Origin-Destination Matrix Volume Development Techniques for the North Carolina Department of Transportation

The North Carolina Department of Transportation (NCDOT) has expanded the use of microscopic simulation over the past decade and now is relying more heavily on simulation for the analysis of complex transportation projects. One of the primary challenges in developing a simulation project is the development of the traffic volume data. The two primary sources of data for traffic volumes on NCDOT projects are either field collected turning movement counts or traffic forecasts. Field collected turning movement counts are used as raw inputs into the analysis process while conversion factors are applied to daily data to calculate hourly data when utilizing a forecast. Typically, neither set of volume data is balanced between intersections and may require some level of adjustment to develop a balanced network for analysis. One of the primary benefits of using simulation-based analysis is that it allows the analyst to better model the actual travel patterns within a network using origin-destination (O-D) matrices. However, the challenge lies in developing O-D matrices that capture the true travel pattern. This paper will provide background and insight into the O-D development process and provide both methodologies and recommendations on the use of varying techniques to develop O-D matrices.

Before discussing the techniques that are available to the analyst, it is appropriate to define a few of the overarching concepts involved in O-D matrix development. An O-D matrix contains traffic flows (most frequently vehicle flows) from every origin to every destination within a model and is a common input for traffic simulation models. With an O-D matrix, traffic has the ability to follow multiple paths to complete the route from origin to destination. This results in the ability to analyze how travel patterns change dynamically due to changes in model impedances.

The O-D development techniques described below are typically utilized in a larger process known as Origin-Destination Matrix Estimation (ODME). ODME is most frequently used to describe a complex process (usually within a simulation software program) where inputs are used to generate an output matrix; however, more simplified methods of developing matrices are also available that utilize spreadsheets to develop O-D matrices. Within the context of this paper, the term ODME will refer to the process whereby traffic data is used as an input to estimate the traffic volumes between each origin and destination in the form of a resultant O-D matrix.

Origin-Destination Matrix Estimation (ODME) Techniques

There are two primary ODME techniques that have been utilized on NCDOT projects to date, including:

- Iterative matrix estimation process described in *NCHRP 255: Highway Traffic Data for Urbanized Area Project Planning and Design (*December 1982)
- Static ODME in TransModeler (developed by Caliper Corporation)

In addition to the techniques listed above, two other techniques have been used on a very limited basis in North Carolina; Static ODME in Vissim/Visum through the TFlowFuzzy program and a simulation-based ODME process developed by Caliper Corporation. Neither of these techniques are described in detail in this paper and requests for additional information on these techniques should be directed to either PTV Group or Caliper, respectively.

The ODME process typically requires at least two inputs, an input (or seed) matrix and target volumes (often developed from observed counts or a forecast) to develop a resultant estimated O-D matrix. The following section includes a brief overview of each of the two techniques:

NCHRP 255 Iterative ODME

This procedure is a manual iteration method (typically applied using a spreadsheet) that has been utilized successfully for over 25 years where an initial input matrix is first iterated for each row of the matrix to attempt to match a predicted target value for each origin. The matrix is then iterated for each column of the matrix to attempt to match the predicted destination target value. This process is repeated numerous times to produce a resultant matrix that is based on the patterns from the initial matrix but matches the predicted origins and destination volumes. For NCDOT projects, this process is typically implemented for 10 iterations of both the rows (origins) and columns (destinations) with a final matrix being developed that averages the tenth iteration of the matrix derived from the rows and the matrix derived from the columns.

Static ODME in TransModeler

The ODME procedure in TransModeler is based on the work of Nielsen (1993, 1998), who independently developed it as a procedure for TransCAD 2.1. The method was re-implemented by Caliper Corporation. This method is a more refined procedure that utilizes the initial input matrix to iteratively develop a resultant O-D matrix based on a set of inputs and constraints that are defined for the actual network being modeled.

Nielsen's method is an iterative (or bi-level) process that switches back and forth between a traffic assignment stage and a matrix estimation stage. The procedure requires an initial estimate of the O-D matrix and the definition of target volumes on portions of the network. This method has the advantages of treating counts as stochastic variables, as well as working with any traffic assignment method. Therefore, it is attractive for use with the Stochastic User Equilibrium Assignment method, as well as with User Equilibrium Assignment. There are many variables that can be defined to better constrain the method and refine the O-D matrix development process.

Origin-Destination Matrix Development Techniques

There are generally six techniques that have been utilized to develop initial input matrices to the ODME process.

- Binary
- Turn Proportions
- Engineering Judgment/Manual Balancing
- Travel Demand Models
- O-D Data Collection
- Turning Movement Based Simulation Output

The following sections provide additional details on each of these techniques.

Binary Technique

The binary technique is by far the simplest technique; however, it also has the greatest limitations and is generally considered to be a technique that should not be utilized considering the availability of the more robust techniques described below. The binary technique for developing an input matrix includes reviewing each O-D pair in your network and then entering a 1 if the path is possible or a 0 if the path is not possible. The idea behind the technique is that you will use one of the ODME techniques to iterate the matrix to match the desired volumes; however, with such little constraint there are a nearly limitless amount of potential output matrices that match the target volumes. This technique essentially makes all potential paths within a network equally likely to be utilized, which is not typically a valid assumption. This has been used several times in the past decade and the analysts have proclaimed success based on how well they are able to match the target volumes; however, this technique provides virtually no constraint or actual intelligence to the O-D development process. Without any constraints on the process it is very easy to match the target volumes; however, there is no real validity to the resultant matrix.

The inclusion of this technique in this paper was debated as it is not considered to be a viable technique for developing O-D matrices. However, since it has been utilized by multiple individuals at different firms or agencies, it has been included. To be clear, the inclusion of this technique in this paper is not to provide any legitimacy to the technique, but more to dispel the notion that it is a valid technique for developing O-D matrices. With a vast array of better techniques available, there is no scenario where this technique should be utilized in the development of O-D matrices.

Turn Proportions

The turn proportions technique was developed as a means of estimating volumes along corridors for the NCDOT Prioritization effort in 2015. The technique is best utilized for corridors; however, the output can be adjusted manually to accommodate a limited number of single intersections adjacent to the corridor. The basis of the methodology is to use the proportions of all the upstream or downstream movements that enter or exit the corridor to divide each entry or exit volume into the network. This methodology also requires the use of the NCHRP 255 iterative ODME technique and is typically implemented utilizing a spreadsheet. The only input needed to utilize this technique is the turning movement volumes at each intersection along the corridor. The first step in implementing this technique is to develop the initial "origin" matrix. The origin matrix is developed by calculating the likely volume from each origin to each destination in the network. The initial origin matrix distributes the entry volume for each origin in the network based on the proportion of all downstream exits from the network (the left and right turns from the mainline at all internal intersections and the left, through, and right turns from the mainline at the last intersection in the network). Similarly, the initial "destination" matrix is developed by distributing the exit volume for each destination in the network based on the proportion of all upstream entrances to the network. Once the initial origin and destination matrices are developed, they can be input into the NCHRP 255 iterative process with the target volumes being defined as the sum of the entry or exiting volumes from the turning movement count data. The origin and destination matrices are then iterated a set number of times (typically 10 full iterations of both the origin and destination matrices) and the final output matrix is developed by averaging the final origin and destination matrix volumes.

The Turn Proportions technique provides a good balance between degree of precision and level of effort. Once an input spreadsheet is developed the effort required to implement this technique is minimal as it simply requires entering the turning movements. The technique relies on the assumption that the volume for each O-D pair is commensurate with the magnitude of the volumes entering and exiting the network. While this may be a large assumption, the simplicity of the technique cannot be understated, especially if there is not a reliable alternative source for determining the travel patterns. The resultant matrix from this technique can also be refined further by utilizing them as a seed matrix in the Static ODME process.

Engineering Judgment/Manual Balancing

The engineering judgment with manual balancing technique requires the greatest level of understanding of the travel patterns in the area to implement consistently. This technique uses the judgment of the analyst developing the matrix to determine the magnitude of traffic between each origin and destination based on a series of steps that produces a balanced matrix. This technique also requires a reliable estimate of the entering and exiting volumes at each origin and destination within the network. These target volumes can come from a variety of sources including turning movement counts, traffic forecasts, or any other means of developing volume data. The first step is to develop an initial estimate of the distribution for each origin to each destination. This is accomplished for each origin by distributing a percentage of trips to each destination (based on engineering judgment of the travel patterns) such that the sum of the percentages along each row is 100%. Once the initial estimate of percentages is completed for all the origins, the next step is to create a matrix by multiplying the target volume for each origin by the percentages for each destination to come up with an initial estimated matrix. The initial estimated matrix will now produce origin volumes that match the target volumes; however, it is very likely that the matrix will not produce destination volumes that match the target destination volumes. The second step is to then compare the resultant estimated destination volumes with the target destination volumes. The third step is to then adjust (based on engineering judgment and knowledge of the travel patterns) the percentages for each origin such that each of the rows still sum to 100% but produce destination volumes that replicate (within some tolerance) the target destination volumes. The adjustment process will continue until the analyst is satisfied that the final O-D matrix represents the travel patterns in the area and replicates the target origin and destination volumes, within some reasonable tolerance.

The engineering judgment technique requires the greatest knowledge of the travel patterns in model study area and is the most subjective technique among those described in this paper. The outcome of the process is reliant on the skill, knowledge, and understanding of the analyst preparing the matrix and could be highly variable between different analysts. The process can be replicated and is transparent in that the final matrices show the analysts breakdown of how vehicles travel within the study area. The challenge is that it is difficult to document each assumption that was made throughout the development process and can result in increased debate and scrutiny over the choices made by the analyst. Additionally, as the network becomes larger and larger, it is more difficult to accurately adjust the percentages to develop a balanced matrix and can devolve into the analyst just moving trips around (without much regard for the true travel patterns) simply to develop a balanced matrix. This technique can also be very time consuming to prepare a set of matrices that are reliable as it requires intimate knowledge of the travel patterns in the study area.

Travel Demand Models

The travel demand model technique has been used by NCDOT on several large-scale simulation models over past few years. The technique involves utilizing a regional travel demand model in TransCAD (also developed by Caliper Corporation) to extract an O-D matrix for the portion of the model that matches the study area for the simulation study. This technique is typically accomplished through specialized subarea analysis tools in TransCAD and can output data for individual time periods if they are included in the overall travel demand model. There are however, several limitations to this technique. Travel demand models do not typically include the same level of detail as simulation models and many of the minor roadways may not be included in the travel demand model. Additionally, travel demand models load volume directly onto roadways in the network through centroid connectors. Depending on the placement of the centroid connectors, the resultant matrices may not capture the full volume on a roadway segment or may distort the volumes due to the inexact loading. Travel demand models also will only be as reliable as the underlying O-D data used for the calibration of the links within the study area. Calibration standards for travel demand models are typically at the overall network level; therefore, individual subareas may vary substantially from the actual count data and the travel patterns may not fully represent the actual patterns in the area.

The use of raw travel demand output matrices should be avoided; however, the utilization of the travel demand model output matrix as an input to the NCHRP 255 iterative ODME process has improved the reliability of the resultant O-D matrices. Overall, the limited experience of utilizing travel demand model output on North Carolina projects has proven to have difficulty developing reliable O-D volumes. Most applications have struggled with not having enough of the model network being included in the model, poorly validated volumes within the subarea network, and questionable O-D patterns, especially with freeway through volumes being over represented. In general, the use of travel demand models should be done very selectively and should be limited to projects with very large study areas and only for models that are well calibrated within the study area and that have good representation of the simulation model network.

O-D Data Collection

The O-D Data Collection technique has shown a lot of promise and has been used successfully on a growing number of recent studies developed by NCDOT. The technique involves utilizing project specific O-D data collection to determine the relative percentages for individual O-D pairs within a defined network. This category includes any of the numerous technologies that are able to collect O-D data, including:

- License Plate Surveys
- Travel Surveys/Roadside Interviews
- Aerial Tracking of Vehicles (Skycomp)
- Bluetooth Readers (BlueToad, BlueMAC, etc.)
- WIFI Data Extraction (Acyclica)
- Tracking of Autonomous Cellular Data (AirSage)
- Truck GPS Tracking (ATRI)
- Global Positioning System/Location Based System (GPS/LBS) Data Extraction (StreetLight Data)

This paper will not discuss the relative merits of each of these O-D data collection techniques; however, the most recent implementation has focused primarily on the GPS/LBS data extraction techniques employed through the use of StreetLight Data. Overall, each of these technologies is able to provide relative volumes between O-D pairs within a network and have a final product that includes an O-D matrix. The initial O-D matrix provided through these technologies typically represents only a fraction of the overall trips and the data is best used to determine the relative percentage of traffic between each O-D pair. To that end, the use of the raw data provided through any of these technologies requires additional refinement using the iterative NCHRP 255 ODME technique. The raw O-D data is used as the input matrix to the process and traffic volumes (either from traffic counts or a traffic forecast) are used as the target volumes to provide a resultant O-D matrix that maintains the relative travel patterns from the input matrix while matching the entering and exiting volumes from the target volumes.

The use of O-D data collection, especially passive data collection, has been found to provide reliable results in developing O-D matrices. The methodology is also flexible in that it can be utilized either with only the NCHRP 255 technique or can be refined further by using the output O-D matrix as the seed matrix for Static ODME in TransModeler. The level of effort is likely to be less than for the Engineering Judgment or Travel Demand Model techniques while slightly longer than the Turn Proportions Along Corridors technique. One of the primary benefits of this technique is that it is transparent and can be reproduced independently due to the process being well defined and not having any subjective aspects. Additionally, StreetLight Data relies on historical data; therefore, the data can be collected immediately once the order is processed. This also reduces the duration of volume development especially during periods where data collection is less reliable (holiday times or when school is not in session). This process also allows the analyst to utilize data from a full year (or more) allowing for the data to be more representative than traffic collected over shorter durations. The limitations of the O-D data collection technique are that the data may be slightly biased as it typically requires specific user types (GPS transponder or smart phone location-based services) that may under represent some populations. The largest limitation; however, is the price of acquiring the O-D data which can easily cost between $5,000 and $25,000+ for each project. Some of this cost may be offset by the effort required to develop the O-D matrices being lower and potentially lower costs associated with working with higher quality data in the calibration and visual validation process.

<u>Turning Movement Based Simulation Output</u>

The Turning Movement-Based Simulation Output technique of developing O-D matrices builds off of the ability in TransModeler to simulate traffic based on turning movement volumes. The technique involves coding the turning movement volumes for each intersection in the network, running the TransModeler simulation, and then extracting the resultant O-D matrix from the simulation run. While this technique is relatively straight forward to implement, it does have several limitations. The determination of a vehicles route or destination is not known when it enters the network but is defined as it reaches each node within the network where the trips are assigned based on the turning percentages derived from the turning movement volumes. While this tends to produce volumes that match the entry and exit volumes included in the turning movement counts, it is not based on existing travel patterns. With this method, each run of the model includes using a different random seed which will result in slight changes between every model run. Therefore, the use of this technique is typically done based on a set of runs (usually 10) and the resultant matrices are averaged to come up with one single matrix. One additional limitation of this technique is that TransModeler (similar to other software programs like SimTraffic) will account for any imbalance in volumes between intersections by adding or removing cars from the network at midblock nodes via sources or sinks. Therefore, unless the volumes are perfectly balanced, some trips will have an origin or destination at a node that is not an external node in the network. To address this, either the input volumes need to be balanced or the internal source/sink trips need to be removed. If the number of source/sink trips is substantial, then the output matrices would likely need to be iterated using the NCHRP 255 methodology to ensure that the total number of trips is consistent with the volume data for the external nodes in the network.

This method has been used on several smaller non-corridor projects and has provided relatively reliable results considering the assumptions included in the method. It is a viable option if the travel patterns are not well known or understood, and when other techniques are not viable (non corridor-based project or in an area without a travel demand model) or are too expensive (O-D Data Collection). This method also can be used to develop an initial seed matrix to be used as an input to Static ODME in TransModeler where it can be refined to better match network volumes.

<u>Weighted or Hybrid Techniques</u>

Several projects undertaken by NCDOT have utilized hybrids of the techniques discussed above or multiple techniques were weighted to provide a single output O-D matrix.

<u>Weighted Techniques</u>

It has been common to implement two or more techniques during the development of the O-D volumes. Many early simulation studies were developed based on utilizing both Travel Demand Model and Engineering Judgment techniques and then creating a single O-D matrix by weighting the individual matrices. The use of weighting can help minimize the limitations of a single technique and balance out the shortcomings of any one technique. At the discretion of the analyst, the individual matrices can be weighted equally, or specific weights can be placed on each individual matrix if the analyst has greater confidence in a particular data set.

<u>Hybrid Techniques</u>

The utilization of many of the techniques described above can be done in conjunction with one another to produced more refined volumes. All the techniques described above (with the exception of the binary technique which is not recommended) can either be used directly in the simulation model or can be an input into the Static ODME process in TransModeler. The use of Static ODME further refines the O-D matrix as it allows for additional constraints to be placed on the development of the output matrix. Static ODME includes a step of network assignment that helps to better reflect the actual volumes on all the links within the network and does not solely match the volumes entering and exiting the network. The use of Static ODME also allows for the constraint of volumes based on defining upper and lower constraints that allow each O-D volume to only change by a defined percentage. Static ODME also can utilize turning movement volumes as an additional constraint, allowing for the output matrix to better align with the collected count data.

Generally, the use of the iterative NCHRP 255 ODME technique in combination with the different techniques described above is the simplest and cheapest method for developing volumes and may be adequate for smaller studies. When the models increase in scale or when the level of precision desired is higher, the implementation of Static ODME is the most appropriate approach and is worth the additional time and resources to develop.

<u>Future Year O-D Volume Development</u>

The development of O-D matrices for future year scenarios (or alternatives to the existing configuration in the base year) should utilize the most appropriate data. If the travel patterns are not anticipated to change substantially between the base year and future year, then the final base year O-D matrix should be utilized as the seed matrix for the development of the future year O-D matrices.

For example, when developing the future year volumes on a project that is utilizing O-D Data Collection and StreetLight Data, the analyst would not utilize the raw StreetLight data pivot table as the seed matrix. The appropriate seed matrix would be the final O-D matrix from the base year as it has already been refined to match the volume data and travel patterns in the base year scenario.

The analyst needs to review the available data and determine the most appropriate seed matrix for use in any alternative scenarios and should build off of previously developed data if it is still determined to be appropriate.

Recommendations

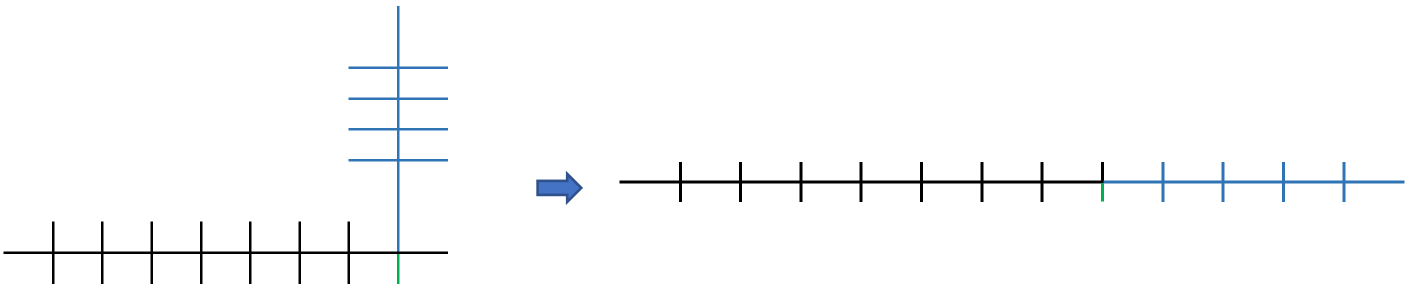
The determination of the most appropriate methodology for developing O-D matrices is dependent on many variables and requires a decision to be made on a project by project basis. However, in an effort to provide some insight into how projects should be evaluated, the following information should be considered:

- The binary technique should not be used under any circumstances.
- For corridor projects (or those with only a few adjacent intersections), the Turn Proportions Along Corridors technique is a viable technique and, absent any major unique travel patterns, should provide reasonable results for most projects. The limited effort required and the ability to independently replicate the procedure are very beneficial attributes of this technique. This is not recommended where any unique travel patterns exist. It may also be less precise along long corridors with a high proportion of through traffic as the process may yield higher turning volumes that are actually present, reducing the volume of longer through traffic. .
- The Engineering Judgment with Manual Balancing technique is a viable option, especially if the analyst has a very good understanding of the travel patterns in the area. This technique is best applied for smaller projects where the relationships can be well understood and the effort required to balance is not substantial. This technique should be avoided for controversial projects due to the subjective nature of the methodology and the difficulty in replicating the volumes independently.
- The Travel Demand Model technique has very limited viability based on the outcome of projects where it has been used to date. The level of detail included in the model is problematic as it typically does not include enough of the network to not require some level of manual post processing. Additionally, the level of precision for origin-destination data that is used when developing travel demand models is much lower than is desired for simulation models. Generally, the use of travel demand data has not proved to be highly reliable and, with a number of other techniques available that have provided better results, the viability of using travel demand models is very limited. However, there may be some benefit to comparing output from another technique with travel demand data to see if there are any notable patterns in the travel demand model that would better inform the development of the matrix.
- The O-D Data Collection technique has shown the greatest promise of these techniques and has many positive attributes. The use of StreetLight Data has proven to be a reliable measure for developing volumes and has strong benefits when compared with their peers in the O-D data collection arena. The O-D development process for this technique is easily implementable and can be replicated independently as it does not have much subjectivity. The process is easily scalable from small projects to very large projects and has very few limitations. The one mitigating factor in its use is that it does come with a cost for obtaining the data, although some of this cost may be reduced as the process is less time consuming from a labor standpoint. It is recommended that, for medium and large size projects, this be the default technique with it also receiving strong consideration for some smaller projects if the cost can be justified.

- The Turning Movement-Based Simulation Output technique has limited viability as a stand-alone technique as there are better options for corridors (Turn Proportions Along Corridors) and medium and large size models (O-D data collection). The technique (as well as the Engineering Judgment technique) is viable for small non-corridor networks. The effort required to develop the matrices is not substantially greater than what is needed to develop the model, so this technique has some viability for non-complex projects.
- For larger, complex, or controversial projects, it is recommended that the ODME Approach include a hybrid approach. The hybrid approach should utilize the methods described above to develop a seed matrix that is as an input to the Static ODME process in TransModeler, which is used to refine the O-D matrices.

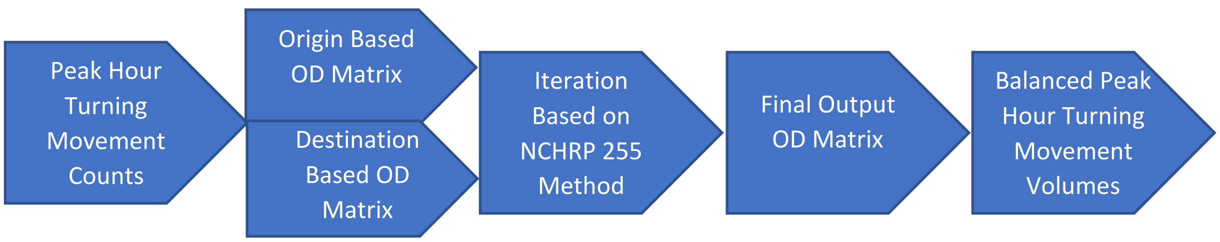
Method 1: Turn Proportions

The methodology for developing O-D matrices utilizes a spreadsheet titled *NCDOT Corridor OD Development*. The procedure is based on the proposed project being a corridor; however, some flexibility exists that would allow for data to be re-arranged to match the corridor procedure. For example, a corridor that turns and then continues perpendicularly can be revised to be a single corridor:



Also, if there are a small number of minor intersections from the main corridor, the main corridor would be developed using this methodology and then the additional intersections added by splitting the origin and destination traffic from the edge node based on the volumes at the additional intersection(s).

The methodology is based on the following steps:

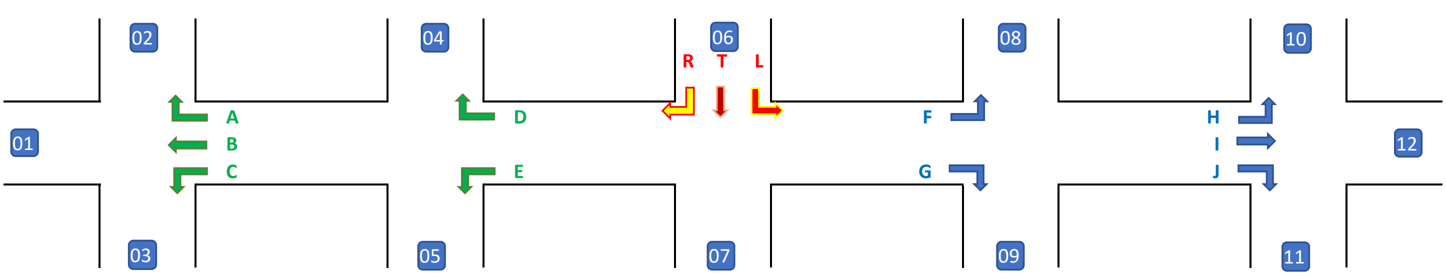


Peak Hour Turning Movement Counts

Peak hour turning movement counts along a corridor are the primary input for the methodology. The counts are either entered on the "UNBALANCED NETWORK" tab or data from the NCDOT Intersection Analysis Utility (IAU) is added on the "IAU INPUT" tab.

Origin-Based O-D Matrix

The next step in the procedure utilizes the spreadsheet to develop an initial origin-based O-D matrix from the peak hour counts. The origin-based matrix is developed such that it proportions the entering volume at each external link based on the magnitude of all the exiting volumes downstream of the entry movement. The graphic below shows how traffic from Node 6 would be distributed to make up the volume for each origin row in the matrix.



06→01 =06R * (B/(A+B+C+D+E))
06→02 =06R * (A/(A+B+C+D+E))
06→03 =06R * (C/(A+B+C+D+E))
06→04 =06R * (D/(A+B+C+D+E))
06→05 =06R * (E/(A+B+C+D+E))

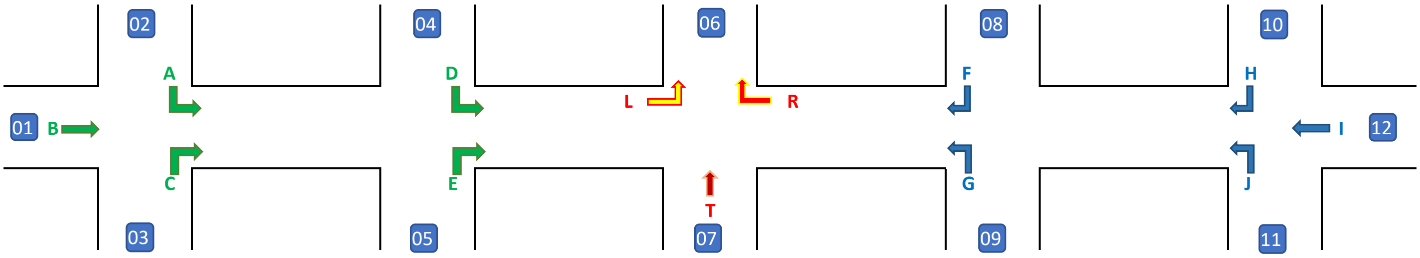
06→07 = 06T

06→08 =06L * (F/(F+G+H+I+J))
06→09 =06L * (G/(F+G+H+I+J))
06→10 =06L * (H/(F+G+H+I+J))
06→11 =06L * (J/(F+G+H+I+J))
06→12 =06L * (I/(F+G+H+I+J))

Method 1: Turn Proportions

Destination-Based O-D Matrix

The next step in the procedure utilizes the spreadsheet to develop an initial destination-based O-D matrix from the peak hour counts. The destination-based matrix is similar to the origin-based matrix; however, it proportions the exiting volume at each external link based on the magnitude of all the entering volumes upstream of the exit movement. The graphic below shows how traffic destined for Node 6 would be distributed to make up the volume for each destination column in the matrix.



01→06 =06L * (B/(A+B+C+D+E))
02→06 =06L * (A/(A+B+C+D+E))
03→06 =06L * (C/(A+B+C+D+E))
04→06 =06L * (D/(A+B+C+D+E))
05→06 =06L * (E/(A+B+C+D+E))

07→06 = 07T

08→06 =06R * (F/(F+G+H+I+J))
09→06 =06R * (G/(F+G+H+I+J))
10→06 =06R * (H/(F+G+H+I+J))
11→06 =06R * (J/(F+G+H+I+J))
12→06 =06R * (I/(F+G+H+I+J))

Iteration Based on NCHRP 255 Methodology

The next step in the process includes developing an input matrix and target volumes to implement the NCHRP 255 matrix iteration methodology. The input matrix includes an average of the values for each O-D pair from the origin-based matrix and the destination-based matrix while target volumes for each origin and destination are taken from the sum of the entry or exit volumes from the "UNBALANCED NETWORK" tab. The input matrix and target volumes are then iterated five times each for twelve rounds of iteration with the through movements for side streets being reset after each round to maintain the through movements. The final matrix is then developed based an average of the final iteration of the final round origin and destination matrices.

Final Output O-D Matrix

The results of the iteration based NCHRP 255 methodology are shown on the "OD MATRIX" tab.

Balanced Network

By definition, the final output matrix is "balanced"; therefore, it is then exported back to the corridor network to display the balanced peak hour volumes on the "BALANCED NETWORK" tab.

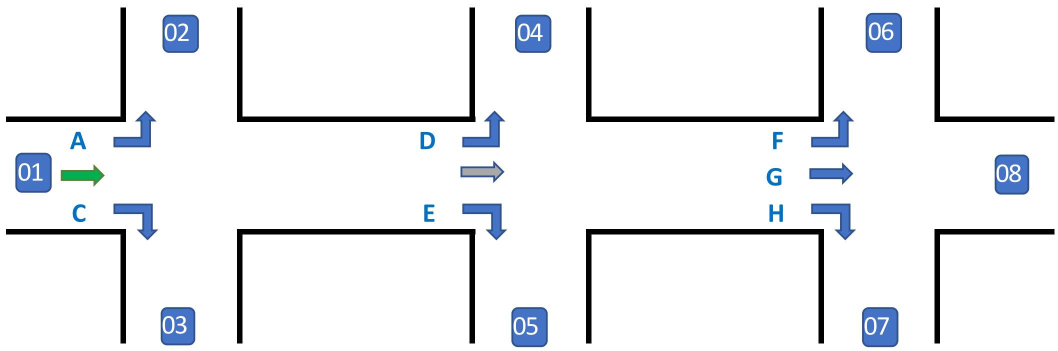
Application

The methodology provides reasonable results given the limitations and underlying assumptions inherent in utilized proportions. The iterative process does tend to slightly underestimate trips at the edges of the network while slightly overestimating those in the middle of the network. The "PROJECT INFO_INSTRUCTIONS" tab includes a reliability index that compares the initial turn volumes to the final volumes. For projects that result in a reliability index of 0.0 to 0.1, the methodology should be reliable and provide reasonable results. For a project with a reliability index of 0.1 to 0.3, the output matrix should be used as the input matrix for the ODME process, while results greater than 0.3 should likely utilize a different method, preferably Method 4: O-D Data Collection.

Method 2: Engineering Judgment/Manual Balancing

The methodology for developing O-D matrices based on engineering judgment utilizes a spreadsheet developed for each project. The basis of the methodology is to utilize engineering judgment to determine the percentage of the total trips from an origin to each of the potential destinations and then manually updating the distributions to create a matrix that most closely replicates target volumes for each origin and destination.

The first step in the process is to develop target volumes for each origin and destination. This can be done through a variety of methods, including using the total link volume for each external link from the IAU or by calculating the volume directly from the forecast by multiplying the Average Annual Daily Traffic (AADT) volume, the Directional Distribution (D) and Design Hour Factor (K) (AADT * K *D) for each entry and exit link. The second step is to estimate the percentage of trips from each origin in the network such that each row in the matrix sums to 100%.



		A	C	D	E	F	H	G		
	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	***TOTAL***	**TARGET**
01		12%	29%	0%	4%	2%	0%	53%	**100%**	**527**
02	12%		75%	0%	2%	0%	0%	11%	**100%**	**728**
03	26%	56%		0%	2%	0%	0%	16%	**100%**	**577**
04	0%	0%	0%		0%	0%	0%	0%	**0%**	**0**
05	55%	16%	20%	0%		0%	0%	9%	**100%**	**164**
06	45%	10%	20%	0%	5%		0%	20%	**100%**	**17**
07	0%	0%	0%	0%	0%	0%		0%	**0%**	**0**
08	52%	16%	25%	0%	5%	2%	0%		**100%**	**631**
TOTAL	**190%**	**98%**	**140%**	**0%**	**14%**	**3%**	**0%**	**56%**		**2644**
TARGET	**694**	**509**	**905**	**0**	**74**	**14**	**0**	**454**	**2650**	

Once the percentages have been estimated for each row (origin), the next step is to multiply the percentages by the target volume for each origin (shown in the last column above). The result of this step will be a matrix that matches the origin volumes (or very closely matches depending on rounding).

	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	***TOTAL***	**TARGET**	Delta
01		63	153	0	21	11	0	279	**527**	**527**	0
02	87		546	0	15	2	0	80	**730**	**728**	-2
03	150	323		0	12	2	0	92	**579**	**577**	-2
04	0	0	0		0	0	0	0	**0**	**0**	0
05	90	26	33	0		0	0	15	**164**	**164**	0
06	8	2	3	0	1		0	3	**17**	**17**	0
07	0	0	0	0	0	0		0	**0**	**0**	0
08	328	101	158	0	32	13	0		**632**	**631**	-1
TOTAL	**663**	**515**	**893**	**0**	**81**	**28**	**0**	**469**		**2644**	
TARGET	**694**	**509**	**905**	**0**	**74**	**14**	**0**	**454**	**2650**		
Delta	31	-6	12	0	-7	-14	0	-15			

Method 2: Engineering Judgment/Manual Balancing

Following this step, the origins match the target volumes for each origin; however, the total trips for each destination are not yet equal to the target destination volumes. Therefore, the next step is to review each value that differs from the target volumes and, based on engineering judgment, modify the percentages to maintain a sum of 100% for each row and replicate the target destination volumes for each column. The goal is to create a matrix that matches the target volumes as closely as possible; however, it is not always possible that a perfectly matching matrix can be developed; therefore, the resultant matrix should *generally* have total volumes for each row or column that are the greater of either 2% of the total or 10 vehicles. This threshold is a general guide and can be modified if appropriately documented and approved. Below is the resultant matrix following the manual balancing:

	01	02	03	04	05	06	07	08	*TOTAL*	TARGET
01		10%	34%	0%	3%	1%	0%	52%	100%	527
02	11%		75%	0%	2%	0%	0%	12%	100%	728
03	26%	60%		0%	1%	0%	0%	13%	100%	577
04	0%	0%	0%		0%	0%	0%	0%	0%	0
05	58%	13%	22%	0%		0%	0%	7%	100%	164
06	47%	12%	17%	0%	6%		0%	18%	100%	17
07	0%	0%	0%	0%	0%	0%		0%	0%	0
08	57%	14%	22%	0%	6%	1%	0%		100%	631
TOTAL	199%	99%	136%	0%	15%	2%	0%	50%		2644
TARGET	694	509	905	0	74	14	0	454	2650	

	01	02	03	04	05	06	07	08	*TOTAL*	TARGET	Delta	
01		53	179	0	16	5	0	274	527	527	0	0.0%
02	80		546	0	15	2	0	87	730	728	-2	-0.3%
03	150	346		0	6	2	0	75	579	577	-2	-0.3%
04	0	0	0		0	0	0	0	0	0	0	0.0%
05	95	21	36	0		0	0	11	163	164	1	0.6%
06	8	2	3	0	1		0	3	17	17	0	0.0%
07	0	0	0	0	0	0		0	0	0	0	0.0%
08	360	88	139	0	38	6	0		631	631	0	0.0%
TOTAL	693	510	903	0	76	15	0	450		2644		
TARGET	694	509	905	0	74	14	0	454	2650			
Delta	1	-1	2	0	-2	-1	0	4				
	0.1%	-0.2%	0.2%	0.0%	-2.7%	-7.1%	0.0%	0.9%				

For very large matrices, once the initial set of volumes has been developed and large discrepancies are reviewed and modified, the *NCDOT OD Matrix Iteration Tool* can be used to produce a matrix that replicates the target volumes. Once the final percentages and final volumes are developed, the analyst should review them to ensure they match expected traffic patterns.

Method 3: Travel Demand Models

The methodology for developing O-D matrices based on travel demand model data requires a subarea matrix extracted from the travel demand model and an estimate of the link volumes for each entry and exit from the study area network being modeled. The two primary inputs into the methodology are a set of target volumes for each external origin and destination in the network and an initial (or seed) matrix (derived from a travel demand model) that estimates the magnitude of trips between each O-D pair.

The first step in the process is to develop target volumes for each origin and destination. This can be done through a variety of methods, including using the total link volume for each external link from the IAU or by calculating the volume directly from the forecast by multiplying the AADT * K *D for each entry and exit link. The second step is to utilize the travel demand model subarea analysis tools in TransCAD to develop an output O-D matrix for both the AM and PM peak period (if the model includes development of volumes for peak periods).

Travel demand models typically do not include all the roadways that are included in the simulation model. Therefore, the selection of the subarea network should carefully consider how the data for the roadways that are not in the travel demand model will be estimated. Consideration should be given to including representative centroid connectors in the subarea network; however, the resultant matrix should be reviewed to determine if scaling is required. If the magnitude of trips from the centroid connector is not aligned with the volume for the link it is intended to represent, then the trips should be scaled to match the relative magnitude of the volume compared with nearby known volumes.

For roadways that are not included in the travel demand model, and do not have a representative centroid connector that can be used to determine the travel patterns, the data from a nearby roadway that has similar characteristics (land use, type of users, etc.) should be used as a surrogate. The O-D data for the surrogate roadway should be scaled, based on the entry/exit volumes derived from the forecast, to produce data that has the same travel patterns but at a relative magnitude that matches the volume of the roadway. The result of this process is a combined input (seed) matrix that includes the travel demand model output, the scaled centroid connector data, and the data from any surrogate roadways. The combined input matrix should have estimated O-D volumes for every origin and destination link prior to being utilized in the iterative process.

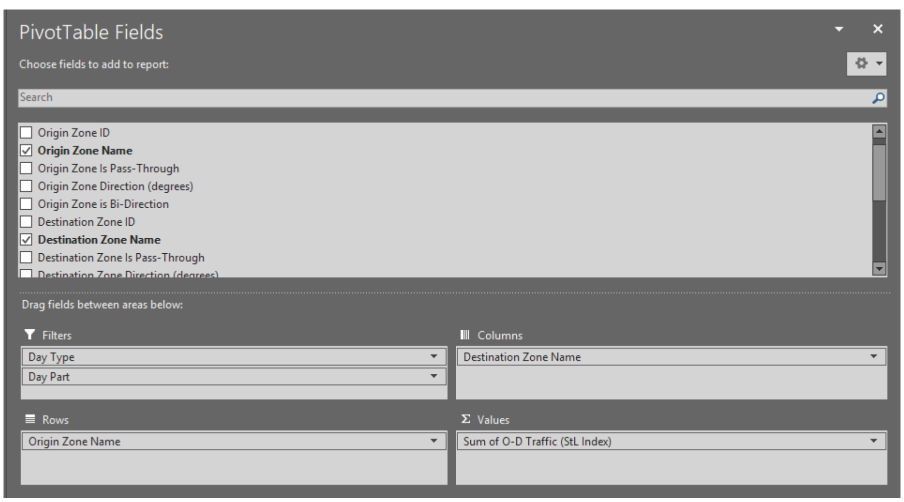
Once the target volumes and initial seed matrix are developed they should be added to the “MATRIX ITERATION TAB” in the *NCDOT Matrix Iteration* tool. The input matrix and target volumes are then iterated twenty times each for the origins and destinations. The final matrix is then developed based an average of the final iteration of the final round origin and destination matrices. O-D data derived from travel demand models should strongly consider utilizing ODME to further refine the O-D matrices.

Method 4: Origin-Destination Data Collection

The methodology for developing O-D data based on Origin-Destination Data Collection can vary depending on the type of data collection technique being utilized. The following description is based on utilizing StreetLight Data but could be modified for use by any type of data collection technique that provides relative volumes between each origin and destination. The two primary inputs into the methodology are a set of target volumes for each external origin and destination in the network and an initial (or seed) matrix that estimates the magnitude of trips between each O-D pair.

The first step in the process is to develop target volumes for each origin and destination. This can be done through a variety of methods, including using the total link volume for each external link from the IAU or by calculating the volume directly from the forecast by multiplying the AADT * K *D for each entry and exit link. The second step is to develop an initial seed matrix based on collected O-D data from the *StreetLight Data Insight* platform. The network should be defined such that each origin and destination is included as a separate data set with the direction defined for each entry or exit such that only one-way volumes are included in the matrix. The *StreetLight Data Insight* project should be run to include, at a minimum 12 months of data and include the default data for Day Types and Day Parts. Both GPS and Location Based Services (LBS) data should be collected for personal trips. If truck traffic is a substantial enough part of the project where collecting the data is meaningful (typically the percentage of trucks is greater than 10 percent of the total AADT volume or 5 percent of the total peak hour volume) then GPS commercial trips should be collected as well.

Once the project is run in *StreetLight Data Insight,* the output data (in the form of a .csv file) should be opened in Excel and a pivot table should be developed (>Insert Menu>Pivot Table). The pivot table should be setup, as shown below, with the Origins being set to Rows, Destinations set to columns, Day Type and Day Part set as filters, and Sum of O-D Traffic as the Values.



Once the output pivot table is developed, it should be copied into a separate sheet and a single input matrix should be developed by combining the data from GPS and LBS in a manner that provides reasonable data. GPS commercial data sets tend to have very large sample sizes while heavy vehicles make up a small portion of the overall traffic; therefore, the data should be factored down to provide a sample that is representative of the overall portion of the traffic in the study area. Also, the weighting of GPS and LBS personal trips should be done based on a logical rationale with no prescribed criteria for developing the output matrix.

Once the target volumes and initial seed matrix are developed they should be added to the “MATRIX ITERATION TAB” in the *NCDOT Matrix Iteration* tool. The input matrix and target volumes are then iterated twenty times each for the origins and destinations. The final matrix is then developed based on an average of the final iteration of the final round origin and destination matrices.

Method 5: Turning Movement Based Simulation Output

The methodology for developing O-D matrices based on turning movement-based simulation output requires peak hour turning movement volumes for all nodes in the network and a fully developed TransModeler model. The process of developing the O-D matrices includes running the model based on turning movement volumes and then extracting an output O-D matrix from the trip data table in TransModeler.

The first step in the process is to develop the model in TransModeler according to the *NCDOT Congestion Management Traffic Simulation Guidelines - TransModeler*. The second step is to code the peak hour turning movements into the model for every node in the network. The turning movement data can be taken from either traffic counts or output from the Intersection Analysis Utility (IAU). It is not critical that the network be balanced; however, any substantial variations in volume between nodes (due to source/sink locations or forecast break lines) should be coded into the model either as dummy source/sink roadways or as centroid connectors. For ease of developing the output O-D matrix, it is recommended that the external nodes (or centroids) all be numbered sequentially (or with some other appropriate method) with all of the internal nodes being re-numbered with IDs greater than the highest value for the external nodes (or centroids). This will allow the output matrix to be extracted more easily as all of the external nodes will be in the top left corner portion of the output matrix.

The third step is to create O-D development scenarios in TransModeler for each peak that only encompass the duration of the desired output matrix. The project settings should include the peak hour turning movement data (_TMC.bin file) added as the basis for the volume input in the TransModeler simulation. The model should then be run for 10 simulation runs using the same fixed random seeds as the full model utilizes. Following the completion of the batch simulation, each of the model runs should be converted to O-D matrices utilizing the Trip Data Table (>Demand>Trip Data Table> Create Matrix in TransModeler 4 and >Demand>Trips>Create a Matrix from a Trip Data Table in TransModeler 5). Once the O-D matrices for the 10 simulation runs have been developed, a final matrix should be developed based on the average of the values from the 10 individual matrices and then converted to integer trips. The final O-D matrices can then be used in the simulation or as a seed for further refinement utilizing ODME.

Origin-Destination Matrix Estimation (ODME) Procedure

The methodology for developing O-D matrices based on the static Origin-Destination Matrix Estimation (ODME) utility in TransModeler requires the following data:

- Seed Matrix (initial estimate of O-D volumes)
- Upper and Lower Bound Constraint Matrices
- Target Volumes for each link in the network
- Link Weights for each link in the network

Additionally, turning movement volumes can be utilized to provide additional constraint to the ODME process.

Seed Matrix

The initial estimate of the O-D volumes between each O-D pair, in the form of a seed matrix, is an essential input into the process. The techniques described in this document for Methods 1 through 5 should be utilized to develop the seed matrix for input into the ODME utility in TransModeler. The total volume for the seed matrix should typically have a similar volume to the sum of the target volumes from the entry and exit volumes from the external links in the network. If the total volumes are not within approximately 10 percent of one another then it can be difficult to adequately constrain them using the upper and lower bound constraint matrices.

Upper and Lower Bound Constraint Matrices

Upper and lower bound matrices are used to further constrain the ODME process, which allows for more reliable results. The constraint matrices improve the reliability by not allowing the estimated seed matrix O-D volume for a specific O-D pair to vary beyond a defined amount. The upper and lower bound matrices are typically developed by assigning a percentage (in decimal form) to each cell that will allow the O-D pair volume to vary up to the given percentage. For example, if the O-D pair has a volume of 600, and the upper and lower bound matrices have a value of 0.5 for the O-D pair then the final resultant O-D volume will be constrained to 600 ± 50% ,or between 300 and 900. Typically, the percentages are assigned based on the magnitude of the volumes within the seed matrix with smaller volumes having higher percentages and larger volume being more tightly constrained with lower percentages. The level of constraint included in the matrices should be based on the confidence level in the seed matrix. Initially, more conservative (lower) constraints should be included in the constraint matrices with the values being increased incrementally if the resultant link volumes are not producing results that match the target link volumes. The use of separate values for the lower and upper constraint matrices may also be utilized. A lower constraint value of 1.0 (100%) can allow the O-D pair to be reduced to zero; therefore, the use of constraints less than 1.0 are typically used for lower constraint matrices while the upper matrices do not require this same constraint and can be increased above 1.0, if needed.

Target Volumes

Target volumes are an essential input into the ODME process and help to provide a basis for determining how well the resultant O-D matrix reproduces the estimated volumes along each link in the network. The target volumes can be developed utilizing several different methods but are typically either the result of the traffic forecasting process or based on traffic count data. Each link in the network should be coded with a target volume for each time period that will be developed into an output O-D matrix. A review of the sum of the entry and exit volumes at each node should be completed to determine if there are any substantial differences (greater than 10-15 percent) between the sum of the entering links and the sum of the exiting links. If substantial imbalances are identified the link volume should be reviewed and adjusted if determined to be appropriate. Explanations of any modifications to the target link volumes should be included in the documentation of the volume development.

Link Weights

The inclusion of link weights provides further constraint to assist in developing the O-D matrices by identifying the links where matching the O-D demand volume to the target volumes are most important. The weights should be added to the link layer and present a relative measure of how important it is to replicate the volumes for each link. Because it is a relative measure, there must be variation between the weights. Defining all links with a weight of 10, 100, or 1000 would all have the same result as they are all the same relative to one another. Those links that are most important to the project design should be designated with the highest weight and then each successive level of importance should have progressively lower weights.

Turning Movement Volumes

The inclusion of turning movement counts allows the ODME process to use them as a secondary constraint and attempts to match the turning volumes to the greatest extent possible. Some caution needs to be employed; however, as turning volumes that vary substantially from the target link volumes can distort the resultant volumes for each link and produce O-D matrices that are not as consistent with the target link volumes. If turning movement count data is available but is not consistent with the target volumes, it can be re-proportioned to adjust the turn movements to better align with the target volumes by using the Forecast Turning Volumes utility (>Demand>Turning Movement Volumes>Forecast Turning Volumes) in TransModeler.

Application

The application of the ODME process in TransModeler (>Demand>O-D Matrix>O-D Matrix Estimation) should include the following settings:

- Method: Stochastic User Equilibrium
- Delay Function: Bureau of Public Road (BPR) *(Default)*
- Alpha: 0.15 *(Default)*
- Beta: 4 *(Default)*
- Preload: 0 *(Default)*
- Assignment Settings
  - Iterations: 500 *(Default)*
  - Relative Gap: 0.0001 *(Default)*
  - Function: Normal *(Default)*
  - Error: 5 *(Default)*
- O-D Matrix Estimation Settings
  - Multiple Paths *(Default)*
  - Iterations: 100
  - Convergence: 0.0001 *(Default)*
- Options
  - Weights: Select Weight Field from Link Layer
  - Value Change Constraints: Select Upper and Lower Constraint Matrices
  - Movement Count Table: Select Count .bin file and define the count field to match the timeframe being estimated

Once the ODME process has been run, an estimated O-D matrix will be developed and a combined Links+Segments+ODME Segment Dataview will be available. The joined table includes fields labeled AB_Flow and BA_Flow that include the resultant link volumes from the ODME process. This data from the _Flow fields should be compared to the input target volumes to determine how well the output matrix from ODME replicated the target link volumes. The comparison of the _Flow field and the target volume should generally meet the following aggregate criteria:

Low Volume (Total Matrix Volume <15,000)*	**High Volume (Total Matrix Volume ≥15,000)***
Link Volume > 500 vph: ± 10% for 90% of links	Link Volume > 1,000 vph: ± 10% for 90% of links
Link Volume 250-500 vph: ±50 vehicles for 90% of links	Link Volume 500-1,000 vph: ±100 vehicles for 90% of links
Link Volume 100-249 vph: ±25 vehicles for 90% of links	Link Volume 100-499 vph: ±50 vehicles for 90% of links
Link Volume < 100 vph: ±15 vehicles for 85% of links	Link Volume < 100 vph: ±15 vehicles for 85% of links
Total matrix volume is based on the total hourly volume in the matrix for the highest one hour period in the scenario being developed.	

Due to variations in the link volumes and input data it is not normally possible to have all links match the criteria listed above, which is why the percentage of links is less than 100% to comply with the criteria. Also, because the ODME process is a static process, it is harder for projects with numerous alternative routes to meet the criteria included above. For projects with large numbers of parallel routes, consideration should be given to using screen lines and cordons to determine how well the volumes are replicated at a higher level. For projects with large numbers of parallel competing routes, Dynamic Traffic Assignment (DTA) is a much more reliable tool; therefore, matching at the corridor or screen line level is acceptable. In the event that the above criteria cannot be attained, the network and all inputs and outputs should be reviewed. If there is a good reason why the targets cannot be attained it is acceptable to document the efforts undertaken and note any reasons why the ultimate goals were not met.

Class-Based Matrix Development Procedure

This section describes the procedure for separating a single O-D matrix that includes the total demand between each O-D pair into separate matrices for each vehicle class. In North Carolina, traffic data is typically reported as passenger cars (PC), trucks with dual tired rear axles (Duals) and Tractor Trailer with Semi-Trailer (TTST). Therefore, the total demand matrices may need to be split into three separate demand matrices for PC, Duals and TTST. The following steps are utilized to develop class-based matrices:

1. Review the truck percentages for each external link in the network and create a reasonable number of groups that have similar truck percentages and have similar land uses.
2. Each external node is then classified and added into one of these groups.
3. Each origin and destination node volume are then multiplied by the vehicle class truck percentage for Duals to determine the likely number of trips entering and exiting the network at each node that are expected to be Duals. The node volumes for all of the nodes in each group are then combined into total volumes and represent a control total for each group.
4. The total for all groups is then combined to develop the overall control total for Duals.
5. Next each O-D pair is reviewed, and a likely truck percentage is selected for each O-D pair until the matrix includes estimated truck percentages for all O-D pairs that carry volume in the total matrix.
6. The O-D volumes in the total demand matrices are then multiplied by each of the percentages developed in Step 4, such that an individual matrix for Duals is developed. The percentages are adjusted iteratively until the volumes meet the following criteria:
   - Each group of Duals with common attributes (identified in Step 2) has a total volume (sum of origin and destination volume) that is within either 10% or 10 vehicles of the control total, calculated in Step 3 above, and;
   - The sum of the total volume for the Duals vehicle class matrix is within 2% of the control total, calculated in Step 4 above.
7. Steps 1-6 are repeated for the TTST class to create the TTST matrix.
8. The PC matrix is developed by subtracting the Dual matrix and TTST matrix volumes from the total demand matrix.

Because the volumes in the matrices are for a one-hour period, there may be relatively low volumes for each matrix cell for some minor roadways, which when combined with lower percentages for trucks, result in fractional trips that typically get rounded to zero when converted to integer trip values. To mitigate this loss of trips, fractional trips above a certain threshold can be rounded up so the distribution of trips includes some trips for these smaller volume roadways.