer a number of advantages over traditional models, beyond just improved handling of non-home-based trips which may be important for an agency to consider. On the other hand, as TRB Special Report 288 states, "there is no single approach to travel forecasting or set of procedures that is 'correct' for all applications or all MPOs." It is in light of precisely this latter point that TMIP offers the following methods as additional options which may be helpful for some MPOs.

The methods presented in this report are intended to address fundamental problems with the accuracy and response properties of non-home-based trips in trip-based models. These problems can be understood in a variety of ways – and can vary in their details depending on the details of a four step models' implementation (e.g., balancing options) – but ultimately are related to the inconsistency of the four-step model with tours and the fundamental fact that in order to properly represent non-home-based trips, two spatial distribution models are required to account for both the trip's origin and destination (whereas the four-step model architecture produces non-home-based trips from only one trip distribution model). The fundamental approach to addressing these issues in the methods presented here is to adopt an alternative trip-based model architecture in which non-home-based distribution is run in series rather than in parallel with home-based distribution models. On the basis of the tests performed as part of this study, it is hypothesized that this relatively simple structural change can improve trip-based models' ability to represent non-home-based trips and their response to land use changes and transportation infrastructure investments.

3.0 Non-Home-Based Trips in Traditional Four Step Models

When four-step models were originally developed in the 1950's and 1960's, non-home-based (NHB) trips accounted for less than 20% of household trips. Perhaps for that reason in combination with the limited computing resources of the period they were treated simplistically and given limited attention; in any event, the process for home-based (HB) trips was simply re-applied to them. However, this treatment of NHB trips has resulted in a number of widely acknowledged problems, and the significance of these problems has only increased as NHB trips have made up an ever-increasing portion of household trips (McGucken et al., 2005). According to the NHTS, by 1990 they accounted for one out of four trips and by 2009, they accounted for nearly a third of all household trips.

The various difficulties with NHB trips in traditional models stem from the fact that, by definition, they are disconnected from the households that make them, and therefore, from the other (HB) trips made by the household. This disconnection plays out across all dimensions of travel – space, mode and time – and results in a representation of NHB trips as a sort of background noise in the model, adjusted in order to bring the total amount of travel up to the proper amount, but generally unresponsive to anything but commercial development patterns and in some cases the total number of households in the region. The following sections briefly review the key problems with NHB trips in traditional models focusing on each of the dimensions of travel.

3.1 NHB Trips are spatially disconnected from HB trips

Perhaps the most problematic aspect of NHB trips in traditional models is that they are spatially disconnected from HB trips such that there is no guarantee, and indeed there should be no general expectation, that the total trip table corresponds to an underlying pattern of closed tours. Real travelers must, of course, move in continuous paths through space and time that create closed tours to the extent that people tend to return home to sleep in the same place at night. Unfortunately, the way NHB trips are represented in traditional models implies that travelers appear and disappear, making trips between locations they never traveled to in the first place.

To clarify the problem, it is helpful to consider the trips made by residents of a single zone, or as an example, the trips generated by a new residential subdivision in a previously undeveloped zone. In our simple example, the new HB trips generated by the new development will be distributed to locations in proximity to the home zone. New NHB trips will be produced by the new households, but they will be distributed all over the model's study area in proportion to commercial development, independent of the location of the new residential development. In the illustration below, which shows a bi-state area, the vast majority of the new HB trip ends are in the state to the south where the new residential development occurs. In contrast, the vast majority of the new NHB trips occur in the state to the north, despite the fact that based on the HB trips, the new residents hardly ever go there.

Source: FHWA

Figure 2. Home-based trips.

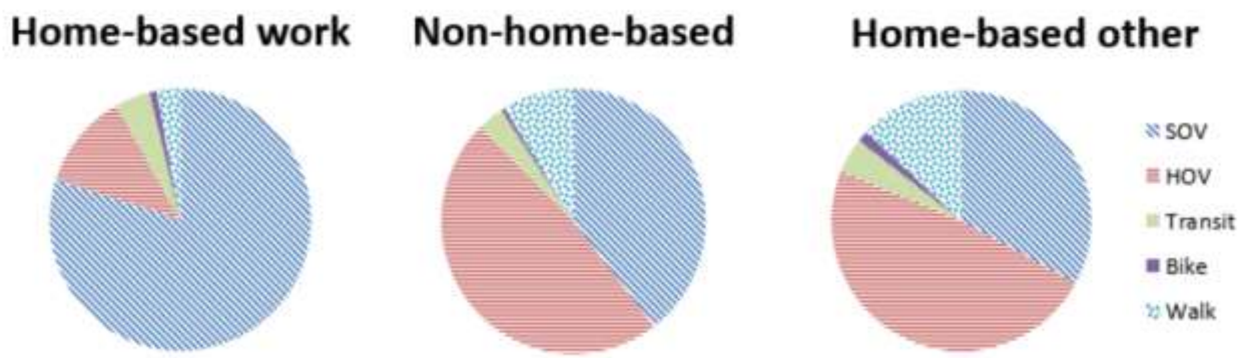
Source: FHWA

Figure 3. Non-home-based trips.

While an argument could be made in this case that the new residents would be more likely to make complex tours when they do cross the river to the north, the pattern above would imply extremely complex tours when they go north with many stops per tour, as opposed to almost no trip chaining ever when they remain in their own state. This imbalance is not plausible. Moreover, it is possible to produce much more extreme examples. Consider, for instance, what happens in a typical statewide model (in which total NHB productions are scaled by households but distributed independently of what households produced them as is typically the case); a new residential development in one city creates NHB trips in other distant cities, independent of and out of any proportion to the probability that the new residents travel to these cities.

3.2 NHB Trips are not generally consistent with HB trip modes

In traditional models, mode choice for NHB trips is also independent of mode choice for HB trips leading to inevitable inconsistencies in mode shares and more importantly, mode shifts. Despite occasional exceptions related to car sharing, company cars, etc., it is generally necessary for a NHB trip to be associated with HB auto trips from the same household in order for it to be SOV. Similarly, it is less likely for a NHB trip to be by transit if it is not associated with at least one HB transit trip. None of the foregoing factors are reflected in traditional four-step models with the result that NHB mode shares are poorly predicted.



Source: National Household Travel Survey 2009

Figure 4. Mode shares by trip purpose from NHTS 2009.

Because NHB trips are not attached to HB trips in any way, they become an indistinct blend of very distinct work and non-work mode shares. (See Figure 4)

3.3 NHB Trips are not generally consistent with HB trip times

Traditional models struggle to represent the dimension of time in a variety of ways, and to a large extent, the temporal dimension will be considered beyond the scope of this manual. However, it is important to observe that NHB trips timing are not, in general, independent of HB trips timing, although this is the way things are treated in traditional trip-based models. For instance, a large portion of NHB trips are made as part of the morning and evening work commute and should shift with HB work trips.

4.0 The Need for Alternatives to Activity-based Models

Activity-based models attempt to address the foregoing problems with NHB trips by modeling NHB trips as parts of tours. However, there are a variety of reasons why some agencies may find value in alternative solutions to these issues. Some agencies can only afford a model enhancement, not a whole new model. Some agency staff may not feel comfortable or confident maintaining and using ABMs. Some agencies may not have any of the other needs that motivate ABMs (non-motorized travel, in depth equity analysis, time of travel questions, built environment effects, etc.). For agencies with some combination of these reasons, it is important to provide alternative methods for addressing the problems with NHB trips that do not require the development and adoption of an entirely new activity-based model framework.

5.0 Techniques for Improving Non-Home-Based Trips in Trip-based Models

This manual presents a series of methods, of increasing complexity, for improving the consistency of NHB trips with HB trips in trip-based models. These methods are intended to be inexpensive enhancements to existing trip-based models that can be implemented quickly in a straightforward manner as part of a model update without requiring the development of a whole new model. Agencies should evaluate the incremental benefits of each method relative to the incremental complexity and run time it introduces to the model and determine the method that is best suited to their particular needs, available time and scripting skill. The goal of this manual is not to present a one-size-fits-all solution, but rather an array of options to provide agencies flexibility and greater choice in their model design.

Three methods are presented in detail in the following subsections. Each method builds on and assumes the implementation of the prior method(s), and each represents a successively more realistic representation of the connection between HB and NHB trips.

All of the following methods derive from a basic insight into the inadequacy of the four-step model's approach to NHB trips.[1] In the four-step model, trips are developed through the first two steps of generation and distribution. Behaviorally, these steps represent a traveler's choice of whether or how frequently to engage in an out-of-home activity (generation) and where to engage in that activity (distribution or destination choice). However, a trip is not generally defined by these two choices. Choosing to go out to eat and choosing where to eat out does not define a trip to the chosen restaurant without a third choice of where to go to the restaurant from; the origin is taken for granted. This is, of course, not a problem for HB trips, if it is known the home is the origin, but in general, and for NHB trips, in particular, these two choices or these two steps (generation and distribution) are not adequate to define a trip. A second spatial choice or distribution model is necessary to assign both an origin and destination to a NHB trip. The methods below, therefore, correct this design flaw of four-step models by putting NHB distribution in series (rather than in parallel) with HB distribution. Sequenced together in this way, HB and NHB distribution can reasonably assign both the origin and destination to NHB trips.

The following sections introduce and overview the three methods explored in this report.

5.1 Method 1: Using Home-Based Attractions

All of the methods for improving NHB trips presented here leave the HB trip purpose models untouched. Although improvements can be made to the distribution of HB trips using destination choice models, that has received considerable attention elsewhere and is beyond the scope of this manual. In all of the methods described in this manual, the HB trip generation, distribution and mode choice models are run as they normally would be.[2] The only difference is that the NHB trip models are omitted.

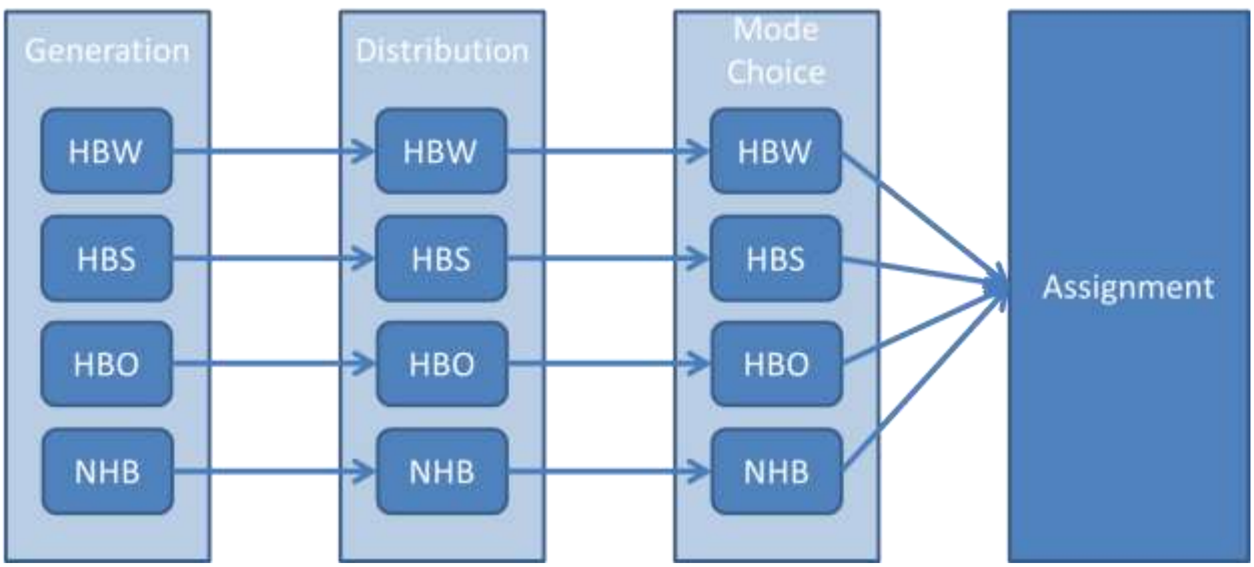
Then, after the HB trip models have been run through mode choice, the attractions are summed by mode across all productions. This is the marginal row sum (the sum of each column) of the

[1] For more background and theory, see Chapter 6, Stop Sequence Choice and the Traveler Conservation Constraint: Closing the Loop in *A Trip-Based Travel Demand Framework Consistent with Tours and Stop Interaction*, V. Bernardin, Dissertation, Northwestern University, Evanston, Ill., 2008.

[2] The only possible exception would be if a model were performing the PA to OD transformation prior to mode choice, in which case, some special adjustments may need to be made, but this is not general practice.

modal trip table matrices in most model implementations. These vectors (either one for each mode or one for each mode and purpose combination) become the primary input to new NHB trip models.

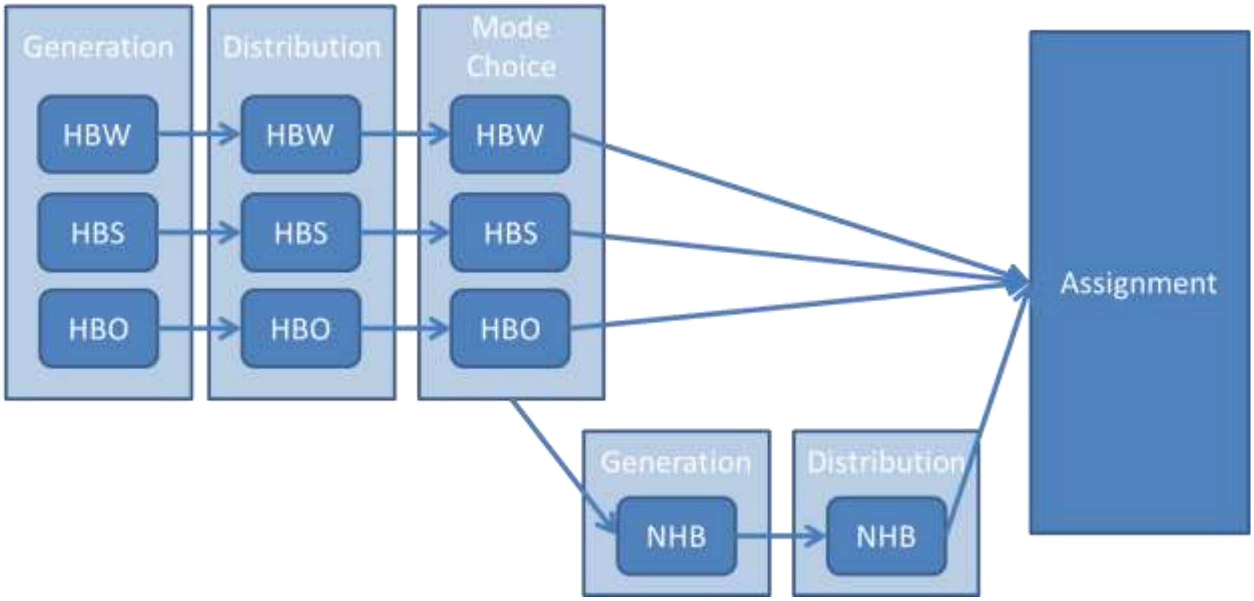
NHB trips are generated by mode for each attraction using the number of HB trips of the same mode attracted to that zone and optionally other factors including the number of HB trips by different modes attracted to the zone. This can be as simple as rates (e.g., 0.35 NHB auto trips per HB auto trip; 0.15 NHB transit trips per HB transit trip, etc.) or can be a regression model (e.g., NHB = 0.1 x HBWork auto trips + 0.2 x HBSchool auto trips + 0.15 x HBOther auto trips, etc.). These rates or equations can be estimated from survey data not unlike traditional generation rates/equations are developed.[3] Despite the fact that NHB trips are not directly linked to the number of households, it is easy to see that they will scale appropriately with the number of households since additional households will produce additional HB trips which in turn will produce more NHB trips. The same argument can generally be made with respect to household characteristics (e.g., an increase in HH income will similarly increase NHB trips indirectly by way of HB trips). It is true that to the extent that some households may produce HB and NHB trips in different proportions (e.g., larger, suburban households may produce more NHB trips per HB trip) that, following this method, the model will be insensitive to changes in this regard. Method 2, however, can correct for this, or alternatively, segmentation of households and HB trips can be carried over to NHB trips. For instance, if HB trips are segmented by income (e.g., for toll modeling), then NHB trips can be similarly segmented, generating high income NHB trips from high income HB trips, low income NHB trips from low income HB trips, etc. This could potentially benefit toll modeling and enable better equity or environmental justice analyses.



Source: FHWA

Figure 5. Traditional four-step model structure.

[3] It is important to estimate the rates to account for NHB trips which are not directly preceded or followed by a HB trip. There are generally few such trips, but even so, they contribute to overall trip-making.



Source: FHWA

Figure 6. Method 1 modified trip-based model structure.

[If desired, NHB trips can also be segmented by purpose, for instance, into NHB trips on Work Tours and NHB trips on Non-Work Tours. This can be of some use in contexts in which time-of-day is determined after mode choice or in order to assign different values of time. However, since mode is already determined, in many models and for many purposes, there would be no particular advantage to representing multiple types of NHB trip.]

The resulting NHB productions/attractions are then used to distribute NHB trips by mode using mode specific impedances. As in most traditional models, the NHB production and attraction vectors are set equal to each other. It is important that the distribution model be doubly constrained as this is necessary (but not sufficient) to ensure consistency with tours.[4] In this context of NHB trip distribution, the double constraint is essentially equivalent to the constraint that as many trips go in, the same number of trips come out. So long as in the course of converting HB trips from PA to OD format, the resulting HB trip tables over all the time periods in the day have the property that their daily marginal row and columns match either other, this ensures a weak consistency with tours.[5]

5.2 Method 2: Incorporating Stops not on HB Trips

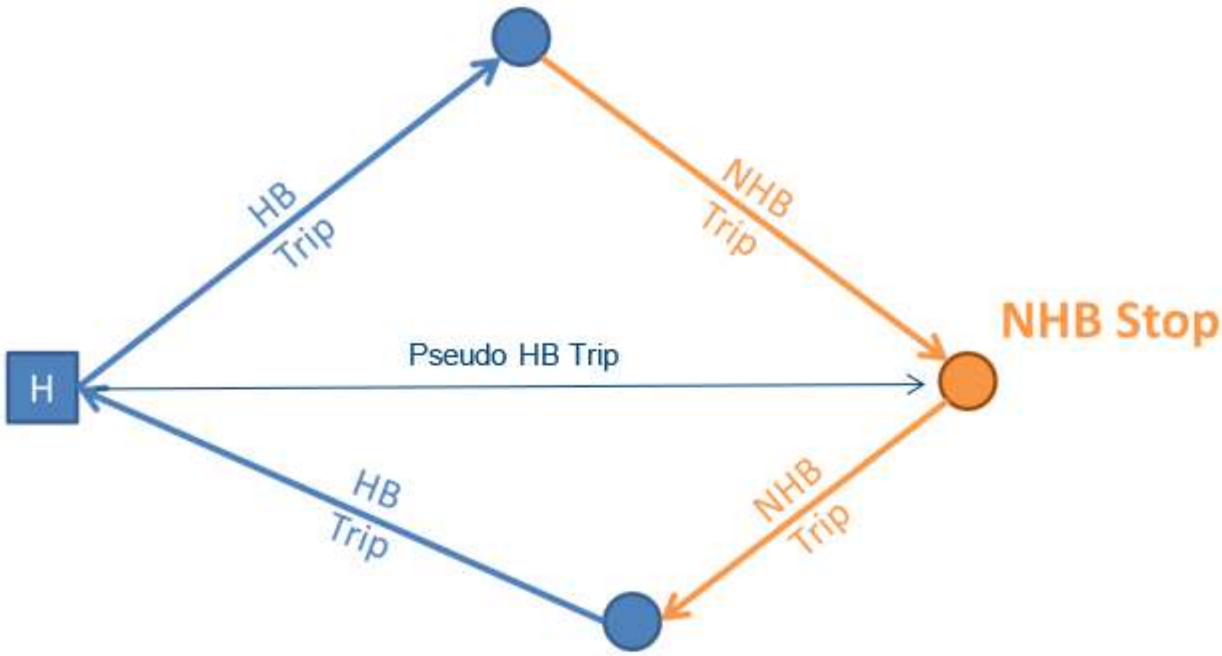
The first method is a bit of an oversimplification in that it treats all NHB trip ends as a subset of HB trip ends and thereby more or less equates the two. There are two potential issues with this, one of which has already been alluded to. First, although most NHB trip ends are also HB trip ends, there are some longer, more complex tours with four or more trips which have NHB trip ends which are not HB trip ends. Second, in general, NHB stops are not likely to be distributed

[4] This is different than HB trips, which can be either singly or doubly constrained and in the case of non-work purposes may be better represented by singly constrained models.

[5] In this context "weak consistency with tours" could be defined negatively as not generally being possible to be proved inconsistent with tours. This is distinct from results of method 3 which might be said to have "strong consistency with tours" indicating that it can be positively proven that the results are consistent with tours.

identically to HB trips but rather are likely to be slightly further from home on average since the stops on a tour closest to home are most likely to be the HB trip ends.

For both of these reasons, the second method introduces two additional component models, the generation, and distribution of "NHB stops." NHB stops are not to be confused with NHB trips. NHB stops are trip ends both preceded and followed by NHB trips (i.e., stops in the middle of a long trip chain). See Figure 7.

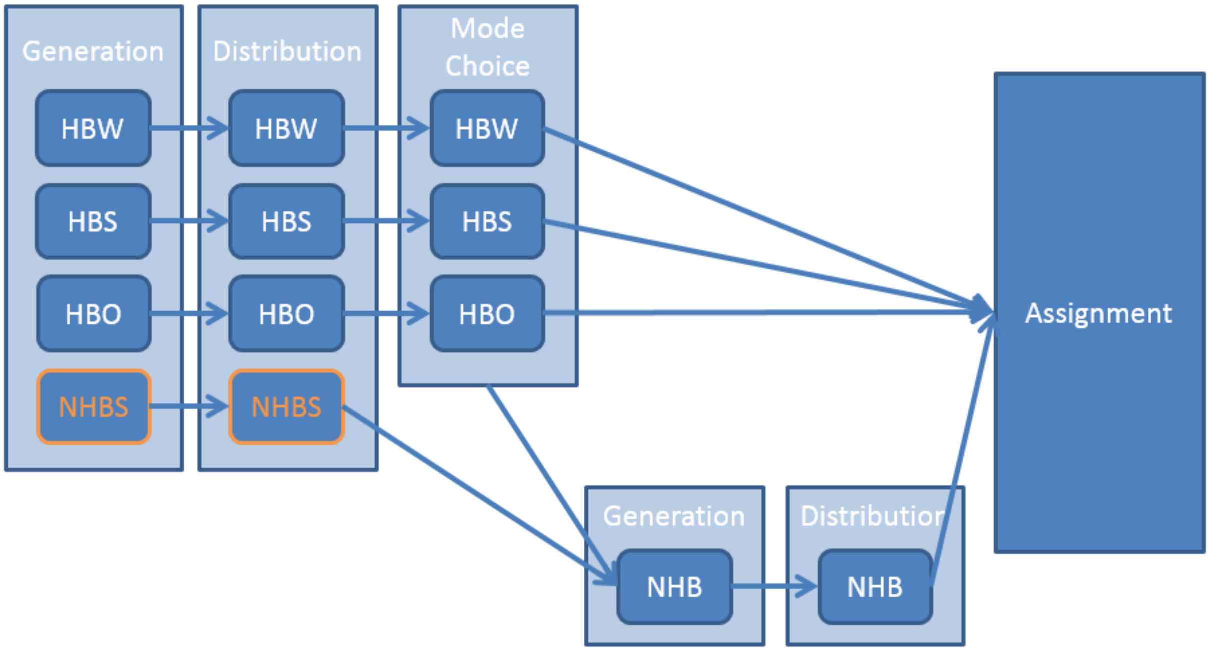


Source: FHWA

Figure 7. Non-home-based stops.

NHB stop productions and attractions can be generated by households using simple rates, cross-classified rates, regression equations, etc., just like HB trips are generated. These rates/equations can also be estimated from household survey data just like other generation rates/equations.

[NHB stops can also be segmented by purpose, if desired. Since there are relatively few NHB stops, however, elaborate schemes are not likely to offer much value and run the risk of spreading survey sample thin for estimation. There may, however, be some value in subdividing NHB stops into NHBWork stops and NHBOther stops, as this allows for the use of very distinct attraction equations and because NHBWork stops may be expected to be further from home than NHBOther stops, just as with HB trip attractions.]



Source: FHWA

Figure 8. Method 2 modified trip-based model structure.

NHB stops can be distributed using a gravity or destination choice model. The model can be either singly or doubly constrained. The distribution of NHB stops is just like those for HB trips. The productions are at the home zone and the attractions are at the out-of-home stop zone. Destination choice models offer a particular advantage for distributing NHB stops, as they can also factor in the distance to HB stops, in addition to the distance from home, through the use of accessibility variables. However, gravity models are also a viable option for distributing NHB stops.

While NHB stops could in theory be split by mode using simple factors or by applying a logit choice model, just like HB trips, it is not clear how the mode of a stop (rather than a trip) should be defined and mode choice would likely involve unrealistic paths as though the traveler went directly to the location from home despite the fact that there was at least one intervening stop, and ultimately, it is simply not necessary. NHB stops can be used directly, without determining mode, in generating non-home-based trips.

Finally, the resulting NHB stop table matrices are summed over the production rows and the resulting marginal column sums of attractions are ***multiplied by two*** and added to the NHB trip production/attraction vector generated from HB trips attractions as in Method 1 (or, added to both the production ***and*** the attraction vector). The NHB stops must be multiplied by two since they are both NHB trip productions ***and*** attractions, both NHB trip origins ***and*** destinations. NHB trips are then distributed using a doubly constrained model just as in Method 1.

5.3 Method 3: Disaggregate Distribution by Production Zone

Method 1 addresses the most problematic aspects of NHB trips by connecting them to HB trips. Method 2 adds some additional fidelity by better representing the complexity of tours, allowing the ratio of HB to NHB trips to vary and capturing the fact that NHB trip ends are generally slightly further from home than HB trip ends. Method 3 adds one final complexity in order to be able to guarantee the model's resulting trip tables are consistent with tours (e.g., that every traveler who leaves home, gets back home by the end of the day). This added complexity may or may not also allow the model to better reproduce real NHB distribution patterns.

In order to prove that everyone gets back home at night, it is necessary to track everyone through the day. Between the distribution of HB trips and of NHB trips, who travelers are/where they live gets lost track of in Methods 1 and 2 because of summing over production zones in the HB trip tables (and NHB stop tables in Method 2). In order to preserve this information and create provable consistency with tours, this summing step must be skipped. Instead, the NHB trip generation models can be applied to each row vector in the HB trip table matrices (instead of to their sum). The result is a matrix rather than a vector of NHB trip productions/attractions, indexed by residence zone. NHB trips can then be distributed one residence zone at a time. This is accomplished by applying a doubly constrained gravity or destination choice model within a loop over the residence zones. The row vector for each residence zone in the production matrix is both the production and attraction (origin and destination) vector for one application of the doubly constrained distribution model. Essentially, this is exactly the same process as in Methods 1 and 2, except instead of doing NHB generation and distribution once, it is done in a loop, once for each residence zone. To save space, the whole resulting three dimensional matrix need not be stored in memory or saved to disk. The final two dimensional NHB trip table matrix can simply be accumulated by adding the matrix from each residence zone to a running total trip table. The trip tables resulting from this process can be formally proven consistent with tours. For the formal proof, see Chapter 6, Stop Sequence Choice and the Traveler Conservation Constraint: Closing the Loop in *A Trip-Based Travel Demand Framework Consistent with Tours and Stop Interaction*, V. Bernardin, Dissertation, Northwestern University, Evanston, Ill., 2008.

5.4 Alternative Methods and Further Improvements

Many other variations on these methods are possible. Of particular interest, there is a whole spectrum of options between Methods 2 and 3, where Method 2 is one extreme in which no information on the residence of NHB trip makers is preserved and Method 3 is the other extreme in which each NHB trip maker's residence is known at the zonal level. In between these alternatives, one might consider methods of segmenting NHB trips by origin districts (e.g., central city and suburbs, etc.) which would preserve some limited information about the NHB trip-makers residence without full detail. The optimal design for various modeling and analysis purposes may well be somewhere along this spectrum rather than at the extremes of Method 2 and Method 3.

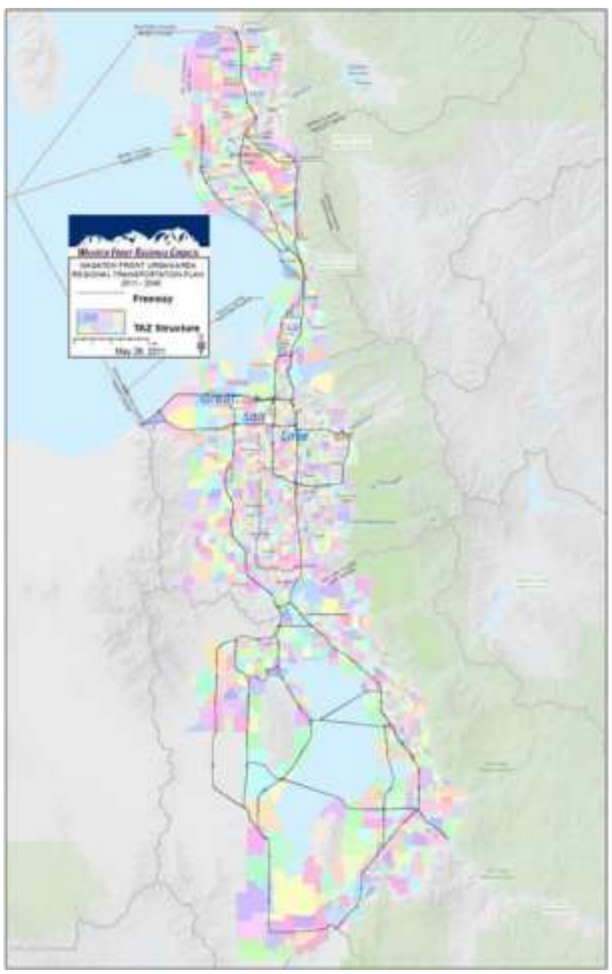
The representation of NHB trips can also be further enhanced by improving the modeling of their time-of-day. However, since the handling of time-of-day varies so considerably in trip-based models, it would be difficult to produce a simple manual on this topic that would be widely applicable.

6.0 Proof of Concept Implementation for Salt Lake City

These three methods were implemented to produce enhanced versions of the Wasatch Front Regional Council (WFRC)'s model of the Salt Lake City region.

Salt Lake City was identified as a strong candidate during the initial scoping of this effort for several reasons. It is a medium/large city (1.7 million metro area 2012 ACS population estimate) with unusually high transit ridership – 116,000 unlinked trips/day in 2012 according to FTA's National Transit Database (NTD). The area has both recent household and on-board transit ridership surveys. The sample sizes of both are good with nearly 5,800 households in the diary survey. The model is implemented in Cube, is of a traditional four-step, trip-based design and is of reasonable complexity for the metro area's size in terms of trip purposes (7) and market segments (192). TMIP also had contractor staff available that were very familiar with the model which would make enhancement efficient.

The WFRC model is a trip-based travel model of fairly typical complexity for a region of its size including an auto ownership model, logit mode choice and a feedback loop from assignment to distribution. It covers all of the developable area of Utah, Salt Lake, Davis and Weber counties with over 2200 TAZ. The model is implemented in Cube and integrated with UrbanSim.



Source: Google Maps™

Figure 9. WFRC geography and TAZ structure.

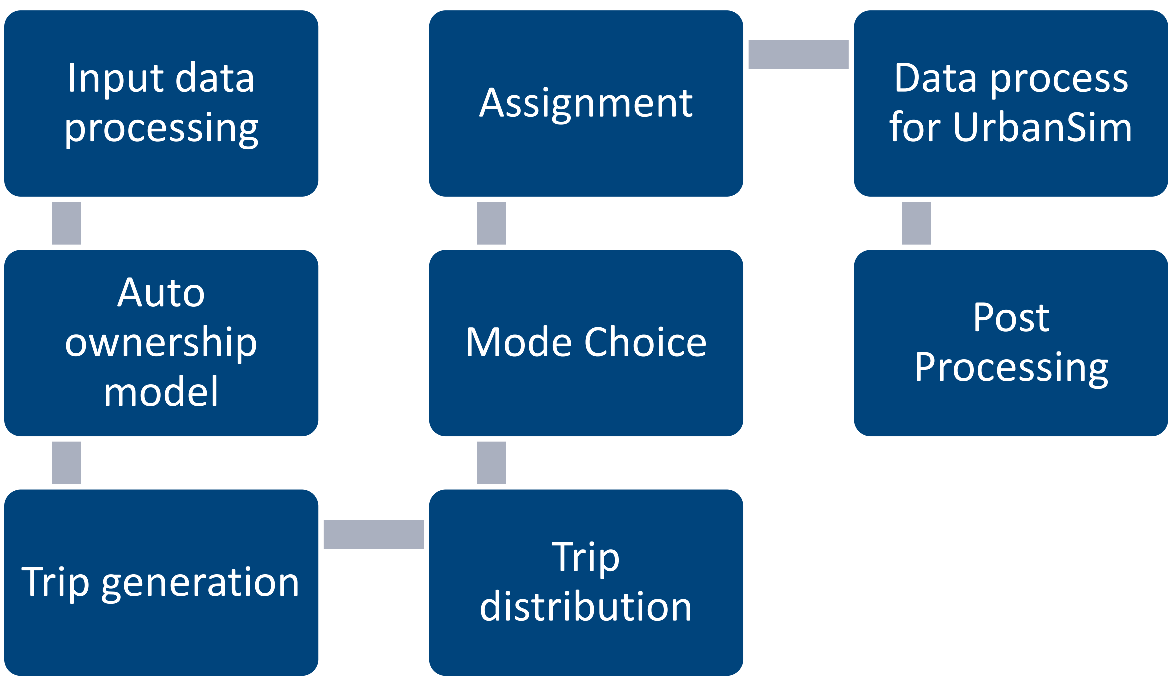
While a variation on Method 3 had been tested previously and shown to represent a real improvement over a four step model's ability to reproduce the spatial distribution of trips (Bernardin and Conger, 2010), Methods 1 and 2 had never been previously tested, nor had the mode choice or transit results. The handling of mode and Methods 1 and 2 are original to this effort for TMIP.

These methods were implemented in the Salt Lake City model with the aim of providing insight into the relative value of each incremental improvement and to confirm the hypothesis that given their greater consistency with tours and real underlying travel patterns, that their response properties would be more logical than those of traditional four-step models, such as in the example illustrated earlier in Figure 1 and Figure 2.

The following sub-sections document in detail the implementation for Salt Lake City with discussion of their calibration and the meaning of resulting parameters and specifications. Following this documentation and discussion of the implementation, the next section presents results from testing to evaluate the accuracy and response properties of the new enhanced model versions.

6.1 *Method 1 Implementation*

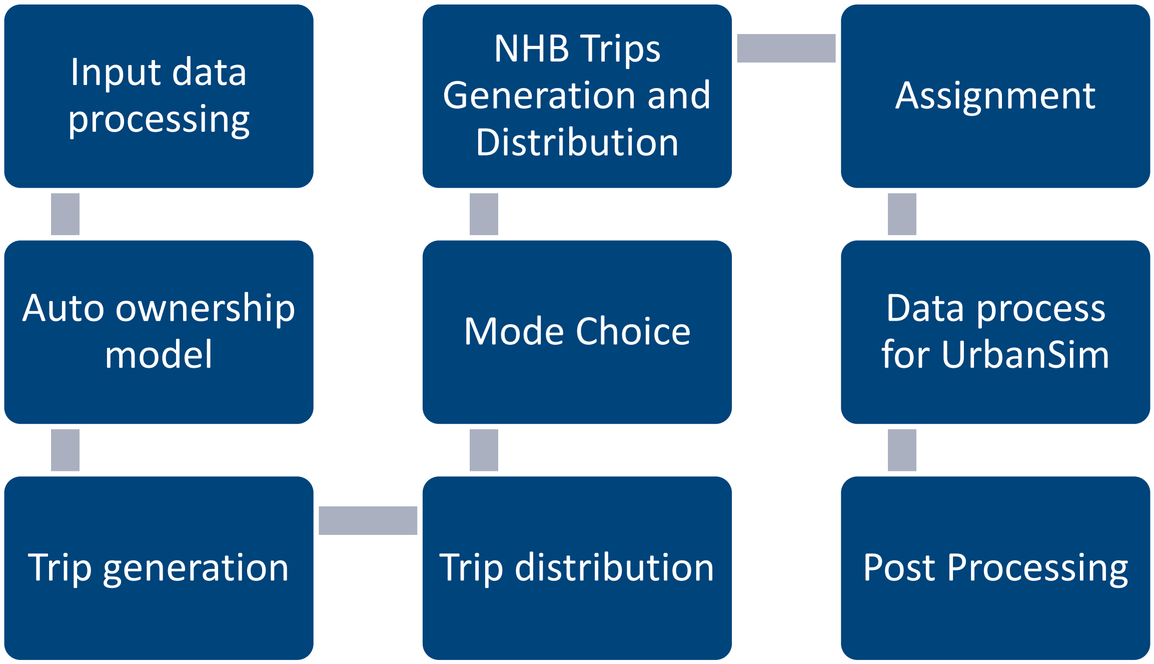
Method 1 was implementation in the (WFRC) Salt Lake City model which is Cube based. The original model implementation is depicted in Figure 10:



Source: FHWA

Figure 10. Original WFRC model implementation.

New NHB trip generation and distribution steps were added after mode choice and before assignment, as shown in Figure 11.



Source: FHWA

Figure 11. Method 1 implementation.

In particular, new "NHB Trips Generation and Distribution" has two sub-steps: NHB trip generation and NHB trip distribution.

6.1.1 NHB Trip Generation

In this step, trip tables by purpose and mode from the "Mode choice" step are summarized to get total HB attractions to each TAZ. These attractions along with the coefficients estimated (see the next section) are used to generate NHB productions of each TAZ, by purpose (NHBW and NHBNW) and by mode (DR, SR2, SR3, NM, TR, and SB).

6.1.2 NHB Trip Distribution

In this step, attractions and productions from the previous step are used to apply trip distribution using a gravity model with friction factors. Generalized travel cost is used as the impedance. Trip time of day is also dealt with in this step. (The time of day factor for NHB trips from the original model was used to calculate the percentage of NHB trips occurring in each period.)

The following sub-sections document and discuss each of these steps.

6.1.3 NHB Trip Generation

NHB trips were generated by mode for each zone using the number of HB trips attracted to that zone. HB trips were allowed to generate NHB trips of a different mode, reflecting the reality that people can drive to a location and then make a walk trip, etc.

In the WFRC model, there are four HB trip purposes (plus the two NHB purposes, external trips, etc.):

- Work (HBW)
- College (HBC)
- School (HBSch)
- Other - shopping, drop off or pick up, personal business, or other social event (HBO).

There are six modes defined in the model:

- Drive alone (DA)
- Shared ride 2 persons (SR2)
- Share ride 3 persons or more (SR3)
- Transit (TR)
- School bus (SB)
- Non-motorized (NM).

Non-home-based (NHB) trips in the WFRC model are divided into non-home-based-work (NHBW) and non-home-based-non-work (NHBNW). NHBW trips have at least one trip end at work. For NHBNW trips, neither trip end is either home or work.

Linear regression model was used to estimate generation equations where NHB trips are estimated as a function of HB trip attractions. In testing generation model specifications, the initial assumption was that a NHB trip could follow any HB trip of any mode and purpose combination. If a combination of purpose and mode proved statistically insignificant, it was dropped from the specification.

The formula below is the general regression model:

$$P_j = f\left(HBWA_{j,mode}, HBCA_{j,mode}, HBSchA_{j,mode}, HBOA_{j,mode}\right)$$

$$A_j = P_j$$

Source: FHWA

Figure 12. Equation. NHB trip generation.

Where:

P_j is the number of NHB(W/NW) trips produced by zone j

A_j is the number of NHB(W/NW) trips attracted by zone j

$HBWA_{j,mode}$ is the number of HBW trips attracted to zone j by a particular mode

$HBCA_{j,mode}$ is the number of HBC trips attracted to zone j by a particular mode

$HBSchA_{j,mode}$ is the number of HBSch trips attracted to zone j by a particular mode

$HBOA_{j,mode}$ is the number of HBO trips attracted to zone j by a particular mode

Regression models were estimation by purpose (NHBW, NHBNW) and mode (Drive alone, SR2, SR3, Non-motorized, transit and school bus) for a total of 11 models (since NHBW cannot be by school bus).

The household travel diary survey from the Salt Lake City region was used in model estimation. The survey data contains 99,308 reported trips reported by 9,155 households including 27,046 persons. See Table 1 through Table 5 for a socio-demographic summary of survey data.

Table 1. Survey data household size distribution.

Household size category	Number of households	Percentage
1	1,554	17%
2	3,313	36%
3	1,318	14%
4	1,213	13%
5	908	10%
6+	849	9%
Total	9,155	100%

Table 2. Survey data household income distribution.

Household Income Category	Number of households	Percentage
Not available	1,109	12%
Under $35,000	1,768	19%
$35,000 - $49,999	1,287	14%
$50,000 - $99,999	3,365	37%
$100,000 or more	1,626	18%
Total	9,155	100%

Table 3. Survey data number of workers distribution.

Number of Workers	Number of households	Percentage
0	1,974	22%
1	3,872	42%
2	2,880	31%
3+	429	5%
Total	9,155	100%

Table 4. Survey data household vehicle ownership distribution.

Number of vehicles	Number of households	Percentage
0	159	2%
1	2,217	24%
2	4,378	48%
3+	2,401	26%
Total	9,155	100%

Table 5. Survey data employment status distribution.

Employment Status	Counts	Percentage
Full Time	7,690	28%
Part Time	1,878	7%
Homemaker	2,419	9%
Not-employed	767	3%
NULL	8,875	33%
Retired	2,985	11%
Self-employed	1,064	4%
Student, employed 25+ hrs./week	997	4%
Student, not employed or employed less than 25 hrs./week	371	1%
Total	27,046	100%

The following tables document trip generation model estimation results for NHBW and NHBNW trips for each mode. For convenience purposes, trips of a particular purpose and mode are abbreviated according to the following table:

Table 6. Abbreviation of trip purpose and mode.

Purpose	Mode	Abbreviation
Home Based Work	Drive alone	HBW_DR
Home Based Work	Shared Ride 2 Persons	HBW_SR2

Purpose	Mode	Abbreviation
Home Based Work	Shared Ride 3 Persons and Plus	HBW_SR3
Home Based Work	Non-motorized	HBW_NM
Home Based Work	Transit	HBW_TR
Home Based Work	School Bus	HBW_SB
Home Based College	Drive alone	HBC_DR
Home Based College	Shared Ride 2 Persons	HBC_SR2
Home Based College	Shared Ride 3 Persons and Plus	HBC_SR3
Home Based College	Non-motorized	HBC_NM
Home Based College	Transit	HBC_TR
Home Based College	School Bus	HBC_SB
Home Based Other	Drive alone	HBO_DR
Home Based Other	Shared Ride 2 Persons	HBO_SR2
Home Based Other	Shared Ride 3 Persons and Plus	HBO_SR3
Home Based Other	Non-motorized	HBO_NM
Home Based Other	Transit	HBO_TR
Home Based Other	School Bus	HBO_SB
Home Base School	Drive alone	HBSh_DR
Home Base School	Shared Ride 2 Persons	HBSh_SR2
Home Base School	Shared Ride 3 Persons and Plus	HBSh_SR3
Home Base School	Non-motorized	HBSh_NM
Home Base School	Transit	HBSh_TR
Home Base School	School Bus	HBSh_SB

Purpose	Mode	Abbreviation
Non-Home Based Work	Drive alone	NHBW_DR
Non-Home Based Work	Shared Ride 2 Persons	NHBW_SR2
Non-Home Based Work	Shared Ride 3 Persons and Plus	NHBW_SR3
Non-Home Based Work	Non-motorized	NHBW_NM
Non-Home Based Work	Transit	NHBW_TR
Non-Home Based Work	School Bus	NHBW_SB
Non-Home Based Non-Work	Drive alone	NHBNW_DR
Non-Home Based Non-Work	Shared Ride 2 Persons	NHBNW_SR2
Non-Home Based Non-Work	Shared Ride 3 Persons and Plus	NHBNW_SR3
Non-Home Based Non-Work	Non-motorized	NHBNW_NM
Non-Home Based Non-Work	Transit	NHBNW_TR
Non-Home Based Non-Work	School Bus	NHBNW_SB

6.1.4 NHBW Drive Alone

The data indicated there are seven types of HB trips with significant chance of generating NHBW_DR trips, see Table 7. HBW_DR is the biggest generator, with 51% of HBW_DR trips associated with NHBW_DR trips. HBW_SR2 is the second biggest generator, with 28% of HBW_SR2 trips associated with NHBW_DR trips. Other significant generators include: HBW_SR3, HBC_DR, HBO_DR, HBO_SR2, HBSch_DR. This suggests that different modes are likely to be used in a trip chain, although the same mode is most likely to be used.

Table 7. NHBW drive alone model coefficients.

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.515323	0.006928	74.384	< 2e-16
HBW_SR2	0.289862	0.01816	15.962	< 2e-16
HBW_SR3	0.257816	0.023149	11.137	< 2e-16
HBW_NM	0.063928	0.02714	2.355	0.0185
HBC_DR	0.148303	0.030249	4.903	9.49E-07

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
HBO_DR	0.056794	0.00683	8.315	< 2e-16
HBSch_DR	0.055696	0.02481	2.245	0.0248

6.1.5 NHBW Shared Ride 2

The data indicated there are six types of HB trips with significant chance of generating NHBW_SR2 trips, see Table 8. HBW_SR2 is the biggest generator, with 28% of HBW_SR2 trips associated with NHBW_SR2 trips. HBW_SR3 is the second biggest generator, with 8.6% HBW_SR3 associated with NHBW_SR2 trips.

Notice that 3% of HBW_NM trips are associated with NHBW_SR2 trips. It suggests that a few people walk or bike to work, and then take a ride with colleague to another place. Similarly, 5% of people who take transit to work then get a ride with someone else to another place.

A seventh variable, HBSch_SR2 was marginally significant (t value of 2.2) but was excluded since it did not seem clear how these trips would generate NHBW_SR2.

Table 8. NHBW shared ride two persons model coefficients.

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.080842	0.003312	24.407	< 2e-16
HBW_SR2	0.283971	0.008682	32.708	< 2e-16
HBW_SR3	0.086155	0.011068	7.784	7.18E-15
HBW_NM	0.032616	0.012976	2.514	0.011954
HBW_TR	0.053384	0.01564	3.413	0.000643
HBO_SR2	0.017329	0.003653	4.744	2.11E-06

6.1.6 NHBW Shared Ride 3 and plus

The data indicated there are seven types of HB trips with significant chance of generating NHBW_SR3 trips. HBW_SR3 is the biggest one, with 33% of HBW_SR3 trips associated with NHBW_SR3 trips. As with NHBW_SR2, notice that nearly 5% of HBW_NM trips are associated with NHBW_SR3 trips. It suggests that some people walk or bike to work, and then take a ride with two or more colleagues to another place. Similarly, nearly 3% of people who take transit to work then get a ride with others to another place. A small number of HBSch_SR3 generate NHBW_SR3. An example of this might be two parents and two children in the morning, where first the first child is dropped off at school, then one parent is dropped off at work.

Table 9. NHBW shared ride 3 and plus model coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.043763	0.00267	16.388	< 2e-16
HBW_SR2	0.068530	0.007	9.79	< 2e-16
HBW_SR3	0.333717	0.008923	37.398	< 2e-16
HBW_NM	0.045410	0.010462	4.341	1.42E-05
HBW_TR	0.027919	0.01261	2.214	0.02683
HBO_SR3	0.010417	0.002407	4.328	1.51E-05
HBSch_SR3	0.016222	0.004936	3.286	0.00102

6.1.7 NHBW Non-motorized (Bike & Walk)

The data indicated there are also seven types of HB trips with significant chance of generating NHBW_NM trips. HBW_NM is the biggest one, with 22% of HBW_NM trips associated with NHBW_NM trips. Transit (HBW_TR) trips generate almost as many walk (NBHW_NM) trips as HBW_NM at 19%. Other significant generators include: HBW_SR2, HBW_SR3, HBC_NM and HBC_DR.

Together, the results indicate that regardless of the mode used to travel to work, there is some probability of making a walk trip from work. The probability is lowest for those who drove alone to work and therefore are known to have a car at work and the probability is highest for those to walked, biked or took transit to work and therefore do not have a car at work. Workers who carpool have an intermediate probability of walking or biking, corresponding to the probability that they have a car.

Interestingly, HBC trips (by drive alone, walk or bike) also appear to have a small chance of generating NHBW_NM trips although the significance of this finding is somewhat marginal. The explanation for this is presumably that many college students who work, work on campus with a part time job as part of their student aid, so it is not unlikely that they walk or drive to campus for classes and then walk to work, for instance, in the dining hall or library.

Table 10. NHBW non-motorized coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.062220	0.004049	15.366	< 2e-16
HBW_SR2	0.048668	0.010614	4.585	4.55E-06
HBW_SR3	0.072240	0.01353	5.339	9.39E-08
HBW_NM	0.222508	0.015863	14.027	< 2e-16
HBW_TR	0.189643	0.01912	9.918	< 2e-16
HBC_DR	0.038385	0.01768	2.171	0.02993
HBC_NM	0.068783	0.02634	2.611	0.00902

6.1.8 NHBW Transit

Despite the relative rarity of these trips overall, there are eight types of HB trips that have a significant chance of generating NHBW_TR trips, with HBW_TR the biggest generator by a considerable margin. Interestingly, HBW_TR trips are more likely to generate NHBW_NM trips than NHBW_TR trips. Only 13% of HBW_TR trips are associated with NHBW_TR trips, while 19% of HBW_TR trips are associated with NHBW_NM trips. There are only 2.7% of HBW_NM trips associated with NHBW_TR trips, while 22% of HBW_NM trips associated with NHBW_NM trips. As with NHBW_NM, we observe the connection with HBC trips. Here we also observe a connection with HBSch_TR, which would not necessarily be expected, but was retained due to the relatively strong statistical evidence for the effect and general reasonableness of the results.

Table 11. NHBW transit coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.006176	0.001062	5.814	6.15E-09
HBW_SR2	0.013121	0.002785	4.712	2.46E-06
HBW_SR3	0.008392	0.00355	2.364	0.018083
HBW_NM	0.027901	0.004162	6.704	2.06E-11
HBW_TR	0.127330	0.005016	25.383	< 2e-16
HBC_SR2	0.030635	0.009204	3.328	0.000874
HBC_TR	0.023250	0.009557	2.433	0.014991
HBSch_TR	0.058946	0.014964	3.939	8.19E-05

6.1.9 NHBNW Drive Alone

There are eight types of HB trips that have a significant chance of generating NHBNW_DR trips, with HBO_DR the largest generator. About 48% of HBO_DR trips would lead to NHBNW trips. Another two major generators of NHBNW_DR trips include HBC_DR and HBSch_DR.

It is not surprising that we see that DR trips by any trip purpose have a chance of generating NHBNW_DR trips. We also observe that shared ride HB trips can generate NHBNW_DR when the driver drops off their passenger(s).

Table 12. NHBNW drive alone coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.026170	0.006585	3.974	7.08E-05
HBC_DR	0.227190	0.028754	7.901	2.84E-15
HBO_DR	0.484504	0.006493	74.623	< 2e-16
HBO_SR2	0.078927	0.007263	10.867	< 2e-16
HBO_SR3	0.029058	0.005935	4.896	9.83E-07
HBSch_DR	0.172964	0.023585	7.334	2.29E-13
HBSch_SR2	0.063176	0.021461	2.944	0.00324
HBSch_SR3	0.027550	0.012174	2.263	0.02364

6.1.10 NHBNW Shared Ride 2

There are also eight types of HB trips that have a significant chance of generating NHBNW_SR2 trips, with 43% of HBO_SR2 trips to linked to NHBNW_SR2 trips.

Table 13. NHBNW shared ride 2 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_DR	0.056408	0.027327	2.064	0.039
HBC_SR2	0.555789	0.054225	10.25	< 2e-16
HBO_DR	0.096998	0.00617	15.72	< 2e-16
HBO_SR2	0.435342	0.006903	63.067	< 2e-16
HBO_SR3	0.073422	0.005641	13.016	< 2e-16
HBO_NM	0.020663	0.009305	2.221	0.0264
HBSch_SR2	0.156386	0.020396	7.667	1.80E-14
HBSch_SR3	0.079154	0.01157	6.841	7.97E-12

6.1.11 NHBNW Shared Ride 3 plus

There are nine types of HB trips that have a significant chance to generate NHBNW_SR3 trips. HBO_SR3 is unsurprisingly the biggest generator, followed by HBC_SR3 and HBSch_SR3.

Table 14. NHBNW shared ride 3 and plus coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_SR2	0.179225	0.064514	2.778	0.00547
HBC_SR3	0.276621	0.088552	3.124	0.00179
HBO_DR	0.040412	0.007341	5.505	3.72E-08
HBO_SR2	0.085036	0.008213	10.354	< 2e-16
HBO_SR3	0.515878	0.006711	76.867	< 2e-16
HBO_NM	0.030187	0.011071	2.727	0.0064
HBSch_DR	0.085709	0.026668	3.214	0.00131
HBSch_SR2	0.148399	0.024266	6.115	9.73E-10
HBSch_SR3	0.315180	0.013765	22.896	< 2e-16

6.1.12 NHBNW Non-motorized (Bike & Walk)

There are ten types of HB trips that have a significant chance of generating NHBNW_NM trips, interestingly with HBO_TR the most significant generator. The second most likely generator is HBC_TR. The coefficients suggest that 40% of HBO_TR trips are followed by NHBNW_NM trips and 12% of HBC_TR trips are followed by NHBNW_NM trips. By comparison, only 12% of HBO_NM and 10% of HBC_NM are followed by NHBNW_NM. This suggests that people are more likely to walk on transit-based tours (where transit is used to get to and/or from home) than on non-motorized tours (where the person walked or biked to/from home). This is somewhat plausible given that a large portion of non-motorized tours are often simple round-trips with one (or no) destination (e.g., a walk from home to the park and back). This finding is not obvious but makes sense and can also be explained as indicating that areas that are attractive to transit are likely to be attractive for walking and areas that attract many transit trips will likely also generate many walk trips.

Table 15. NHBNW non-motorized mode coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_NM	0.098034	0.019604	5.001	5.74E-07
HBC_TR	0.126067	0.027113	4.65	3.34E-06
HBO_DR	0.018488	0.002971	6.222	4.95E-10
HBO_SR2	0.020809	0.003324	6.261	3.88E-10

	Estimate	Std. Error	t value	Pr(>|t|)
HBO_SR3	0.011564	0.002716	4.257	2.07E-05
HBO_NM	0.119969	0.004481	26.774	< 2e-16
HBO_TR	0.407062	0.020848	19.526	< 2e-16
HBSch_DR	0.029081	0.010793	2.694	0.00705
HBSch_SR3	0.011203	0.005571	2.011	0.04436
HBSch_NM	0.065553	0.009791	6.695	2.18E-11

6.1.13 NHBNW Transit

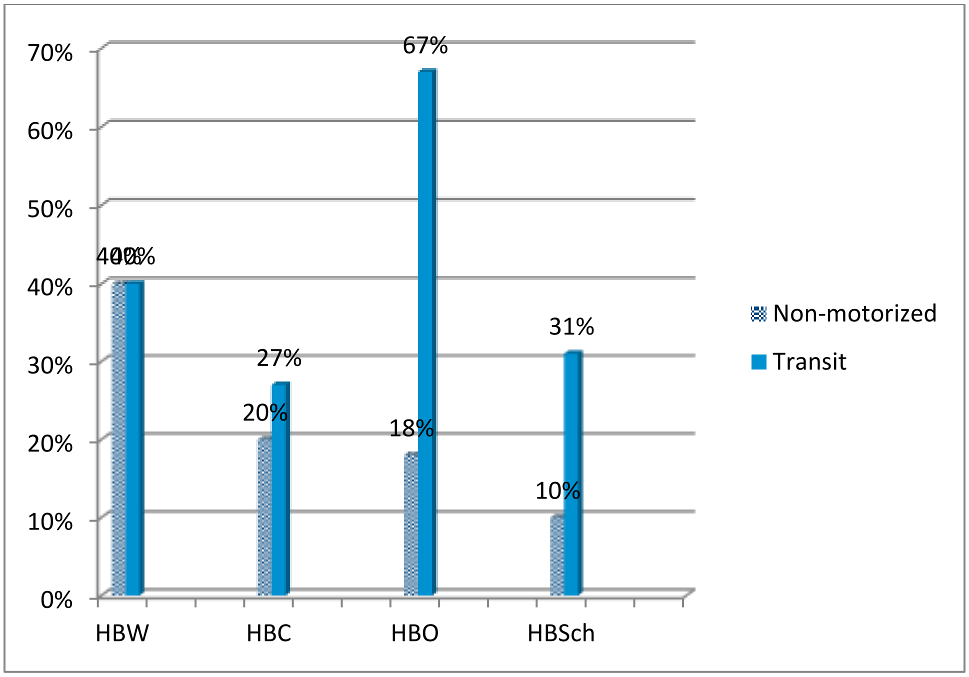
There are nine types of HB trips that have a significant chance of generating NHBNW_TR trips, with HBO_TR and HBSch_TR to be two primary generators. Unsurprisingly, in general, NHBNW_TR trips are most likely to be generated by other TR trips.

Table 16. NHBNW transit coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_DR	0.017775	0.006164	2.884	0.003935
HBC_SR2	0.107874	0.012232	8.819	< 2e-16
HBC_NM	0.032989	0.009184	3.592	0.000329
HBC_TR	0.119372	0.012702	9.398	< 2e-16
HBO_SR3	0.003198	0.001272	2.514	0.011953
HBO_NM	0.009877	0.002099	4.705	2.54E-06
HBO_TR	0.264920	0.009767	27.125	< 2e-16
HBSch_DR	0.012359	0.005056	2.444	0.014522
HBSch_TR	0.246318	0.019888	12.385	< 2e-16

Transit vs. Non-motorized mode in NHB trips

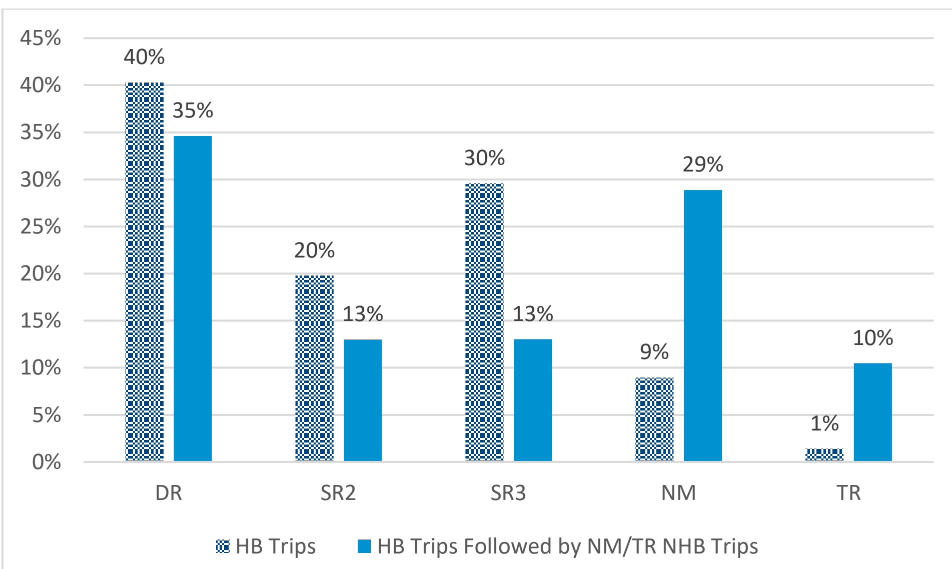
Figure 13 shows the percentage of transit and non-motorized HB trips generating NHB trips. In general, HB trips by transit are more likely to be followed by NHB trips, compared to non-motorized HB trips. For transit HB trips, HBO trips are most likely to generate NHB trips compared to other purpose. For non-motorized HB trips, HBW trips are most likely to generate NHB trips compared to other purpose.



Source: FHWA

Figure 13. Percentage of home based transit and non-motorized trips followed by NHB trips.

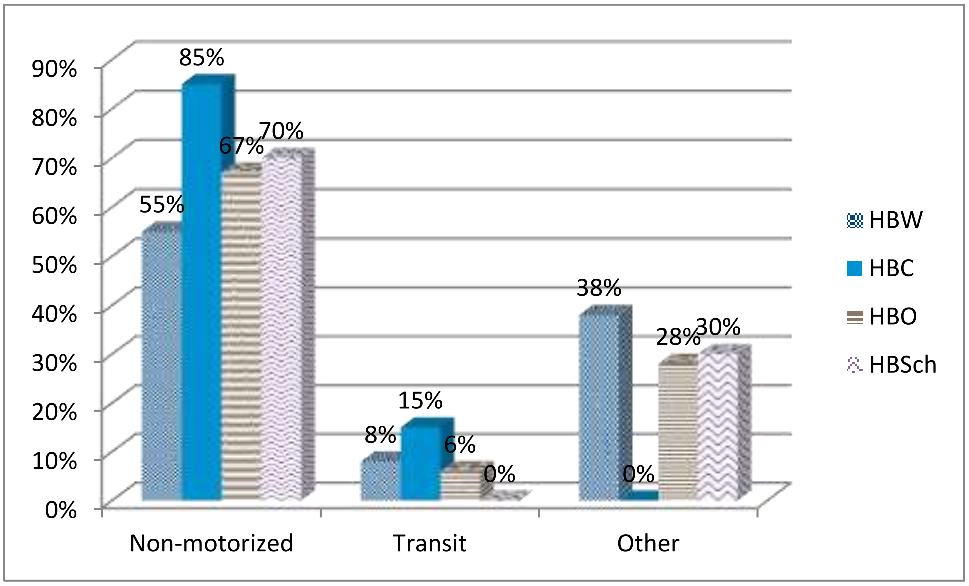
Figure 14 shows the mode share of home based trips compared to home based trips generating non-motorized and transit NHB trips. The change in mode also confirms that HB trips by transit are more likely generate NHB trips.



Source: FHWA

Figure 14. Mode share of home-based trips and home based trips followed by NM/transit NHB trips.

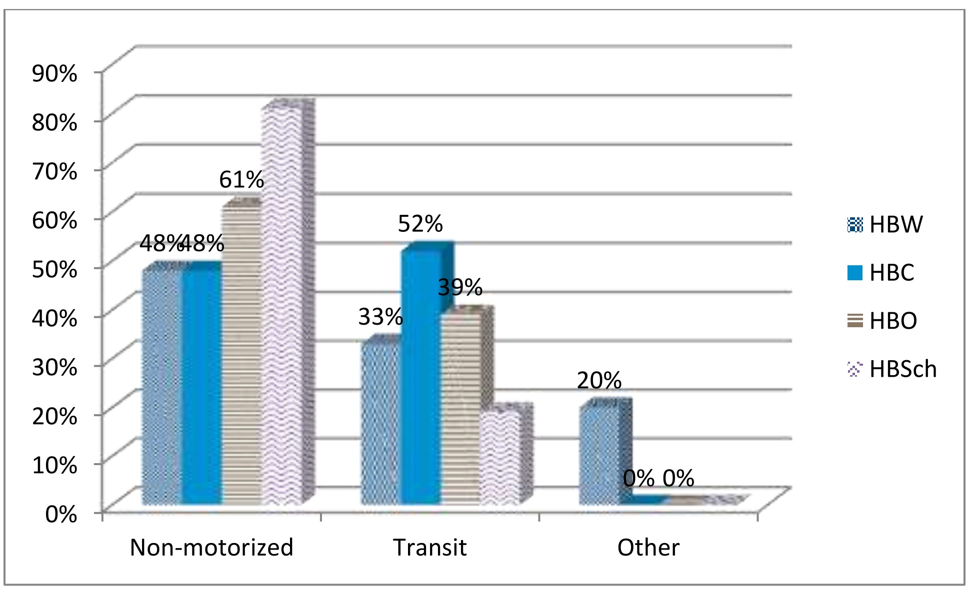
Figure 15 shows the mode split of NHB trips that are generated by non-motorized HB trips. In general, the non-motorized mode is the primary mode used in NHB trips following non-motorized HB trips. For NHB trips following HBW, HBO, and HBSch, the primary mode is non-motorized but secondary mode is other, not transit.



Source: FHWA

Figure 15. Mode split of NHB trips generated by non-motorized HB trips.

Figure 16 shows the mode split of NHB trips that are generated by transit HB trips. In general, the non-motorized mode is the primary mode used in NHB trips following transit HB trips. The only exception is HBC trips, in which non-motorized and transit are basically equally used.

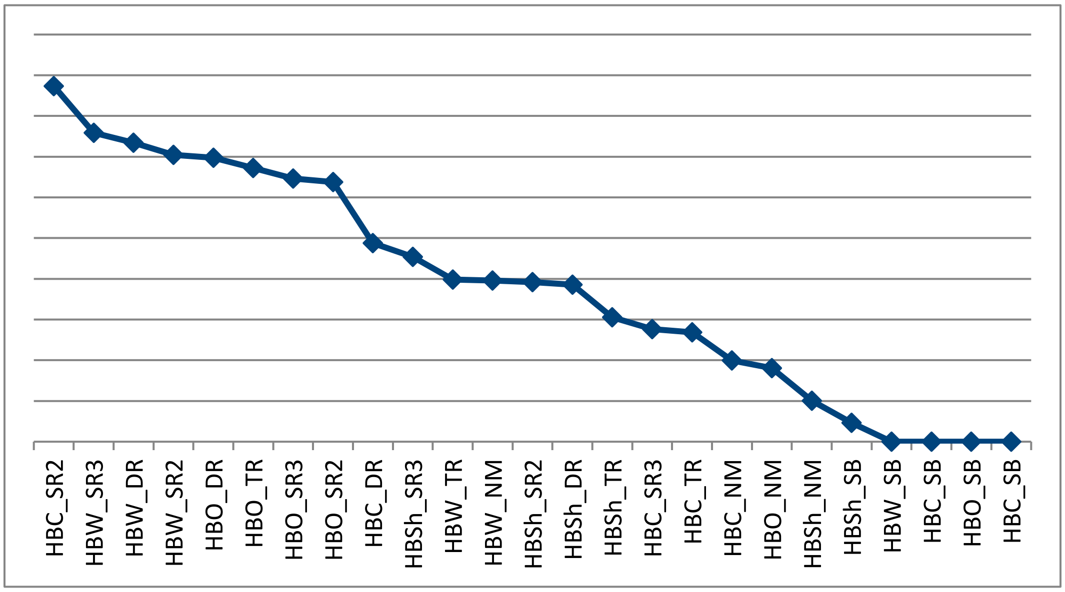


Source: FHWA

Figure 16. Mode split of NHB trips generated by transit HB trips.

The result suggests that, if a person started trip with transit mode, he/she is more likely to continue the trip to another destination comparing to non-motorized mode, especially for HBO and HBSch purpose (see Figure 13). The only exception is HBW trips. For the NHB trips generated by transit or non-motorized trips, the non-motorized mode is more likely to be used (see Figure 15 and Figure 16). The results reflect the travel pattern of taking transit to one major activity zone and finishing all activities within walking distance, which is quite consistent with observed behavior. The results also reflect the reluctance of making trip chaining when trips start with non-motorized mode.

Summary



Source: FHWA

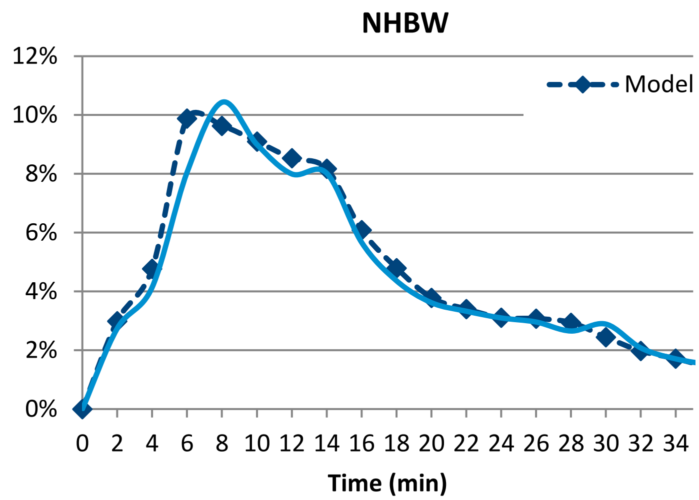
Figure 17. Relative generation of NHB trips by HB trips by purpose and mode.

Figure 17 shows order of HB trips in term of the relative likelihood of generating NHB trips. In general, we could observe trip chaining or NHB trips are more likely to happen in certain scenarios:

1. Trip chaining or NHB trips are more likely to occur in vehicle tours (HB trips) than transit or non-motorized tours (HB trips).
2. Trip chaining or NHB trips are more likely to occur in shared ride tours than drive alone tours.
3. Trip chaining or NHB trips are more likely to occur in transit tours than non-motorized tours, although a non-motorized mode is more likely to be used for the NHB trips generated by transit HB trips.

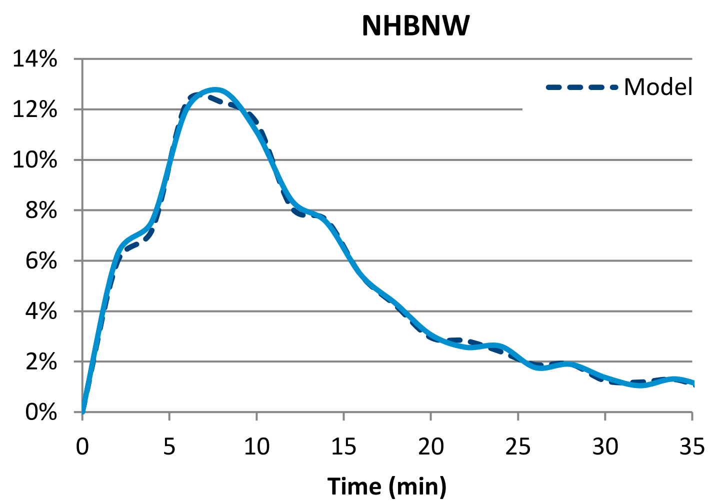
6.1.14 NHB Non-Transit Trip Distribution

Friction factors for the gravity model for NHB non-transit trips were adjusted to calibrate trip length by work and non-work purposes using highway generalized cost skim. Figure 18 shows the generalized cost distribution (measured as minutes) from the model and the survey for the NHBW purpose. Figure 19 shows the generalized cost distribution (measured as minutes) from the model and the survey for the NHBNW purpose. As can be seen in the figures, it was relatively easy to calibrate friction factors for gravity models to reproduce the observed trip length distributions.



Source: FHWA

Figure 18. NHBW trip length calibration.

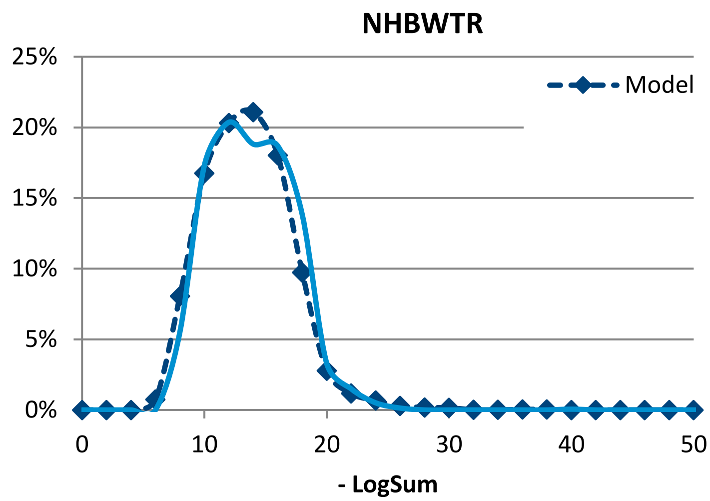


Source: FHWA

Figure 19. NHBNW trip length calibration.

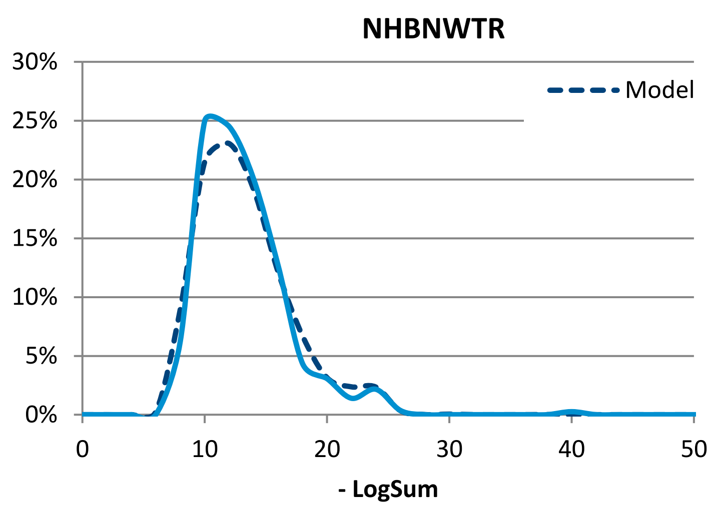
6.1.15 NHB Transit Trip Distribution

Friction factors for NHB transit trips were calibrated using transit logsum skim. In highway generalized cost skim, a value of 10 could be valued as 10 minutes travel (not exactly same). In logsum skim, there is no positive value due to the fact that it is a disutility. If an OD pair has no transit access, the logsum is coded as -99. If there is transit access, there will be a logsum value larger than -99 (typically the value is around -6 to -30). For easy comparison and understanding, the minus logsum is used as travel cost by transit, see Figure 20 and Figure 21 for the minus logsum distribution of NHB transit trips.



Source: FHWA

Figure 20. NHBW transit trip length calibration.

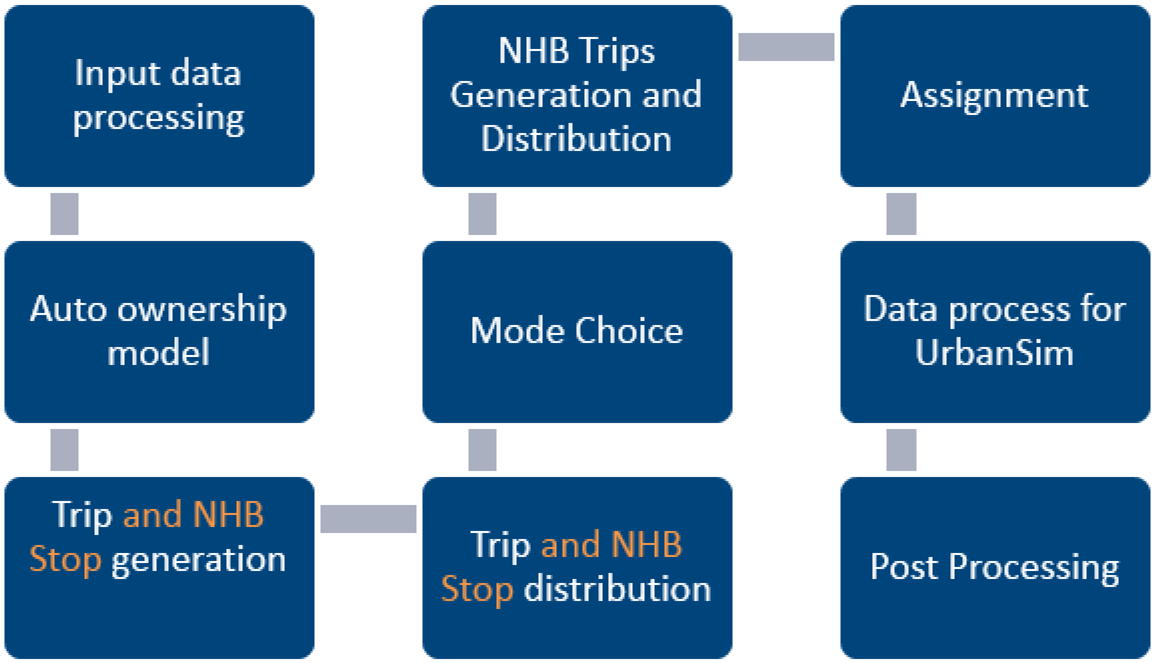


Source: FHWA

Figure 21. NHBNW transit trip length calibration.

6.2 Method 2 Implementation

Figure 22 shows the implementation framework for method 2 which is the same as for Method 1 except that Trip Generation and Trip Distribution are modified to incorporate NHB stops. NHB trip generation and distribution steps in Method 2 also must be modified to consider NHB Stops in the generation and distribution of NHB trips.



Source: FHWA

Figure 22. Method 2 implementation.

6.2.1 NHB Stops in Trip Generation

As discussed earlier, Method 1 is unrealistic in treating all NHB trip ends as a subset of HB trip ends because NHB trips without HB trip ends do occur in longer trip chains. Thus, Method 2 introduces two additional component models, the generation, and distribution of "NHB stops."

The trip generation module in the WFRC model was modified to generate NHB stop productions and attractions, treating the pseudo-trip from home to the NHB stop as if it were an actual HB trip. (Refer back to Figure 5.)

Table 17 and Table 18 show the production coefficients of NHBW stops and NHBNW stops. For NHBW stops, households with more workers would generate more NHBW stops. Households with more vehicle would also generate more NHBW stops. Households with retired persons (life_cycle3 = 1) would generate less NHBW stops. For NHBNW stops, larger household size is associated with more NHBNW stops, and households with children under 18 (life_Cycle2 = 1) or retired persons (life_cycle3 = 1) would generate more NHBNW stops.

Table 19 shows attraction coefficients for NHBW stops. NHBW stops are most likely attracted to the zones with retail or food service, with every one food service employee generating 0.77 NHBW stops (note that a NHBW trip is not necessarily a work trip, rather a trip with one trip end at work, in this case likely a work to lunch NHB trip). Every one retail employee will generate 0.17 NHBW stops (most likely work to shopping NHB trip). A few other significant generators include office employment, health employment, construction employment, and total households.

Table 20 shows attraction coefficients for NHBNW stops. NHBNW stops are most likely attracted to zones with retail or food service, but with much higher generation rates. Every one food service employee will generate 1.4 NHBNW stops. Every one retail employee will generate 0.81 NHBNW stops. Total households is the third biggest generator of NHBNW stops, which likely are associated with visiting friends or relatives.

Table 17. NHBW stop trip production coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
worker1	0.43164	0.0305	14.15	< 2e-16
worker2	0.66142	0.03942	16.779	< 2e-16
worker3	0.75769	0.06902	10.978	< 2e-16
veh2	0.09532	0.03556	2.68	0.00737
veh3	0.20069	0.04229	4.745	2.12E-06
life_cycle3	-0.07509	0.03791	-1.981	0.04766

Table 18. NHBNW stop trip production coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.32034	0.06672	4.801	1.61E-06
hhsize23	0.34901	0.07637	4.57	4.95E-06
hhsize4	0.7233	0.11091	6.521	7.35E-11
hhsize5	1.1087	0.1241	8.934	< 2e-16
hhsize6	1.32703	0.1226	10.824	< 2e-16
life_cycle2	0.23479	0.07924	2.963	0.00305
life_cycle3	0.43917	0.07591	5.785	7.49E-09

Table 19. NHBW stop trip attraction coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
RETL	0.179163	0.03083	5.811	6.80E-09
FOOD	0.753594	0.061214	12.311	< 2e-16
WSLE	0.094462	0.024223	3.9	9.82E-05
OFFI	0.139388	0.032258	4.321	1.60E-05
GVED	0.111966	0.006187	18.097	< 2e-16
HLTH	0.079069	0.017051	4.637	3.67E-06
OTHR	0.059575	0.018879	3.156	0.00162
FM_CONS	0.130851	0.045307	2.888	0.0039

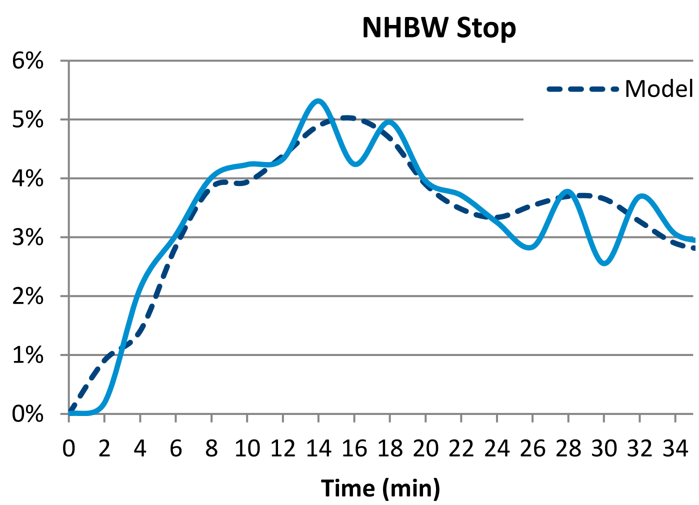
	Estimate	Std. Error	t value	Pr(>|t|)
TOTHH	0.096283	0.010693	9.004	< 2e-16

Table 20. NHBNW stop trip attraction coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
RETL	0.8161	0.05334	15.301	< 2e-16
FOOD	1.41863	0.10732	13.219	< 2e-16
GVED	0.11243	0.01101	10.213	< 2e-16
HLTH	0.10429	0.03034	3.437	0.000595
TOTHH	0.28108	0.01873	15.007	< 2e-16

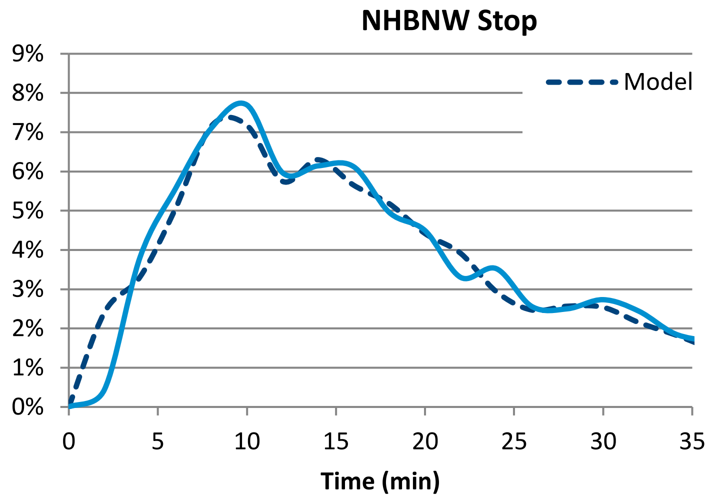
6.2.2 NHB Stops in Trip Distribution

The trip distribution module in the WFRC model was also modified to distribute NHB stops (pseudo-trips). Table 21 shows the calibration of NHBW stop location, the distance from the NHBW stop to the home location. Table 22 shows the calibration of NHBNW stop location, the distance from the NHBNW stop to the home location.



Source: FHWA

Figure 23. NHBW stop location calibration.



Source: FHWA

Figure 24. NHBNW stop location calibration.

Table 21 shows the average trip length for each home based purpose and NHB Stop. Both NHBW and NHBNW stop average trip lengths are much longer than home based trips, which is consistent with expectation of spatial location of NHB stops – NHB stops tend to locate farther away from home than home base trip destination.

Table 21. Average trip length by purpose.

Purpose	Average Trip Length (Generalized Cost, minutes)
HBW	29.6
HBSch	10.6
HBShp	14.0
HBO	14.8
NHBW-Stop	38.2
NHBNW-Stop	34.2

6.2.3 Update of NHB Trip Generation

NHBW stops and NHBNW stops are added as additional NHB trip generators. The following section details the revised NHB Trip generation models including these NHB stops. Since Method 1 treats all NHB trips as generated by HB attractions, while Method 2 allows some NHB trips to be generated by NHB stops, the coefficients for HB attractions should generally decrease in Method 2 relative to Method 1. In some cases, HB attractions that proved significant in generating NHB trips in Method 1 became insignificant in Method 2. This may reflect limitations on the sample size of the survey data, particularly for uncommon trip types or it may reflect the way the data was processed for estimation. It does, however, raise a potential drawback of Method 2.

NHBW_DR

Table 22 shows Method 2 NHBW_DR trips coefficients and Table 23 shows the comparison of Method 1 and Method 2 results. About 66% of NHBW stops would attract a NHBW drive alone trip. Due to the introduction of NHBW stops, coefficients of HBW_SR3 and HBO_SR2 become insignificant. This suggests that most of these trips are involved in complex tours.

Table 22. NHBW_DR coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.262670	0.005163	50.871	< 2e-16
HBW_SR2	0.044234	0.013122	3.371	0.000749
HBC_DR	0.097939	0.021747	4.504	6.70E-06
HBO_DR	0.034272	0.004912	6.978	3.05E-12
HBSch_DR	0.035492	0.017836	1.99	0.04661
NHBWSTOP	0.659963	0.00356	185.407	< 2e-16

Table 23. Comparison of NHBW_DR method 1 and method 2 coefficients.

Coefficient	Method 1	Method 2
HBW_DR	0.515323	0.262670
HBW_SR2	0.289862	0.044234
HBW_SR3	0.257816	
HBW_NM	0.063928	
HBC_DR	0.148303	0.097939
HBO_DR	0.056794	0.034272
HBSch_DR	0.055696	0.016054
NHBWSTOP	0	0.659963

NHBW_SR2

Table 24 shows Method 2 NHBW_SR2 trips coefficients and Table 25 shows the comparison of Method 1 and Method 2 coefficients. About 18% of NHBW stops would generate a NHBW SR2 trip.

Table 24. NHBW_SR2 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.010809	0.003144	3.439	0.000585
HBW_SR2	0.215895	0.007987	27.029	< 2e-16
HBW_SR3	0.020703	0.010159	2.038	0.041576
HBO_SR2	0.014589	0.003344	4.363	1.29E-05
HBSch_SR2	0.021842	0.009879	2.211	0.027039
NHBWSTOP	0.182930	0.002172	84.21	< 2e-16

Table 25. Comparison of NHBW_SR2 method 1 and method 2 coefficients.

Coefficient	Method 1	Method 2
HBW_DR	0.080842	0.010809
HBW_SR2	0.283971	0.215895
HBW_SR3	0.086155	0.020703
HBW_NM	0.032616	dropped due to insignificance
HBW_TR	0.053384	dropped due to insignificance
HBO_SR2	0.017329	0.014589
HBSch_SR2	0.024102	0.021842
NHBWSTOP	0	0.18293

NHBW_SR3

Table 26 shows Method 2 NHBW_SR3 trips coefficients and Table 27 shows the comparison of Method 1 and Method 2 coefficients. About 10% of NHBW stops would generate a NHBW SR3 trip. Due to the introduction of NHBW stops, coefficients of HBW_DR and HBW_TR become insignificant.

Table 26. NHBW_SR3 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_SR2	0.029544	0.006744	4.381	1.18E-05
HBW_SR3	0.296253	0.008579	34.532	< 2e-16
HBW_NM	0.024715	0.010037	2.463	0.0138

	Estimate	Std. Error	t value	Pr(>|t|)
HBO_SR3	0.009659	0.002308	4.186	2.85E-05
HBSch_SR3	0.015131	0.004733	3.197	0.00139
NHBWSTOP	0.104740	0.00177	59.162	< 2e-16

Table 27. Comparison of NHBW_SR3 method 1 and method 2 coefficients.

	Method 1	Method 2
HBW_DR	0.043763	
HBW_SR2	0.068530	0.029544
HBW_SR3	0.333717	0.296253
HBW_NM	0.045410	0.024715
HBW_TR	0.027919	
HBO_SR3	0.010417	0.009659
HBSch_SR3	0.016222	0.015131
NHBWSTOP	0	0.104740

NHBW_NM

Table 28 shows Method 2 NHBW_NM trips coefficients. Table 29 shows the comparison of Method 1 and Method 2 coefficients. About 26% of NHBW stops would attract a NHBW NM trip. Because of NHBW stops, coefficients of HBW_DR, HBW_SR2, etc. all become insignificant.

Table 28. NHBW_NM coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_NM	0.17067	0.01387	12.303	<2e-16
HBW_TR	0.13940	0.01672	8.339	<2e-16
HBC_NM	0.05504	0.02302	2.391	0.0168
NHBWSTOP	0.26237	0.00243	107.994	<2e-16

Table 29. Comparison of NHBW_NM method 1 and method 2 coefficients.

	Method 1	Method 2
HBW_DR	0.062220	
HBW_SR2	0.048668	
HBW_SR3	0.072240	
HBW_NM	0.222508	0.17067
HBW_TR	0.189643	0.13940
HBC_DR	0.038385	

	Method 1	Method 2
HBC_NM	0.068783	0.05504
NHBWSTOP		0.26237

NHBW_TR

Table 30 show the Method 2 NHBW_TR trips coefficients. Table 31 shows the comparison of Method 1 and Method 2 coefficients. Compared to other modes, NHBW stops only attracts 1.8% of NHBW transit trips, which suggests that transit is unlikely to be involved in complex tours.

Table 30. NHBW_TR coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_SR2	0.006309	0.002775	2.273	0.02303
HBW_NM	0.024285	0.004131	5.879	4.16E-09
HBW_TR	0.123825	0.004978	24.875	< 2e-16
HBC_SR2	0.029784	0.00913	3.262	0.00111
HBC_TR	0.022931	0.00948	2.419	0.01558
HBSch_TR	0.058137	0.014844	3.917	9.00E-05
NHBWSTOP	0.018301	0.000727	25.177	< 2e-16

Table 31. Comparison of NHBW_TR method 1 and method 2 coefficients.

	Method 1	Method 2
HBW_DR	0.006176	--
HBW_SR2	0.013121	0.006309
HBW_SR3	0.008392	--
HBW_NM	0.027901	0.024285
HBW_TR	0.127330	0.123825
HBC_SR2	0.030635	0.029784
HBC_TR	0.023250	0.022931
HBSch_TR	0.058946	0.058137
NHBWSTOP	--	0.018301

NHBNW_DR

Table 32 shows the Method 2 NHBNW_DR trips coefficients. Table 33 shows the comparison of Method 1 and of Method 2 coefficients. About 35% of NHBNW stops would attract a NHBNW drive alone trip. Due to the introduction of NHBW stops, coefficients of all shared ride mode HB trips become insignificant.

Table 32. NHBNW_DR type 1 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBW_DR	0.019374	0.005651	3.428	0.000608
HBC_DR	0.179736	0.024677	7.284	3.31E-13
HBO_DR	0.374396	0.005653	66.231	< 2e-16
HBSch_DR	0.114913	0.020244	5.676	1.39E-08
NHBNWSTOP	0.359137	0.003116	115.249	< 2e-16

Table 33. Comparison of NHBW_DR method 1 and method 2 coefficients.

	Method 1	Method 2
HBW_DR	0.026170	0.019374
HBC_DR	0.227190	0.179736
HBO_DR	0.484504	0.374396
HBO_SR2	0.078927	--
HBO_SR3	0.029058	--
HBSch_DR	0.172964	0.114913
HBSch_SR2	0.063176	--
HBSch_SR3	0.027550	--
NHBNWSTOP	0	0.359137

NHBNW_SR2

Table 34 shows the Method 2 NHBNW_SR2 trips coefficients. Table 35 shows the comparison of Method 1 and Method 2 coefficients. About 34% of NHBNW stops would attract a NHBNW SR2 trip. Due to the introduction of NHBW stops, coefficients of HBC_DR, HBO_DR, HBO_NM, etc. become insignificant.

Table 34. NHBNW_SR2 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_SR2	0.374583	0.046824	8	1.28E-15
HBO_SR2	0.336899	0.00602	55.964	< 2e-16
HBSch_SR2	0.093886	0.017611	5.331	9.81E-08
NHBNWSTOP	0.340276	0.002968	114.635	< 2e-16

Table 35. Comparison of NHBNW_SR2 method 1 and method 2 coefficients.

	Method 1	Method 2
HBC_DR	0.056408	--
HBC_SR2	0.555789	0.374583
HBO_DR	0.096998	--
HBO_SR2	0.435342	0.336899
HBO_SR3	0.073422	--
HBO_NM	0.020663	--
HBSch_SR2	0.156386	0.093886
HBSch_SR3	0.079154	--
NHBNWSTOP	0	0.340276

NHBNW_SR3

Table 36 shows the Method 2 NHBNW_SR3 trips coefficients. Table 37 shows the comparison of Method 1 and Method 2 coefficients. About 43% of NHBNW stops would attract a NHBNW drive alone trip. Due to the introduction of NHBW stop trip, coefficients of HBC_SR2, HBO_DR, HBO_SR2 and HBO_NM become insignificant.

Table 36. NHBNW_SR3 coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_SR3	0.182369	0.073729	2.474	0.013384
HBO_SR3	0.395819	0.005666	69.858	< 2e-16
HBSch_SR2	0.067379	0.020213	3.334	0.000858
HBSch_SR3	0.234112	0.011478	20.396	< 2e-16
NHBNWSTOP	0.438209	0.003423	128.017	< 2e-16

Table 37. Comparison of NHBNW_SR3 method 1 and method 2 coefficients.

	Method 1	Method 2
HBC_SR2	0.179225	0
HBC_SR3	0.276621	0.182369
HBO_DR	0.040412	0
HBO_SR2	0.085036	0
HBO_SR3	0.515878	0.395819
HBO_NM	0.030187	0
HBSch_DR	0.085709	0.105425
HBSch_SR2	0.148399	0.067379
HBSch_SR3	0.315180	0.234112
NHBNWSTOP	0	0.438209

NHBNW_NM

Table 38 shows the Method 2 NHBNW_NM trips coefficients and Table 39 shows the comparison of Method 1 and Method 2 coefficients. About 8% of NHBNW stops would attract a NHBNW NM trip.

Table 38. NHBNW_NM coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_NM	0.088332	0.018814	4.695	2.68E-06
HBC_TR	0.116547	0.02602	4.479	7.52E-06
HBO_NM	0.112704	0.004302	26.2	< 2e-16
HBO_TR	0.36751	0.020019	18.358	< 2e-16
HBSch_NM	0.06024	0.009396	6.411	1.46E-10
NHBNWSTOP	0.089618	0.001573	56.974	< 2e-16

Table 39. Comparison of NHBNW_NM method 1 and method 2 coefficients.

	Method 1	Method 2
HBC_NM	0.098034	0.088332
HBC_TR	0.126067	0.116547
HBO_DR	0.018488	--
HBO_SR2	0.020809	--
HBO_SR3	0.011564	--
HBO_NM	0.119969	0.112704
HBO_TR	0.407062	0.367510
HBSch_DR	0.029081	--
HBSch_SR3	0.011203	--
HBSch_NM	0.065553	0.060240
NHBNWSTOP	0	0.089618

NHBNW_TR

Table 40 shows the Method 2 NHBNW_TR trips coefficients. Table 41 shows the comparison of Method 1 and Method 2 coefficients. About 2% of NHBNW stops would attract a NHBNW TR trip.

Table 40. NHBNW_TR coefficients.

	Estimate	Std. Error	t value	Pr(>|t|)
HBC_DR	0.015197	0.006112	2.486	0.01291
HBC_SR2	0.097542	0.012134	8.039	9.34E-16
HBC_NM	0.030888	0.009105	3.392	0.000694
HBC_TR	0.117310	0.012593	9.316	< 2e-16
HBO_NM	0.008272	0.002082	3.973	7.10E-05
HBO_TR	0.256357	0.009688	26.461	< 2e-16
HBSch_TR	0.241106	0.019718	12.228	< 2e-16
NHBNWSTOP	0.019402	0.000762	25.47	< 2e-16

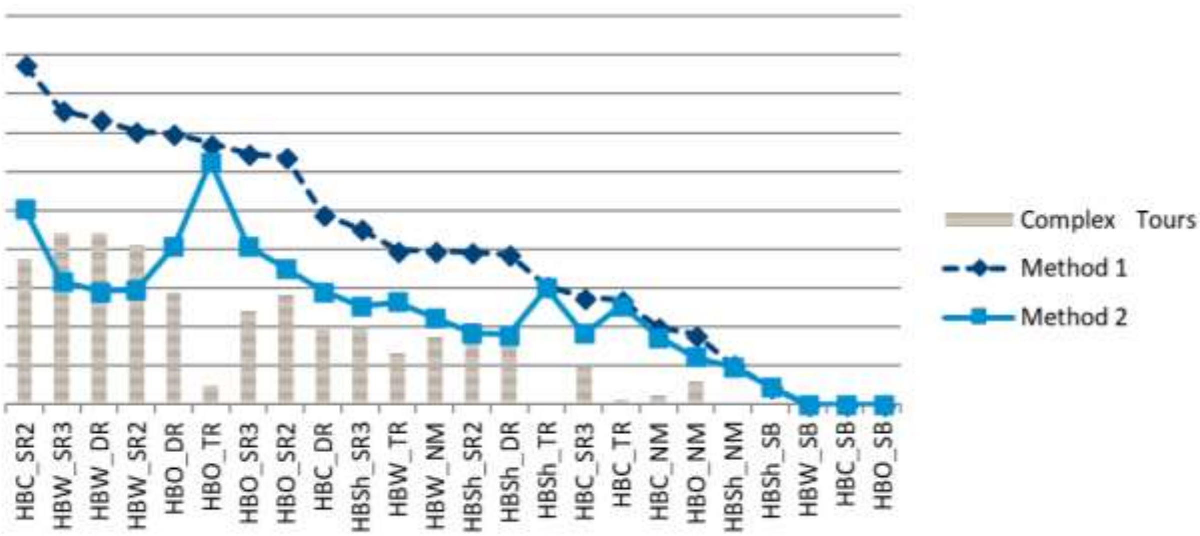
Table 41. Comparison of NHBNW_TR method 1 and method 2 coefficients.

	Method 1	Method 2
HBC_DR	0.017775	0.015197
HBC_SR2	0.107874	0.097542
HBC_NM	0.032989	0.030888
HBC_TR	0.119372	0.11731
HBO_SR3	0.003198	0
HBO_NM	0.009877	0.008272
HBO_TR	0.26492	0.256357
HBSch_DR	0.012359	0
HBSch_TR	0.246318	0.241106
NHBNWSTOP	0	0.019402

Summary

Figure 25 shows the order of HB trips in term of percentage of HB trips generating NHB trips for both Method 1 and 2. The gap between Method 1 and Method 2 lines suggested NHB stops associated NHB trips (complex tour). All the discussions in Method 1 still apply in Method 2. A few additional observations:

1. NHB stops are more likely to occur in HBW_SR3, HBW_DR, and HBW_SR2. In other words, HBW trips are more likely to be involved in complex tour with more than 3 trips in a tour.
2. NHB Stops contribution for these trips are very small: HBO_TR, HBSch_TR, HBC_TR, HBC_NM, HBSch_NM, and HBSch_SB. This suggests that transit, non-motorized mode and school bus are less unlikely to be involved in NHB stops. In other words, these three modes are less likely to be involved in complex tours with more than 3 trips in a tour.

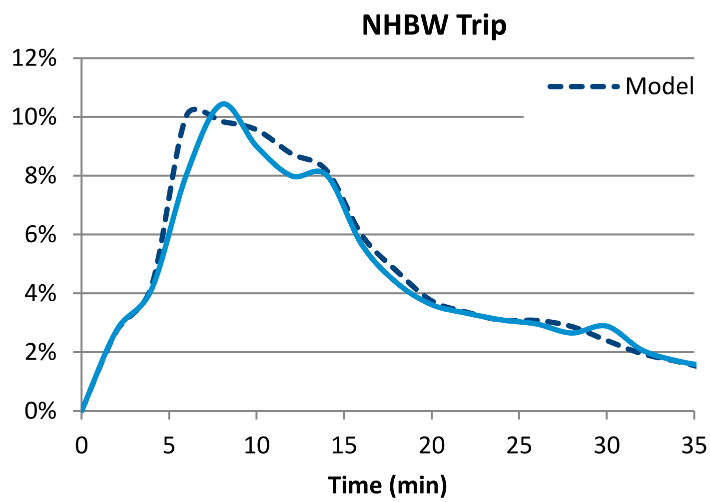


Source: FHWA

Figure 25. Generation orders.

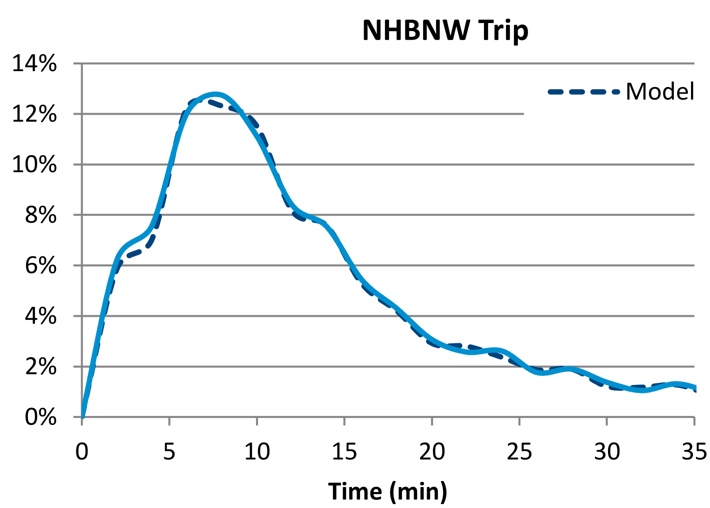
6.2.4 Update of NHB Non-Transit Trip Distribution

Figure 26 and Figure 27 show the calibration of NHBW and NHBNW trip lengths. Note that trip length is for actual NHB trips, not for pseudo-trips to NHB stops. As in Method 1, it was easy to calibrate friction factors for gravity models to replicate observed trip length frequency distributions.



Source: FHWA

Figure 26. NHBW Trip length calibration.

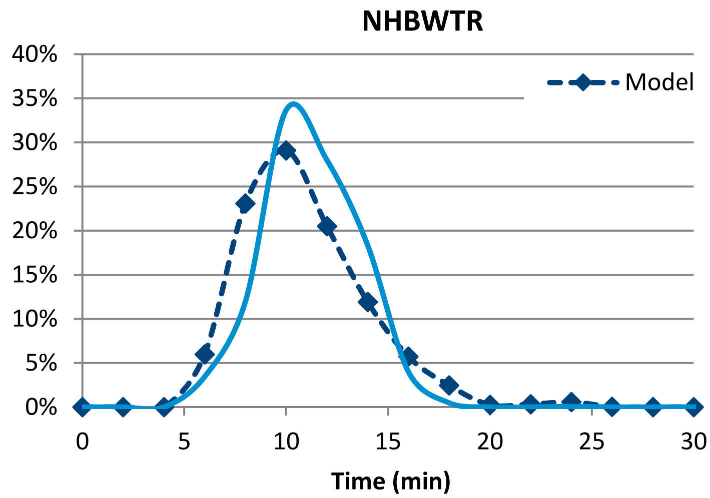


Source: FHWA

Figure 27. NHBNW trip length calibration.

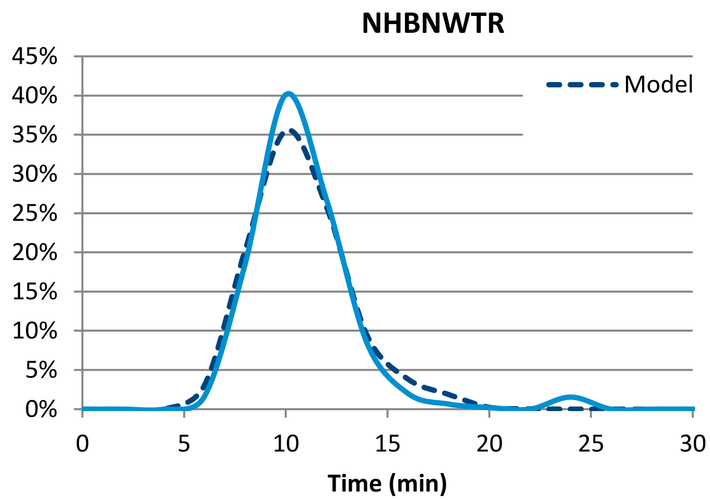
6.2.5 Update of NHB Transit Trip Distribution

Figure 28 and Figure 29 show calibrated NHBW and NHBNW transit trip length (measured as –LogSum of transit mode). Due to difference of method 1 and method 2, the LogSum distribution from survey is slightly different (see Figure 20 and Figure 21).



Source: FHWA

Figure 28. NHBW transit trip length calibration.

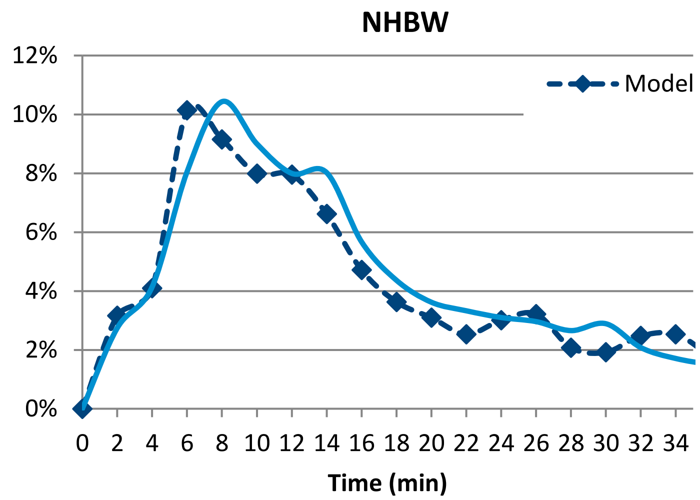


Source: FHWA

Figure 29. NHBNW transit trip length calibration.

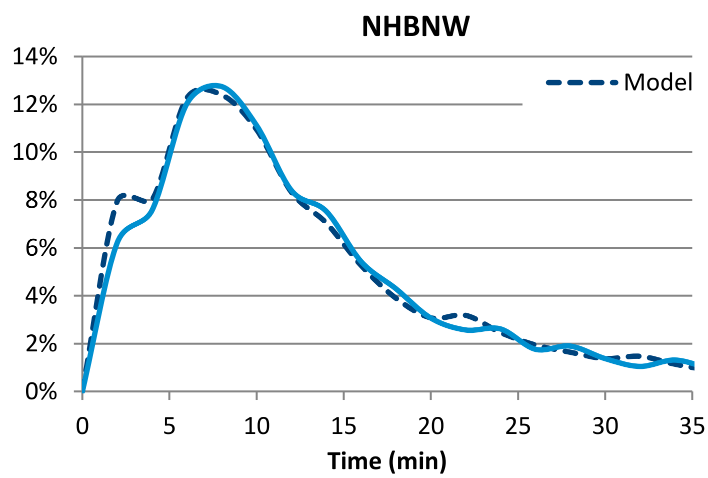
6.3 Method 3 Implementation

Method 3 was implemented solely as a structural change – conducting NHBW and NHBNW trip distribution within a loop over (HB trip) production zones rather than once for all zones. The NHB trip generation parameters were the same as for Method 2. The friction factors were also used from Method 2, with additional calibration. Due to run time and memory limitation, the implementation of method 3 is slightly revised from proposed. Instead of conducting trip distribution zone by zone, the distribution is conducted by zones within the same district. The NHB non-transit trips and NHB transit trips were recalibrated for method 3, see Figure 30 through Figure 33).



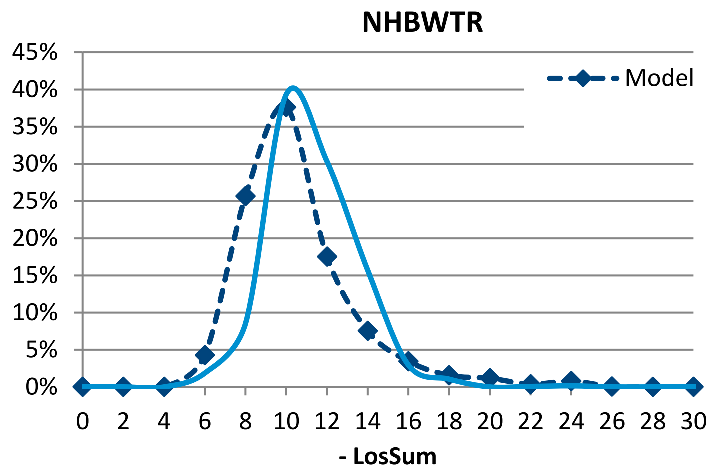
Source: FHWA

Figure 30. NHBW non-transit trip length calibration.



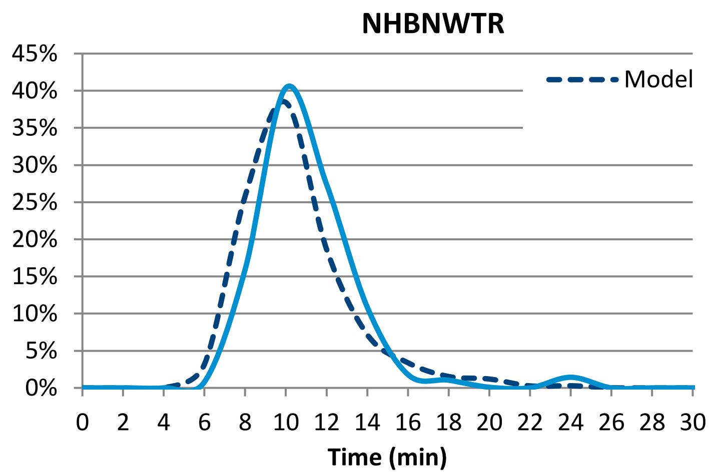
Source: FHWA

Figure 31. NHBNW non-transit trip length calibration.



Source: FHWA

Figure 32. NHBW transit trip length calibration.



Source: FHWA

Figure 33. NHBNW transit trip length calibration.

7.0 Testing Scenarios and Results

While a variation on Method 3 has been tested and shown to represent a real improvement over a four step model's ability to reproduce the spatial distribution of trips (Bernardin and Conger, 2010), Methods 1 and 2 have never been tested, nor has the mode choice or transit results. The handling of mode and Methods 1 and 2 are original to this effort.

The calibration results for both Method 1 and 2 provide not only a demonstration of the feasibility of these approaches but also provide some validation arising from the extremely intuitive and plausible results which agree with other research on the complexity of tours, etc. For instance, these models indicate that transit and non-motorized tours are less complex, which has been observed in research studies and in activity-based model development.

However, it is critically important to test the response the properties of the alternative model structures to confirm the hypothesis that given their greater consistency with tours and real underlying travel patterns, that their response properties will be more logical than those of traditional four-step models.

For these reasons, two types of testing were conducted: first, logical response testing and second, comparisons to survey data.

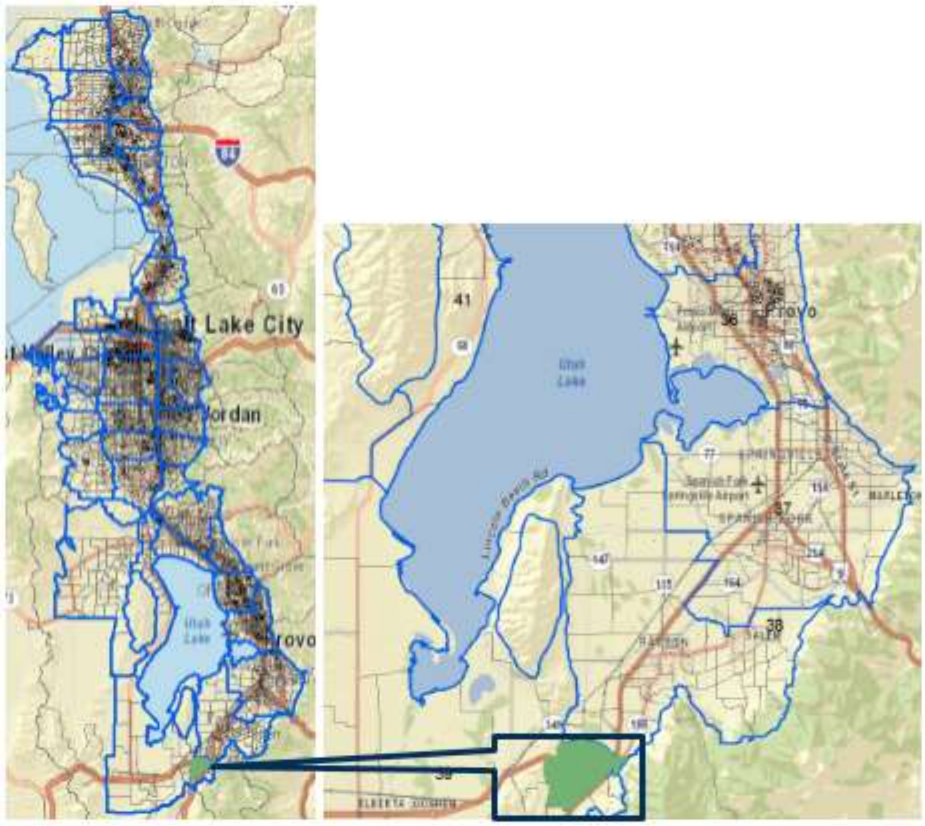
7.1 Response Testing

Part of the key motivation of this effort is the poor and sometimes even potentially illogical response properties of NHB trips in traditional trip-based models, such as those illustrated in the example in Figures 1 and 2 (e.g., a new subdivision can produce new NHB trips in areas where it produces practically no HB trips). One of the key hopes is to demonstrate that the response properties of models improved according to the proposed methods are superior to their unenhanced predecessors; that they produce logical and reasonable responses to basic changes in inputs. As straightforward as this may seem and as easy as this can be to take for granted, it is important to confirm this given the fundamental architectural changes to the model structure that the proposed methods represent.

Four scenarios were used for logical response testing. The first scenario mirrors the example discussed earlier and involves a hypothetical new residential development in a previously undeveloped zone. The second scenario involves a new commercial development. The third scenario involves a highway travel time improvement (new facility or congestion relief) and the fourth scenario represents a new or improved transit service.

7.1.1 Test Scenario One: New Residential Development

Figure 34 shows the study area of the WFRC model. The new residential area is designed to locate in the far south of the region. The dots in the map represent employment density. New residential zones locate in district 39, where there is very little employment. There is some employment in District 37 and 38, but not much. Most employment locates in district 36 and above.



Source: Google Maps™

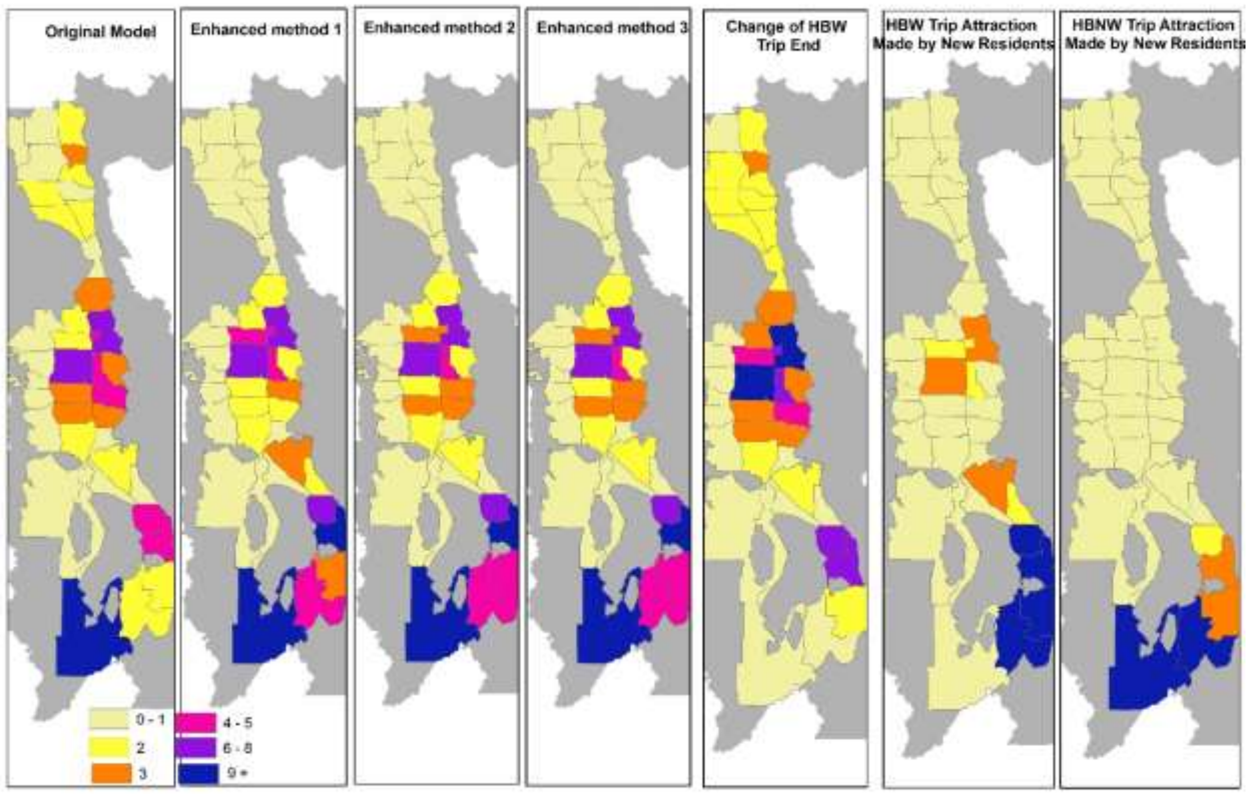
Figure 34. New residential zones.

In the WFRC model, average population density by TAZ is about 3,000 persons per sq. mile. The TAZ with highest population density is TAZ 2001, with more than 45,000 persons per sq. mile. The chosen new residential zones located in rural area, and current population densities range from 7 to 3,000. It is assumed that there is major residential development around the area that would push the population density to 12,000 persons per sq. mile. The average household size remained unchanged. Table 42 shows total population, household and population density for the base scenario, the scenario with new residential development and the change in the new development zones. The increase represents a 1.9% increase over the total base year population and a 1.7% increase in households.

Table 42. New residential development scenario setting.

TAZ	Area (Sq. Miles)	Base Scenario (Population)	Base Scenario (Population Density)	Base Scenario (HH)	New Residential Zone Scenario (Population)	New Residential Zone Scenario (Population Density)	New Residential Zone Scenario (HH)	Changes (Population)	Changes (HH)
2210	1.02	1115	1089	312	12284	12000	3441	11169	3129
2223	0.60	4	7	1	7256	12000	2033	7252	2032
2222	0.55	11	20	3	6616	12000	1853	6605	1850
2211	0.22	392	1766	110	2664	12000	746	2272	636
2212	0.48	142	294	40	5792	12000	1622	5650	1582
2218	0.23	777	3324	217	2805	12000	786	2028	569
2219	0.29	617	2152	172	3441	12000	964	2824	792
2213	0.27	367	1355	103	3250	12000	910	2883	807

Figure 35 shows the percentage change of trip attractions by district. From left to right, they are change in NHBW attractions from original model, change in NHBW attractions from Method 1 model, change in NHBW attractions from Method 2 model, change in NHBW attractions from Method 3 model, change of HBW attractions (same in all models), HBW trip attractions made by new residents (same in all models), and HBNW trip attractions made by new residents (same in all models).



Source: FHWA

Figure 35. Percentage change of NHBW trip attraction: base vs. scenario one.

The maps on the right indicate where the new residents travel on their HB trips. The map second to right shows the distribution of HBW trip attraction made by new residents. They would appear in:

1. Provo and its neighbors in the south
2. the Salt Lake City area

Since the HB models are same in all versions of the model, these results do not depend on the whether the model is enhanced or not.

The map on the far left shows the location of new NHB attractions in the original model and suggests that new NHB trip attractions would appear in (ordered in terms of magnitude of percentage):

1. the far south home district where the new residents live;
2. the Salt Lake City area, which has the most employment opportunities but is fairly far from home;
3. the Provo area, which also has many employment opportunities and is closer to home;
4. some areas in and around Ogden in the very north of the region;

This pattern is clearly inconsistent with the pattern of HBW trips generated by the new households as illustrated in the maps second from the right. **The new households make essentially no HBW trips to the Ogden area in the far north of the model area, yet the model predicts new NHBW trips there.** The relative distribution of NHB trips among the other areas is also inconsistent with Salt Lake City showing more new NHB trips than Provo and areas south, while clearly more of the new HB trips are attracted to Provo and areas south and only some of the new HBW trips are attracted to Salt Lake City.

Instead of reflecting the new HB trips, the new NHB trips in the original model clearly largely reflect the fourth map in Figure 35 which shows the change of HBW trip ends (note that this is the same for original and enhanced models). Due to the increase of population in the far south, the change of HBW trip end mainly appear in:

1. the Salt Lake City area
2. Provo and its neighbor districts
3. Areas around Salt Lake City
4. some areas in and around Ogden in the very north of the region

Note that although we did not assume an increase of employment, there is a scaling or balancing process in the original model so that total available HBW attractions actually increased to match the increase in HBW productions. This clearly drives the original model's response and may still exert an indirect and less pronounced effect on the enhanced models.

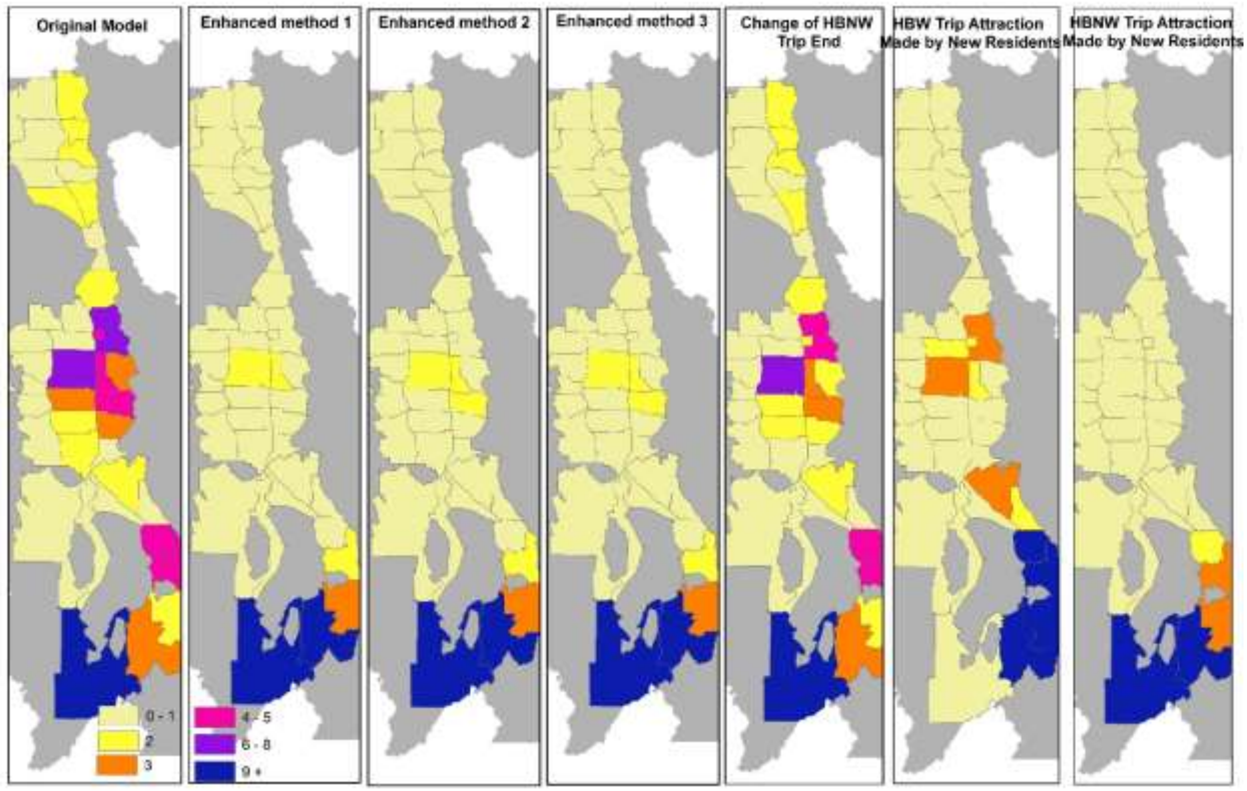
Turning finally to the enhanced models in the second to fourth maps from the left, the enhanced Method 1 model suggests that new NHB trip attractions would appear in (ordered in terms of magnitude of percentage):

1. the far south home district where the new residents live and
2. the Provo area which has many employment opportunities and is also close to home;
3. the Salt Lake City area which has the most employment opportunities but is far from home;

The enhanced Method 2 and Method 3 models suggest largely similar patter as method 1 only in it, NHB attractions are skewed even closer to home and less in Salt Lake City, more consistent with the distribution of new HB trips.

Clearly the enhanced models represent a more consistent spatial distribution of HB and NHB trips than the original model with no enhancements. The enhanced models are not perfect, either, but represent a major improvement. A significant part of the problem which appears dominant in the original model and still remains to a lesser extent in the enhanced models is the method of balancing attractions to productions over the whole model area. The model could likely be further enhanced if a more flexible system of balancing could be developed. Even a simple scheme where balancing was done at the level of some super-districts would likely yield notably improved results.

Figure 36 shows the percentage change of NHBNW trip attraction by district. From left to right, they are change from original model, change from Method 1 model, change from Method 2 model, change from Method 3 model, change of HBNW trip end, HBW trip attraction made by new residents, and HBNW trip attraction made by new residents.



Source: FHWA

Figure 36. Percentage change of NHBNW trip attraction: base vs. scenario one.

Again, the maps on the right indicate where the new residents travel on their HB trips. The map on the far right map in Figure 36 shows the distribution of HBNW trip attraction made by new residents. They would appear in:

1. the far south home district where the new residents live and its neighbors
2. Provo and its neighbors in the south

And as noted above, the map second to right shows the distribution of HBW trip attraction made by new residents. They would appear in:

1. Provo and its neighbors in the south
2. the Salt Lake City area

The original model on the far left suggests that new NHBNW trip attractions would appear in (ordered in terms of magnitude of percentage):

1. the far south home district where the new residents live;
2. the Salt Lake City area, which has large retail and food services but is far from home;
3. Provo and surrounding areas which also have large retail and food services and also is close to home;
4. some areas in and around Ogden in the very north of the region.

As above with NHBW trips, this pattern is clearly inconsistent with the pattern of HB trips generated by the new households as illustrated in the two rightmost maps. **The new households make essentially no HB trips to the Ogden area in the far north of the model area, yet the model predicts new NHBNW trips there.** The relative distribution of NHB trips among the other areas is also inconsistent with Salt Lake City showing more new NHB trips than Provo and areas south, while clearly more of the new HB trips are attracted to Provo and areas south and only some of the new HBW trips are attracted to Salt Lake City.

In contrast, the enhanced Method 1 model suggests that new NHBNW trip attractions would appear in (ordered in terms of magnitude of percentage)

1. the far south home district where the new residents live and its neighbor;
2. the Provo area which has many shopping, eating, etc. opportunities and is also close to home;
3. the Salt Lake City area which has more shopping, eating, etc. opportunities but is far from home;

The enhanced Method 2 and 3 models predict basically the same pattern as Method 1.

The fourth map in Figure 36 shows the change of HBNW trip end (note that this will be the same for original and enhanced models). Due to increase of population in district 37, the change of HBNW trip end mainly appear in:

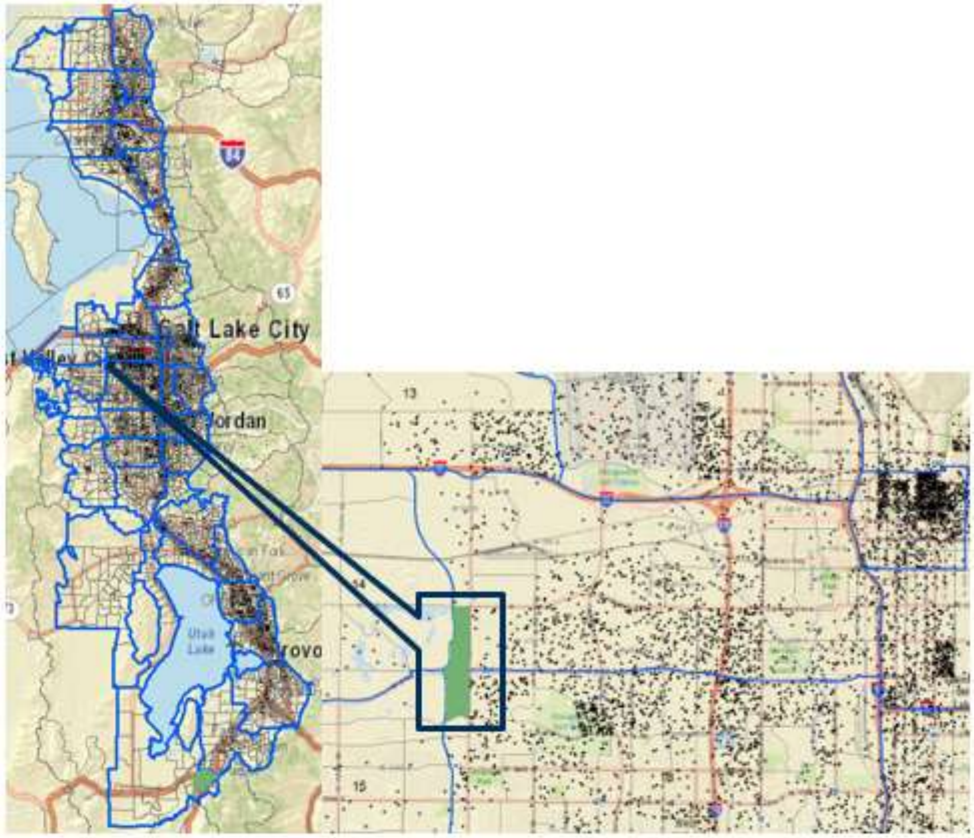
1. the far south home district where the new residents live
2. the Salt Lake City area
3. the Provo area
4. some areas in and around Ogden in the very north of the region

As with the work trips, this map is helpful in illustrating how the generic, model-wide balancing of attractions to productions results in unrealistic response properties in the original model. In this case, the enhanced models appear to be able to compensate for the problem. Again, the enhanced models are still not perfect and may be a bit overly restrictive in the distribution of new NHBNW trips. However, on the whole, their distributions appear far more consistent with the new HB trips than the distribution from the original model. The overly restrictive nature of the distributions is at least in part a result of the distribution of the new HB trips.

In summary, the first test scenario indicates that the enhanced methods produce much more reasonable responses to new residential developments than the original model, but that they are still not necessarily perfect. Moreover, the test suggests that in addition to the NHB enhancements explored here, simplistic balancing procedures common in many four-step models should be reconsidered as they may in themselves produce problematic model responses.

7.1.2 Test Scenario Two: New Commercial Development

Figure 37 shows the proposed new commercial development zones, located to southwest of CBD. Region-wide average employment density is 3,300 jobs per sq. miles and maximum density is 200,000 jobs per sq. miles. The new commercial development would be split between food and retail employment, given that these two categories generate the most NHB stops.



Source: Google Maps™

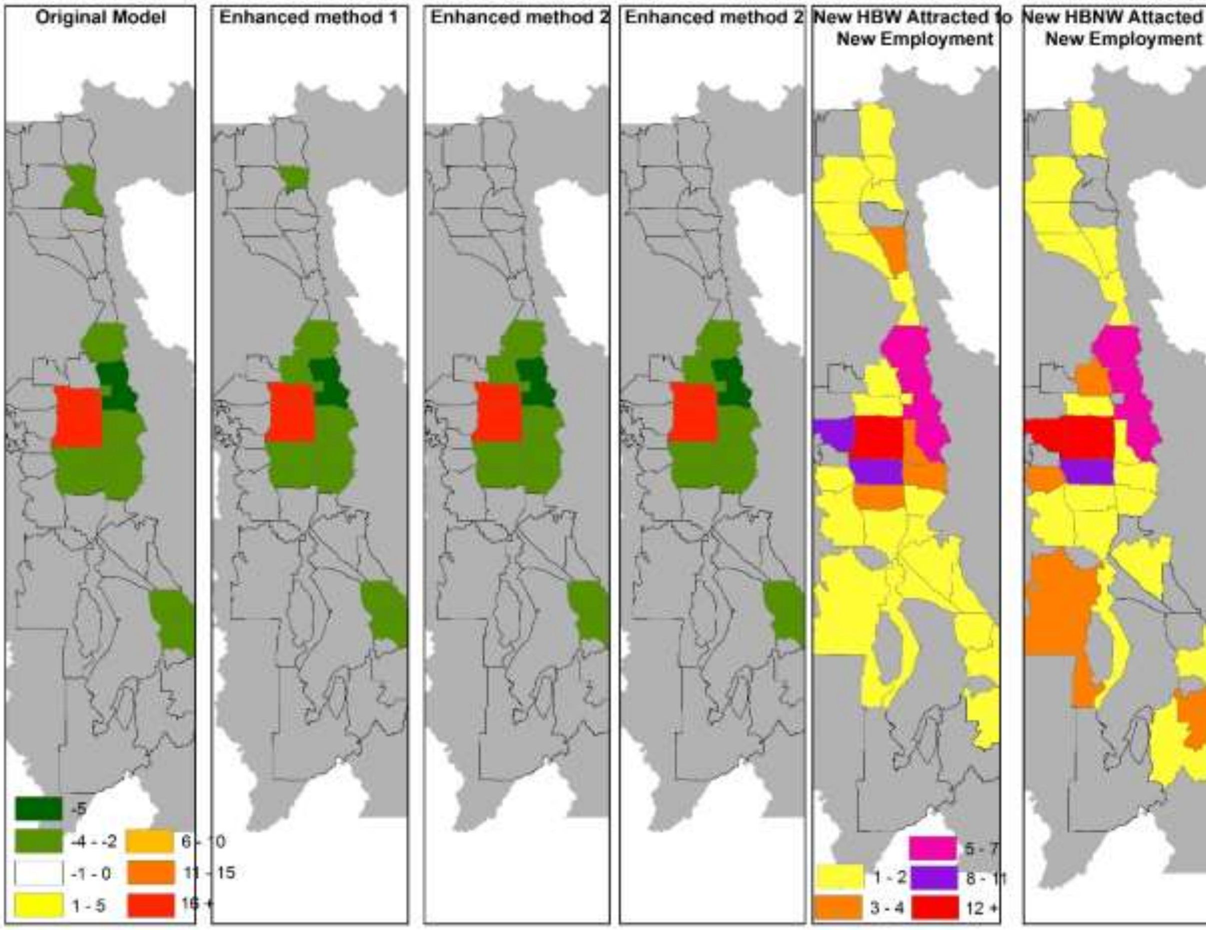
Figure 37. New commercial development.

The chosen new commercial development is located in TAZ 641 and 655, where there is currently almost no commercial development. Test scenario two increases the employment density to 50,000 jobs per sq. miles, a considerable amount compared to region-wide average but still significantly less than the CBD, see Table 43.

Table 43. New commercial development scenario setting.

Zone	Area	Base Scenario Employment	Base Scenario Employment Density	New Commercial Scenario Employment	New Commercial Scenario Employment Density	Increased Employment
641	0.29	0	0	14384	50000	14384
655	0.27	235	11	13709	50000	13474

Figure 38 shows the percentage change of NHBW trip attraction by district. From left to right, they are change from original model, change from method 1 model, change from method 2 model, change from method 3 model, new HBW trips attracted to district 17 and district 18, and new HBNW trips attracted to district 17 and 18.



Source: FHWA

Figure 38. Percentage change of NHBW trip attraction: base vs scenario two.

The original model suggests that NHBW trip attractions would:

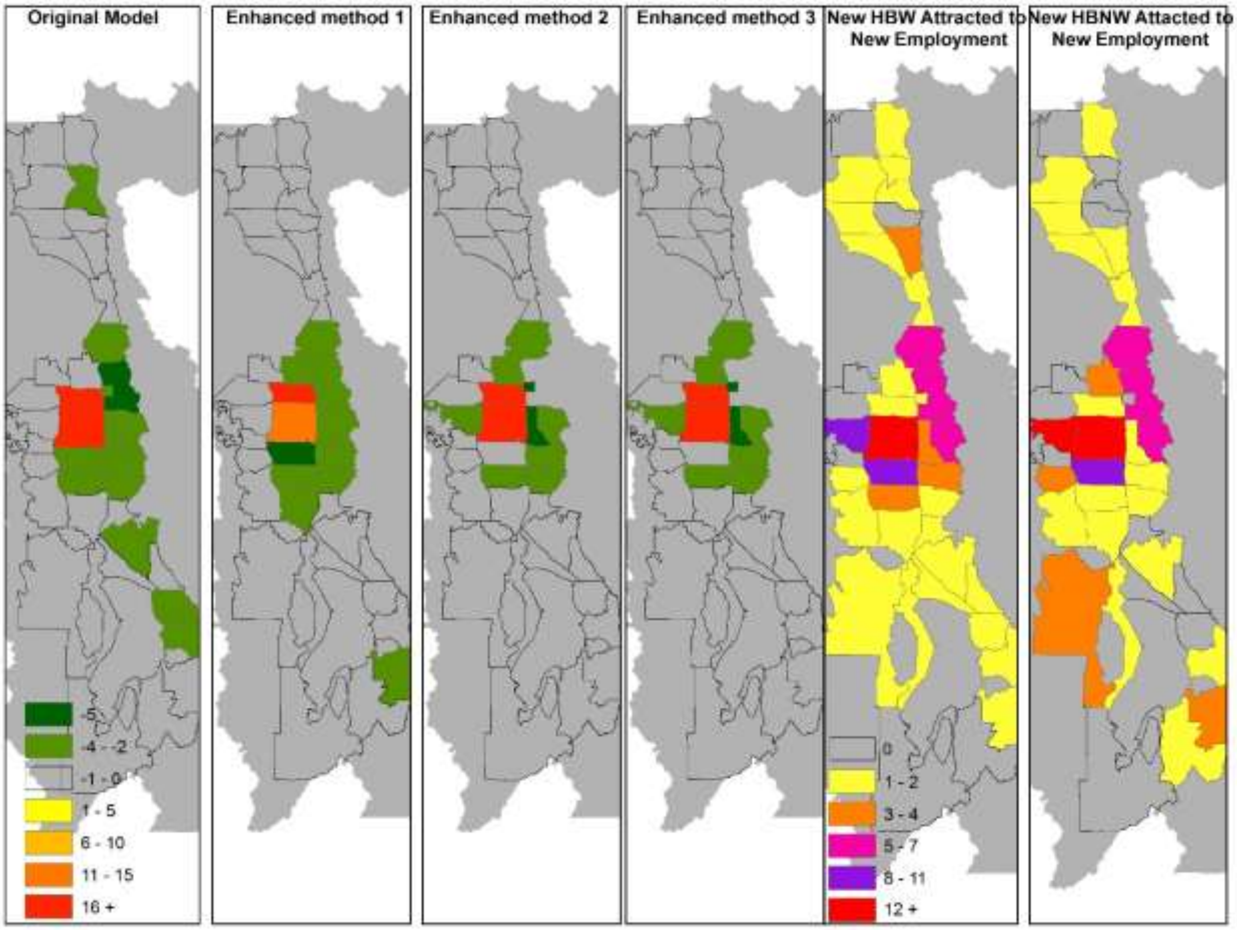
1. Increase in District 17 and 18 where the new employment located and nearby;
2. Decrease elsewhere, especially for central Salt Lake City, but also in Ogden and Provo

The enhanced model 1, 2 and 3 tell almost the same story as original model, but show just slightly less decrease in NHBW trips further away from the new development (with Method 2 showing just slightly less than Method 1). The fifth map in Figure 38 shows the origins of new HBW trips attracted to district 17 and district 18. These trips mainly come from:

1. District 17 and 18 where the new employment located and nearby
2. Zones surrounding district 17 and 18

The dropping of NHBW trip attractions in central Salt Lake City is due to diversion of HBW trips to district 17 and 18 from the CBD. In this comparison, both original and enhanced models have largely consistent change of NHBW patterns with change of HBW pattern although the enhanced methods show slightly more localized impacts.

Figure 39 shows the percentage change of NHBNW trip attraction by district. From left to right, they are change from original model, change from method 1 model, change from method 2 model, change from method 3 model, new HBW trips attracted to district 17 and district 18, and new HBNW trips attracted to district 17 and 18. The change patterns of NHBNW trip attraction are basically similar to NHBW. Both the original and enhanced models are fairly reasonable and consistent with each other and intuition but again, the enhanced methods show slightly more localized impacts.



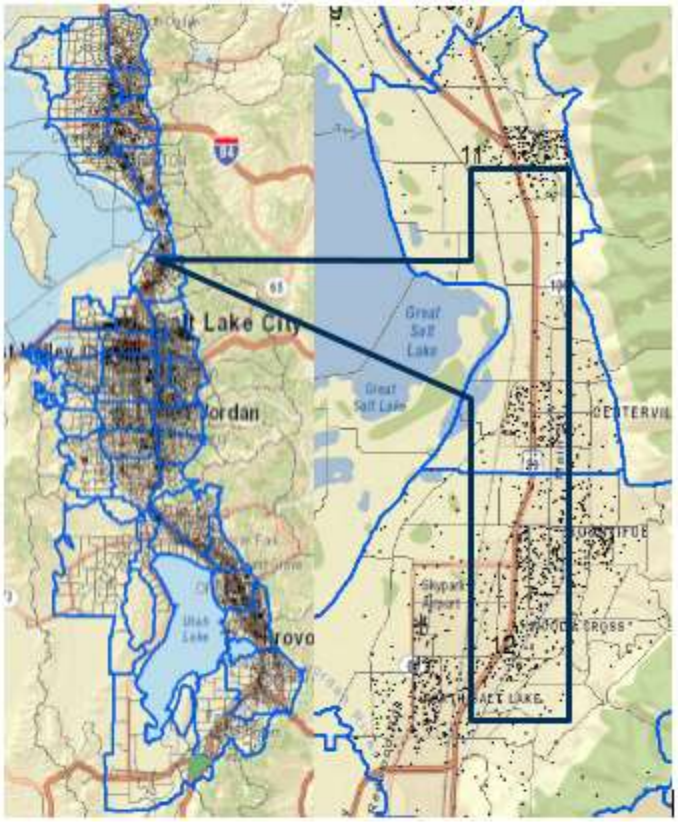
Source: FHWA

Figure 39. Percentage change of NHBNW trip attraction: base vs scenario two.

In summary, the second test scenario shows generally similar results between the original and enhanced models, with slightly more localized impacts in the enhanced model. The greater localization of impacts seems plausible but is not necessarily more accurate than the original model; empirical studies with real world before and after data would be required to determine if one model were actually more realistic.

7.1.3 Testing Scenario Three: Highway Improvement

Figure 40 shows the highway improvement testing scenario setting. It is planned to improve the capacity (double number of lanes, from 4 lanes each direction to 8 lanes each direction) of freeway 89 connecting Salt Lake City CBD and Ogden. The corridor is quite congested in the afternoon peak period with volume over capacity larger than 1 from the original WFRC model assignment results.



Source: Google Maps™

Figure 40. Highway improvement scenario.

The study region is divided into two parts to observe the effect of a highway improvement connecting these two parts: Ogden to the north and the rest of the area to the south of the improvement.

Table 44 shows the OD pattern change for HBW auto trips between Ogden and the rest of the model. There is little change in HBW auto trips between the two parts. There are even confusing results from the various models. For instance, the shared ride between the two districts increased according to original model and method 2 and 3, however they decreased in method 1. Given the very small magnitude of change, the observed change might simply be due to rounding error.

Table 44. OD pattern change for HBW auto trips.

Methods	Auto (Ogden)	Auto (Rest)	DA (Ogden)	DA (Rest)	Shared Ride (Ogden)	Shared Ride (Rest)
Original (Ogden)	0.01%	-0.11%	0.04%	-0.19%	-0.03%	0.91%
Original (Rest)	-0.15%	0.00%	-0.22%	0.01%	0.91%	-0.05%
Method 1 (Ogden)	0.01%	0.07%	0.02%	0.11%	0.13%	-0.47%
Method 1 (Rest)	-0.05%	-0.01%	-0.02%	-0.01%	-0.47%	0.00%

Methods	Auto (Ogden)	Auto (Rest)	DA (Ogden)	DA (Rest)	Shared Ride (Ogden)	Shared Ride (Rest)
Method 2 (Ogden)	0.02%	-0.56%	0.13%	-0.72%	0.00%	1.63%
Method 2 (Rest)	-0.54%	0.01%	-0.67%	0.02%	1.37%	-0.10%
Method 3 (Ogden)	0.02%	-0.56%	0.13%	-0.72%	0.00%	1.63%
Method 3 (Rest)	-0.54%	0.01%	-0.67%	0.02%	1.37%	-0.10%

Table 45 shows the OD pattern change for HBO auto trips between Ogden and the rest. All three models suggest the increase of both drive alone and shared ride between Ogden and the rest which is a logical response to the decrease in congestion.

Table 45. OD pattern change for HBO auto trips.

Methods	Auto (Ogden)	Auto (Rest)	DA (Ogden)	DA (Rest)	Shared Ride (Ogden)	Shared Ride (Rest)
Original (Ogden)	-0.07%	1.07%	-0.06%	0.77%	-0.07%	1.42%
Original (Rest)	1.00%	0.00%	0.61%	0.01%	1.46%	0.00%
Method 1 (Ogden)	-0.06%	1.19%	-0.06%	1.07%	-0.07%	1.34%
Method 1 (Rest)	1.20%	0.00%	0.96%	0.00%	1.48%	0.00%
Method 2 (Ogden)	-0.06%	1.21%	-0.05%	0.92%	-0.08%	1.55%
Method 2 (Rest)	1.29%	0.00%	0.97%	0.00%	1.67%	0.00%
Method 3 (Ogden)	-0.06%	1.21%	-0.05%	0.92%	-0.08%	1.55%
Method 3 (Rest)	1.29%	0.00%	0.97%	0.00%	1.67%	0.00%

Table 46 shows the OD pattern change for NHB auto trips between Ogden and the rest. Both model 1 and model 2 suggest the increase of both drive alone and shared ride between Ogden and the rest. Model 3 suggest the increase of NHB trips within Ogden area only, which may be a result of the difference in methodology.

Table 46. OD pattern change for NHB auto trips.

Methods	Auto (Ogden)	Auto (Rest)	DA (Ogden)	DA (Rest)	Shared Ride (Ogden)	Shared Ride (Rest)
Original (Ogden)	-0.07%	2.04%	-0.06%	1.33%	-0.11%	3.30%
Original (Rest)	2.04%	-0.02%	1.33%	-0.01%	3.30%	-0.05%
Method 1 (Ogden)	-0.16%	2.03%	-0.15%	1.89%	-0.18%	2.38%
Method 1 (Rest)	3.02%	-0.04%	2.71%	-0.04%	3.72%	-0.04%
Method 2 (Ogden)	-0.13%	2.44%	-0.12%	2.39%	-0.13%	2.58%
Method 2 (Rest)	3.04%	-0.05%	2.92%	-0.05%	3.33%	-0.05%
Method 3 (Ogden)	0.04%	0%	0.05%	0%	0.02%	0%
Method 3 (Rest)	0%	-0.01%	0%	-0.01%	0%	0.00%

In general, no major differences was observed from the results of original and enhanced models in this scenario test. It is perhaps unsurprising that there is little difference in the results for HB trip purposes since the HB trip models are unchanged by the enhancements and the only differences come indirectly from the differences in the contribution of NHB trips to congestion in assignment which feeds back to affect HB trips in distribution.

The greatest difference observed is in the NHB trips. While not extremely large, the enhanced models (1 & 2) do show greater sensitivity and a greater shift of NHB trips in response to the added capacity (a 2.5 – 3.0% increase in trips between Ogden and the rest in the enhanced models versus a 2.0% increase in the original model). Method 3, in contrast, shows almost no change in NHB trips. Neither the reason nor the reasonableness of these differences are apparent to the authors at this time.

In summary, test 3 shows a very small differences between the original and enhanced models, and it is not apparent which result is more realistic.

7.1.4 Testing Scenario Four: Transit improvement

In this testing scenario, light rail transit headway were reduced to improve transit accessibility. The NHB trip mode split of the original model is a function of auto and transit accessibility. It is expected that there will be some mode shift reported by the original model. In the enhanced models, the NHB trip mode depends on preceding HB trip mode choice models. However, since we have found that HB trips by transit mode are much less likely to generate NHB trips, this suggests that mode shift in the enhanced model may be in smaller magnitude. Table 47 shows the mode split for base scenario NHB trips, Table 48 shows the mode split for test scenario 4, and Table 49 shows the change. Note that the percentage change in Table 49 is in terms of individual mode: from 0.09% to 0.12% increase is 34% of NHB transit trips according to original model. The enhanced model however only suggested about 5% to 7% increase of NHB trips by transit.

Table 47. NHB mode split for base scenario.

Mode	Original Model	Method 1	Method 2	Method 3
Auto	95.38%	92.71%	93.39%	93.37%
NM	4.53%	6.43%	5.51%	5.50%
Transit	0.09%	0.86%	1.10%	1.13%

Table 48. NHB mode split for test scenario 4.

Mode	Original Model	Method 1	Method 2	Method 3
auto	95.16%	92.59%	93.23%	92.98%
NM	4.72%	6.50%	5.61%	5.83%
transit	0.12%	0.91%	1.17%	1.19%

Table 49. NHB mode split change.

Mode	Original Model	Method 1	Method 2	Method 3
auto	-0.23%	-0.13%	-0.18%	-0.42%
NM	4.16%	1.18%	1.73%	5.97%
transit	33.98%	5.27%	6.57%	5.76%

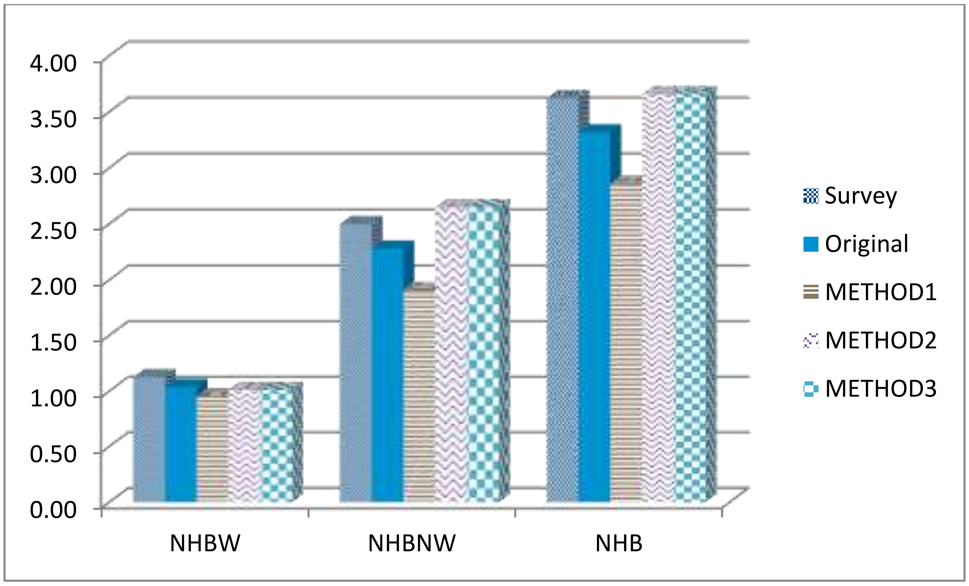
The enhanced models do show less responsiveness of NHB trips as expected based on the enhanced NHB trip generation results. There is some plausibility of the enhanced results; however, whether they are actually more accurate would require empirical case studies with real before and after data. However, the test also highlight that enhanced methods result in slightly different base mode shares from the original model. In this case the enhanced models actually agree better with the survey data than the original model and the near agreement of the mode shares without any calibration of the enhanced NHB models to mode shares does offer some validation of the enhanced models.

7.2 Comparisons to Survey Data

This proposed testing also involved comparing and testing base scenario model results against real travel patterns observed in the household travel and on-board transit surveys. The observed origin-destination patterns by mode from the surveys would be compared with the four versions of the model for each region.

7.2.1 NHB Trip Rates

Figure 41 shows the comparison of NHB trips between the survey and the original model and enhanced methods 1, 2, and 3.



Source: FHWA

Figure 41. NHB trip rates.

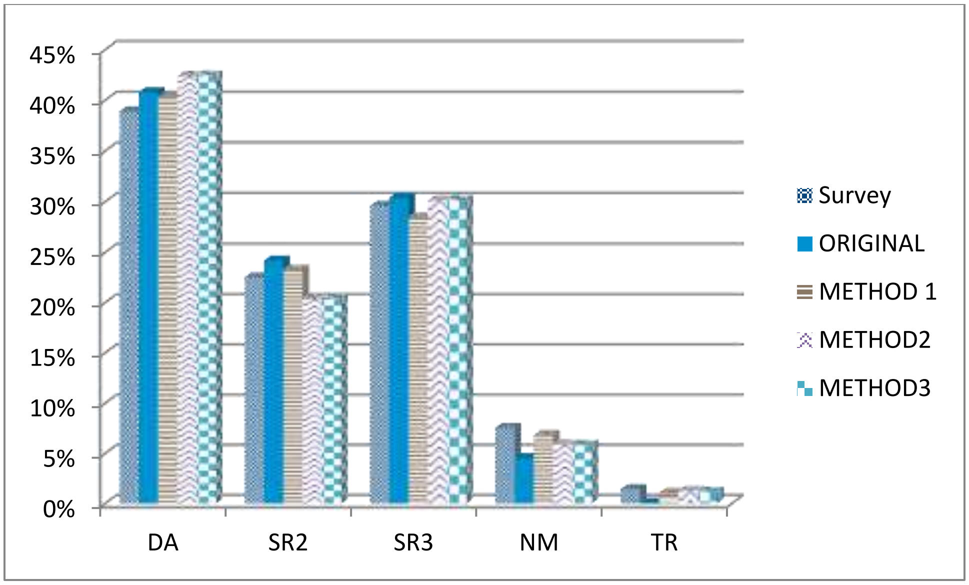
The enhanced Method 2 and 3 models replicate the observed survey rates best and significantly better than the original model. However, the enhanced Method 1 model is worst at replicating the observed survey rates, significantly worse than the original model. This provides some indication that Method 2 may offer a significant improvement over Method 1 and the original model while it suggests that Method 1 may require some further calibration beyond trip generation estimation and/or that it actually may be slightly less accurate than the original model in this regard.

7.2.2 NHB Trip Lengths

The fit of NHB trip lengths to observed lengths has already been established in Figure 18, Figure 19, Figure 20, and Figure 21. Since the goodness-of-fit of these distributions is purely a result of the number of iterations of friction factor calibration, there is no meaningful comparison or contrast between these measures across the various model forms.

7.2.3 NHB Trip Mode Share

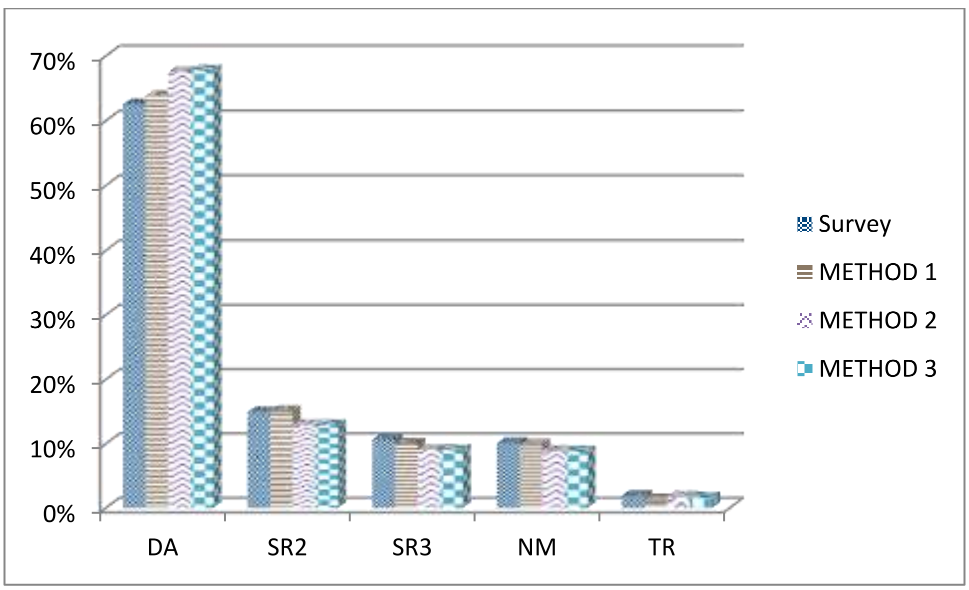
Figure 42 shows the comparison of mode share of NHB trips from household travel survey and three versions of model for base scenario. In general all models' mode split for NHB trips are fairly consistent with survey, but the enhanced models generally agree with the survey slightly better than the original model. In particular, the enhanced models do a better job of replicating non-motorized and transit mode shares for NHB trips. Especially considering that the original model was calibrated to replicate the survey mode shares and the enhanced models were not calibrated but simply estimated directly from survey data, this does seem to offer some validation of the enhanced models and potentially some superiority over the original, standard approach.



Source: FHWA

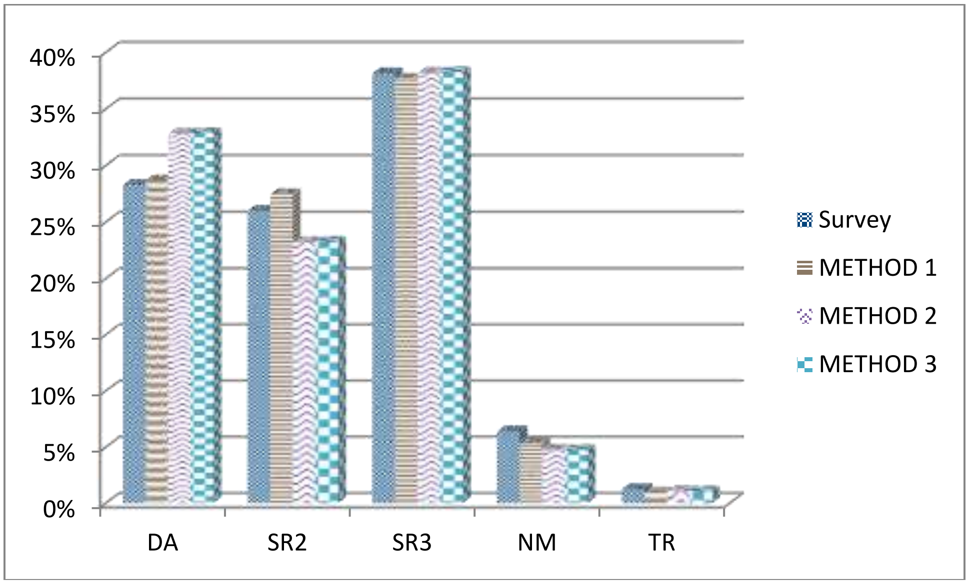
Figure 42. Mode share of NHB trips comparison.

In the original method, the NHBW and NHBNW trips are summed together for the mode choice model. In the enhanced methods, however, the NHBW and NHBNW trips by mode have separate functions. Figure 43 and Figure 44 show the comparison of mode share of NHBW and NHBNW trips from the household travel survey and enhanced models. In general, the mode splits from enhanced models are consistent with survey NHBW and NHBNW mode split.



Source: FHWA

Figure 43. Mode share of NHBW trips comparison.



Source: FHWA

Figure 44. Mode share of NHBNW trips.

7.2.4 Formal Statistical Goodness-of-Fit

The final metrics proposed are formal statistical measures of the goodness-of-fit of each model to the survey data. These metrics are:

- Adjusted rho-squared versus zero of the final NHB auto trip table
- Adjusted rho -squared versus zero of the final NHB transit trip table
- Adjusted rho -squared versus zero of the final NHB trip tables across both modes

The auto trip tables from the model were compared to the household survey data (auto mode observations) and the transit trip tables from the models were compared to the on-board survey data. The adjusted rho-squared is derived by comparing the log-likelihood of the model versus the observed data to the log-likelihood of a uniform discrete distribution versus the observed data. (It can be thought of as analogous to or an extension of the common r^2 used as a standardized goodness-of-fit measure for regression models derived from the sum of squared errors.)

$$\rho_0^2 = 1 - \frac{LL(model\ distribution) - degrees\ of\ freedom}{LL(uniform\ distribution) - degrees\ of\ freedom}$$

Figure 45. Equation. Rho-squared.

The log-likelihood of a probability distribution versus a set of discrete observations (weighted trips by mode in this case) is defined as follows:

$$LL = \sum_{o,d,m} w_{odm} ln(P_{odm})$$

Figure 46. Equation. Log-likelihood of distribution.

where,

o: origin zone

d: destination zone

m: mode

w: weighted number of observations

P: probability

Although it is not common to think of trip-based model results as probability distributions, they can be easily understood and interpreted this way. The final trip tables can be easily converted into probability distributions by dividing each cell by the grand sum of the matrix (or of all matrices). A uniform probability distribution is simply a matrix (or matrices) of constants equal to the inverse of the dimensions of the distribution (number of zones x number of zones x modes).

Although adjusted rho-squared statistics may be less transparent than metrics such as average distances, they can be interpreted as the percentage of the variation in the observed data explained by the model, and they are the best statistical measures of the similarity of the models to the observations.

Table 50 shows rho-squared for just NHB auto trip and Table 51 shows rho-squared for both NHB auto and transit mode.

Table 50. Rho-squared statistics of auto trips.

	Rho-Squared	**Horowitz's non-nested hypothesis test**
Original Model	0.328	
Enhanced Method 1	0.343	<0.001
Enhanced Method 2	0.341	<0.001
Enhanced Method 3	0.329	<0.001

Table 51. Rho-squared statistics of both auto and transit.

	Rho-Squared	**Horowitz's non-nested hypothesis test**
Original Model	0.294	
Enhanced Method 1	0.328	<0.001
Enhanced Method 2	0.323	<0.001
Enhanced Method 2	0.310	<0.001

Table 52. rho-squared statistics of transit.

	Rho-Squared	Horowitz's non-nested hypothesis test
Original Model	-1.924	
Enhanced Method 1	-0.430	<0.001
Enhanced Method 2	-0.525	<0.001
Enhanced Method 2	-1.075	<0.001

The enhanced models clearly offer some improved statistical goodness-of-fit over the original model. Although the improvement is modest for autos and overall, it may still be meaningful. The improvement in both total trips from 0.29 to 0.33 in relative terms is a 10% increase in the explanatory power of the enhanced model over the original model. While this magnitude of difference is not a clear mandate for the enhanced methods by itself, together with the improved response properties illustrated in the Scenario 1 test and the improved accuracy of trip rates and mode shares versus the survey, it makes a case for the superiority of the enhanced models.

In this implementation, Method 3 used the friction factors calibrated for Method 2, and this may explain the relatively poorer performance of Method 3 and indicate that it is necessary to calibrate friction factors specially for this method. This could be attempted in future work but would require non-trivial additional effort.

The enhanced methods result in a dramatic improvement in the distribution of transit NHB trips versus the original model. All the models are still poor; however, this result may in part be due to changes in transit service since the latest on-board survey that were incorporated in the model's latest transit networks. Despite the general poor performance of the transit distribution, the enhanced methods clearly demonstrate superiority over the original traditional method, explaining four times as many trips correctly as the traditional method.

8.0 Conclusion

This report has presented methods for enhancing trip-based models to better represent non-home-based trips. It has documented clear theoretical motivation for them and reason for expecting them to be superior to traditional four-step modeling methods while requiring only minimally more effort to implement. Further, the methods have been thoroughly tested using a trip-based model of the Salt Lake City metropolitan area, and these empirical tests have both demonstrated the feasibility of the approach and the ability of the enhanced methods to produce more accurate and realistic results than traditional methods.

At the theoretical level, the basic critique of traditional four-step models' treatment of NHB trips is straightforward: in traditional four-step models, NHB trips are not connected in any way to HB trips or the travelers who make them. Ultimately, this makes the four-step model as a whole inconsistent with tours, rather representing travelers as appearing to make trips in locations they arrived at in the first place. The result is that NHB trips can be inconsistent with HB trips in their spatial distributions and mode shares and can respond in illogical ways.

The theoretical solution advanced here is similarly simple. The methods advanced here result from modeling NHB trips in series with and conditional on HB trips rather than in parallel with and independent of them. Models of HB trips are unchanged and NHB trip models are basically just moved to later in the model stream and slightly reformulated as a result. The result is that these enhanced models, while still trip-based, can claim greater consistency with tours.

In a real-world pilot test in the Salt Lake City metropolitan area, the enhanced models were

- better able to replicate NHB trip rates and mode shares from the local household travel survey with less calibration,
- able to produce significantly more reasonable responses to hypothetical new residential developments demonstrating greater consistency of NHB and HB trips in the enhanced models, and
- better replicated NHB OD patterns observed in the local household and on-onboard surveys based on formal statistical analysis.

Further empirical studies in other metropolitan areas and with actual before and after data would be desirable and necessary for drawing an ultimate conclusion on the superiority of the proposed methods over traditional ones. However, this study provides good preliminary evidence for the conclusion that these enhanced methods may be more accurate and realistic than traditional ones. Moreover, given the very low marginal effort to implement the enhanced methods, it may be reasonable to consider them even if some uncertainty remains about their superiority. The pilot testing in this study does clearly demonstrate that they can be implemented in a straightforward manner and produced results that were generally at least as good and in some cases clearly better than traditional methods.

NOTICE

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