ON TO 2050 TRAVEL DEMAND MODEL DOCUMENTATION

CMAP

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1. Overview

The Chicago Metropolitan Agency for Planning (CMAP) is, and its predecessor the Chicago Area Transportation Study (CATS) was, the primary agency responsible for the development and maintenance of travel forecasting methods for the Chicago region. CMAP/CATS has been developing and improving these travel forecasting procedures regularly since 1956. Northeastern Illinois originally developed and employed travel demand models to assist in the development of regional transportation plans. The four-step process (trip generation, trip distribution, mode split, and traffic assignment) was fundamental from the beginning. Early enhancements focused on making the process run more quickly on the computers available at the time and on the calibration of individual model components. As time passed and transportation questions changed, the model was updated, revised, and extended to answer them.

In the 1970s, in response to concerns about improving public transit, CATS concentrated enhancement activities on the mode split model and transit assignment techniques.

In the late 1970s and early 1980s, efforts were focused on adapting the modeling process to sub-area and project specific studies. For example, CATS developed a block-by-block zone system for the downtown area. Trips were generated based on zonal floor space from a building-by-building file of the area. Networks were coded with detailed pedestrian links. These techniques were employed to evaluate transit alternatives for the Central Business District. Similarly, zone sizes were reduced and more detailed highway networks were coded in suburban areas to evaluate freeway proposals.

When federal regulations were changed to require emissions estimates for conformity analysis, the regional models were initially employed as they then existed. It was in 1994 that the first significant model changes, explicitly motivated by conformity issues, were implemented. Since then, CATS, and now CMAP, has committed substantial resources to develop models that are responsive to the needs imposed by air quality requirements. CMAP continuously strives to improve its travel forecasting techniques in response to policy priorities.

This report documents the current status of CMAP's regional travel demand model. Much of the text in this document is drawn from predecessor reports developed for the adoption of the

GO TO 2040 plan[1] and its update.[2] Since that time a number of procedural and model coefficient updates have been implemented within the CMAP model.

Overview of the Regional Model Structure and Process

The CMAP travel demand models represent a classical "four-step" process of trip generation, distribution, mode choice, and assignment, with considerable modifications used to enhance the distribution and mode choice procedures. The present CMAP region, for analysis purposes, includes the counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will in Illinois, and parts of other Illinois, Indiana, and Wisconsin counties buffering the region.

Figure 1 contains a flow chart showing the general steps used in the travel demand modeling process. The ovals in the chart represent data inputs that feed model procedures and processes. These model processes are represented by the blue rectangles. The orange rectangles denote data that are generated by the model processes; in most instances these also serve as input to subsequent procedures.

The first step in the procedure is to use the socioeconomic and land use data to estimate the trip ends for each trip type. Population synthesis software is used to develop a distribution of households for the region, including all of the characteristics of both the household and the people who live in it. The synthesized households are generated based on input parameters and observed census household characteristics. For home based trips, trip ends located at the travelers' homes are defined as productions, and trip ends located at the non-home end are defined as attractions.

Trip generation is the first of the four sequential steps utilized by CMAP to forecast travel behavior. It is the means by which land use planning/zoning quantities such as households and employment are converted into trip origins and destinations that serve as measures of transportation demand. The process uses an enumeration of all households in the modeling area and matches them to households from the Travel Tracker survey to develop trips made by household members

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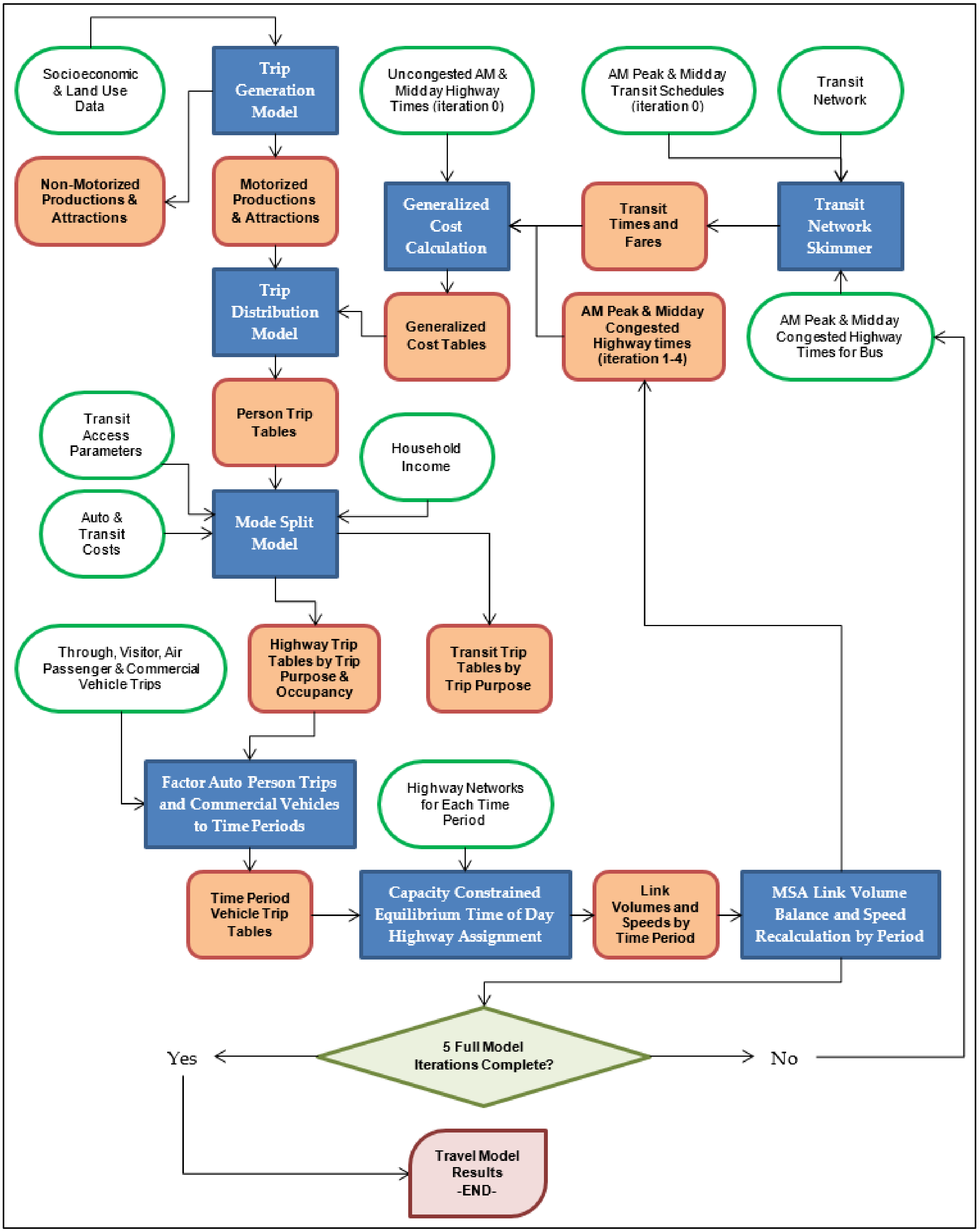
[1] Chicago Metropolitan Agency for Planning, "Travel Model Documentation Final Report" (2010, October), http://www.cmap.illinois.gov/documents/10180/29685/Travel-Model-Documentation_10-2010.pdf/526a71e3-62c2-450d-a34e-4cda1f81b1ad.

[2] Chicago Metropolitan Agency for Planning, "GO TO 2040 Update Appendix: Travel Model Documentation" (2014, October).

Figure 1. Modeling Process Overview



The trip generation model estimates total trips, including both motorized trips such as those made by auto and public transit, and non-motorized trips such as those made by pedestrian and bicycle modes. Non-motorized trips are removed and only the motorized trips are carried through the remaining model steps.

The next model in the four step process is the distribution model, which "distributes" the trip ends to produce person trips being made between modeling zone origins and destinations. The CMAP procedure uses an intervening opportunity distribution model, which uses the trip ends from the trip generation model as a measure of the number of satisfying opportunities, and a measure of the "difficulty" to travel between analysis areas (a trip impedance measure). The impedance measure used in the distribution model is the combined time and cost for both the highway and transit systems. This combined impedance (or generalized cost) measure is called the *LogSum* variable. The use of generalized cost allows the distribution model to be sensitive not only to highway and transit service levels but also to highway and transit costs.

The distribution model also incorporates the use of L-values, measures of how "selective" trip makers are towards "accepting" an opportunity to fill a trip need. The lower the L-value is, the more selective the person is in accepting an opportunity and, therefore, the longer the trip length is for a set of given opportunities. Typically the L-values are low in the center city, where there are many opportunities (attractions) and a person can be more selective, and high in low density suburban areas, where the opportunities are more limited. Years ago, L-values were developed based upon the geographic location of the traveler. These locations were primarily identified as the counties in the region and the city of Chicago. The current procedure relates the L-values to the number of opportunities that can be reached within a given generalized cost boundary. Thus the L-value is now related to the transportation service level (the generalized cost) and the land use form (the number of destination opportunities) which are explicit measures of transportation system service rather than travelers' location which was, at best, a proxy for this service level. This change in the method of estimating L-values allows the distribution model to respond to changes in residential and employment density (as density increases the L-value decreases) and changes in both transit and highway travel times and costs (as times or costs decrease the L-value decreases).

Mode choice is the third model in the process. This model, used after distribution, divides the total person trips resulting from the distribution model into transit person trips or automobile person trips. This allocation is based upon the times and costs for the available modes and the socioeconomic status of the traveler. The CMAP mode choice model is a multinomial logit model and is unique in that it uses simulation techniques to estimate many of the time and cost variables. The Monte Carlo simulation is an attempt to decrease the errors inherent in using average values by allowing the model to use knowledge of the distribution of attributes. The simulation techniques are used to estimate parking costs, the traveler's income, and the access and egress times from the primary transit routes. The model estimates the probability of this person trip using either mode and then the Monte Carlo simulation technique is used to allocate this person's trip to a specific mode, i.e. transit or auto user. The Monte Carlo simulations are run 100 times per each zonal interchange to reduce the variability in the results.

The fourth step of the travel demand procedure are the assignment models. The highway assignment and transit assignment models rely on two different algorithms. The highway assignment model uses the auto person trips from the mode choice model and a description of the transportation system to estimate the volume of trips on each segment of the road network. For the air quality analysis, the highway assignment procedure is essential for estimating the vehicle miles traveled (VMT) on each highway segment, and also to estimate the speed of each highway segment. The highway assignment step has two significant features that are important for both transportation and air quality analysis. First, because it is a capacity-constrained equilibrium assignment, the level of service (in terms of travel time) worsens as additional volumes are assigned to each link. Second, the equilibrium procedure solution ensures that simulated travelers are not able to improve their level of service (i.e. travel time) by any alternate routing. For each individual simulated traveler, travel times are optimal to the supply and demand of transportation because the traveler cannot find a shorter route.

The transit assignment model is a multipath procedure that evaluates the potential times and costs of all the transit strategies between an origin and destination, identifies the good strategies, and creates zone to zone times and costs. This model is also used to assign person trips to the transit network. The transit assignment model is important because it generates the transit side times and costs for the trip distribution and mode split model, while the assignment of trips to transit routes is needed for project studies.

As shown in the diagram, the steps of trip distribution, mode split and time-of-day assignment are iterated through five times (iterations zero through four). Morning peak congested times and distances are used for the work trip purposes and midday times and distances are used for the nonwork purposes. To create these, the link volumes from each full model iteration time of day assignment are combined (the step termed volume balancing and speed recalculation) with the link volumes from the same period in the previous iterations using the Method of Successive Averages (MSA). For example, the link volumes resulting from the first and second iterations of the time-of-day highway assignment for period 3 are combined using the MSA procedure, then skimmed to produce the highway travel information input to the generalized cost calculation for the next iteration of the process.

This process is enhanced through the inclusion of iterative feedback involving the transit system. During initial global iteration 0, the transit schedules for a.m. peak and midday service are used to feed the generalized cost calculation. Buses that operate on roadways are obviously impacted by other traffic on the road (and vice-versa). Once the congested roadway times are calculated at the end of global iteration 0, they are fed back into the appropriate transit schedules, which are adjusted to reflect the traffic conditions. These updated transit times are then used in the revised generalized cost calculations. Buses that have special operating priorities (such as bus-on-shoulders or traffic signal vehicle pre-emption) are only subject to the congested roadway times for the appropriate segments of their itinerary.

The time-of-day traffic assignment procedure more realistically matches travel demand to network supply and structure as these vary over the course of 24 hours. The time of day procedure relies on a multiclass traffic assignment enabling the conformity emissions analysis to reflect link volumes by specific vehicle type, rather than using regional or statewide averages. The traffic assignment also includes consideration of tolling where the separate vehicle classes experience different toll rates and toll rate weights. The highway time-of-day assignment splits into eight time periods the final highway trip tables from the iterated process. Separate assignments estimate highway vehicle-miles and travel speeds for eight time periods during the day including:

1. The ten hour late evening-early morning off-peak period.
2. The shoulder hour preceding the AM peak hour.
3. The AM peak two hours.
4. The shoulder hour following the AM peak hour.
5. A four hour midday period.
6. The two hour shoulder period preceding the PM peak hour.
7. The PM peak two hours, and.
8. The two hour shoulder period following the PM peak hour.

Results of the separate period assignments are accumulated into daily volumes, and also tabulated into the vehicle-mile by vehicle type by speed range tables needed for the vehicle emission calculations. The principal new element in this analysis is the adaptation of model outputs for emissions calculation by the Motor Vehicle Emissions Simulator (MOVES) model.

The remainder of this document discusses each component of the four-step model and describes the various data inputs required to run the model.

2. Travel Model Data Inputs

A number of data inputs are required to provide the trip-based models with the information necessary to estimate travel patterns. "Demand" side information includes travel surveys to inform the models, as well as socioeconomic data on where people live and work. "Supply" side data include the physical roadway and transit networks. Different zone systems are used to aggregate data to meaningful geographies. This chapter briefly describes the data used to develop and apply the regional model.

2.1 Travel Survey Data

Travel models are behavioral models of travel choices made by people, and require data describing observed travel behavior. These data comes from travel surveys. The original CATS home interview survey was taken in 1956 and consisted of almost 40,000 household interviews. The present set of models was originally developed using a 1970 home interview survey, which obtained the daily travel patterns for over 21,000 households in the region.

In 1979 a much smaller home interview was conducted. This survey was combined with the 1980 Census Journey to Work data and was used to review and modify the agency's modeling procedures. Between 1988 and 1991 another large-scale home interview survey (over 19,000 households) was conducted. The information from this survey and the 1990 and 2000 Censuses have been used to update and modify the travel demand procedures.

Starting in January 2007 and lasting one year, CMAP completed a comprehensive travel and activity survey for northeastern Illinois called "Travel Tracker." A total of 10,552 households participated in either a 1-day or 2-day survey, providing a detailed travel inventory for each member of their household on the assigned travel day(s).[3] As a test of available technology, 460 Travel Tracker participants also volunteered to wear global positioning devices (GPS) or to use auto-based devices to track their travel.

Most recently, spring 2018 marked the beginning of data collection for "My Daily Travel," the newest household travel survey for the region, which will conclude in 2019.

In addition to the home interview surveys, there have been several other data collection efforts, including a 1986 Commercial Vehicle Survey, a 1963 Pedestrian Survey, a 1987 Survey of Parkers in the Chicago Central Business District, and a 1991 Survey of Parking Spaces in the

[3] In coordination with CMAP the same data were also collected for the Northwestern Indiana Regional Planning Commission (NIRPC) for three counties in northwest Indiana. The CMAP Travel Tracker data are available at [Travel Tracker Survey -- Chicago Metropolitan Agency for Planning].

Chicago Central Business District, all of which have been used to enhance the region's travel demand procedures.

2.2. Socioeconomic Data

Base Year (2015) Data

Socioeconomic data used for trip generation estimates are derived primarily from three sources: 2010 Census Summary File 1 (SF-1), the American Community Survey (ACS), and ES-202 data from the Illinois Department of Employment Security. Data were updated to 2015 values to take advantage of more up-to-date data resources, particularly from the Census Bureau's ACS and Population Estimates Program (PEP). All data are reported at the subzone level for the entire modeling area. The geography will be described later in this document. Along with the necessary geographic identifiers, the socioeconomic file contains the following variables:

Number of Households (HH)

Data were benchmarked to 2015 based on Census estimates (PEP Vintage 2015), supplemented with ACS household size data to estimate the total number of households. Household totals were disaggregated to the parcel level (with CMAP's 2013 Land Use Inventory as the base), using data from the 2011-15 ACS, CoStar, CMAP's Northeastern Illinois Development Database (NDD), and county Assessor data to provide parcel-level estimates of households and population. Parcel-level estimates were then aggregated to the subzone level.

Average Number of Adults (aged 16 & over) per Household, Average Number of Children (aged 15 & under) per Household

For each Census block group in the modeling area, data from the ACS (2011-15, table *B01001*) was used to estimate the percentages of the population composed of children (under 16) and adults (16 and older). For the seven-county CMAP region, these rates were applied to the parcel-level population in each block group to estimate the number of adults and children living in each parcel. For the other counties in the modeling area, the rates were instead applied to the block group-level population. These parcel- and block group-level counts were aggregated to the subzone level and divided by the number of households to obtain estimates of adults per household and children per household.

Average Number of Workers per Household

For each Census block group in the modeling area, data from the ACS (2011-15, table *B08303*) was used to estimate the percentage of adults composed of workers. For the seven-county CMAP region, this rate was applied to the parcel-level adult population in each block group to estimate the number of workers in each parcel. For the other counties in the modeling area, the rate was instead applied to the block group-level adult population. These parcel- and block group-level counts were aggregated to the subzone level and divided by the number of households to obtain estimates of the number of workers per household.

Household Income Index

This is defined as the *mean income of the subzone* divided by the *regional median income*.

- Subzone Mean Income**:** Block group-level data from the ACS (2011-15, tables *B19025* and *B01001*) was used to divide aggregate income by number of households, yielding the mean household income (in 2015 dollars) of each block group. For the seven-county CMAP region, each household at the parcel level was assigned the block group-level mean. For each subzone, the income of each household within it was summed to obtain an aggregate income for each subzone, which was subsequently divided by the number of households to obtain a subzone-level estimate of mean household income.
- Regional Median Income: Since the CMAP modeling area does not conform to a reported Census geography, a regional median was estimated by applying a grouped frequency distribution to block-group level income data for all 21 modeled counties from the ACS (2011-15, table *B19001*). Using this technique, the 2015 regional median income was estimated to be $57,870. The general approach was to determine a median value using grouped frequency distributions.

Private Vehicle Mode Share of All Worker Trips to Work (PVMS)

This is the ratio between the workers in a subzone (all workers, not just those in households) who commute by auto (single-occupant vehicles, carpool and taxi) divided by the number of workers in the subzone. Estimates of workers at the block level were taken from tables generated during the **Workers per Household** (above) and **Workers in Non-Institutional Group Quarters** (below) procedures. This total was then split into a sum of "drivers" (car, truck or van, alone or in carpool, plus those taking a taxi) based on the ACS (*Table B08301, Means of Transportation to Work*) percentage of workers using those modes for the census split-tract that each block belongs to. The drive/no-drive totals were then summed to subzone; final PVMS is calculated as (Drivers)/(Drivers + Non-Drivers).

For consistency with previous trip generation files, all subzones with a "0" PVMS value (due to being unpopulated) were assigned a non-zero value based on the PVMS of the closest subzone, using the GIS “Near” function.

Pedestrian Environment Factor (PEF)

Pedestrian Environment Factor is used to help predict mode choice based on how walkable an area is and is also used to estimate household vehicle availability. There is no single, commonly-accepted method for calculating PEF; however, most case studies cite the need for a large amount of highly-detailed data (such as availability and condition of sidewalks, pedestrian route connectivity, and amenities/destinations) which are not available for the entire CMAP region. Street network density is used as a proxy for walkability, filtering out the obviously non-walkable roadways (such as Interstates), and adding pedestrian routes where available. The source for this street/pedestrian network is NAVTEQ®.

Network density is calculated for each subzone's "catchment area," which is an expanded version of the subzone. Finally, the density figure is scaled by a constant value so that the range of scores conforms to the historic range of values used in earlier versions of the models, which relied on a straight count of Census blocks.

Group Quarters Variables

- Persons in military barracks
- Persons in college or university dormitories
- Persons in other group quarters aged 16 to 64
- Persons in other group quarters aged 65 and older

These data are based on 2010 Census SF-1 block-level table P43, "Group Quarters Population by Sex by Age by Group Quarters Type." Block-level populations were geocoded to subzone using block centroids. Base-year (2015) estimates by subzone are based on each subzone's share of the 2010 total for each Group Quarters type, and scaled to match 2015 regional estimates provided by the consultants as part of their contract to develop the CMAP Regional Forecast for ON TO 2050.

Employment Variables

- Total Wage & Salary Employment in Subzone
- Total Retail (Wage & Salary) Employment in Subzone

Employment totals for all Illinois subzones (CMAP region plus Illinois counties in the modeling area) are internally-derived estimates based on Illinois Department of Employment Security (IDES) ES-202 data, geocoded at CMAP. Totals are controlled at the sector (NAICS-2) level using Bureau of Labor Statistics (BLS) data from two sources: the Quarterly Census of Employment and Wages (QCEW), and State and Metro Area Employment (for certain sectors not fully represented in QCEW).

Employment estimates for the Indiana and Wisconsin portions of the CMAP modeling area used Dun and Bradstreet business location data as a starting point to determine the distribution of employment in those areas; they were then subject to the same BLS control procedures as the Illinois data.

Retail Employment is a subset of Total Employment, and are controlled by QCEW estimates for NAICS 44-45 (Retail Trade).

Forecast Year Data

Socioeconomic forecasts are required to develop a long-range transportation plan, which includes a horizon year that is at least twenty years out from the plan's adoption date. An understanding of forecasted population and employment trends helps shape the recommendations of ON TO 2050, and forecasts are used as an input to CMAP travel models for air quality conformity analyses, project studies, small-area traffic projections, and various ad-hoc analyses. The forecast has two major components: the regional socioeconomic forecast totals, and the disaggregation of regional totals down to the local level -- known as Local Area Allocation (LAA). The process is divided into these two major stages since they draw on different disciplines.

The regional forecast totals were developed using an economic-demographic model to link the two primary socioeconomic components: regional employment and population. These two components were modeled separately and subsequently linked through a labor-induced migration adjustment to balance labor supply (population) and demand (employment).

The second major component of the forecasting process is the disaggregation of the regional forecast to the local level. This is necessary to produce the socioeconomic inputs required by CMAP's travel models for conformity analysis. The results are also shared with transportation planners and consultants for project analyses, and to county and local governments for long-range planning purposes. The ON TO 2050 local allocation of forecasted growth is an articulation of the comprehensive plan's policies and goals, balancing market factors with policy goals. The subregional allocation model is guided by a number of elements including the base year allocation; information on existing land uses, densities and developable space; details on planned developments; and transportation accessibility, along with weighted policy priorities. Total households, household composition variables (adults, children, workers, age of householder and income), as well as total and retail employment were produced by the LAA tool.

A more complete discussion of the regional forecast process and the LAA can be found in *ON TO 2050 Appendix: Regional Socioeconomic Forecast.*

2.3 Highway Network

The Master Highway Network (MHN) is the official road network database used to develop travel demand model networks at CMAP. The MHN includes roads within northeastern Illinois that have a functional classification of Minor Collector or higher. In certain instances, additional local roads have been included in the MHN to provide connectivity within the network.

The MHN covers an area of more than 10,000 square miles and extends into northwestern Indiana and southeastern Wisconsin, as shown in **Figure 2**. The MHN includes roadways for the following areas:

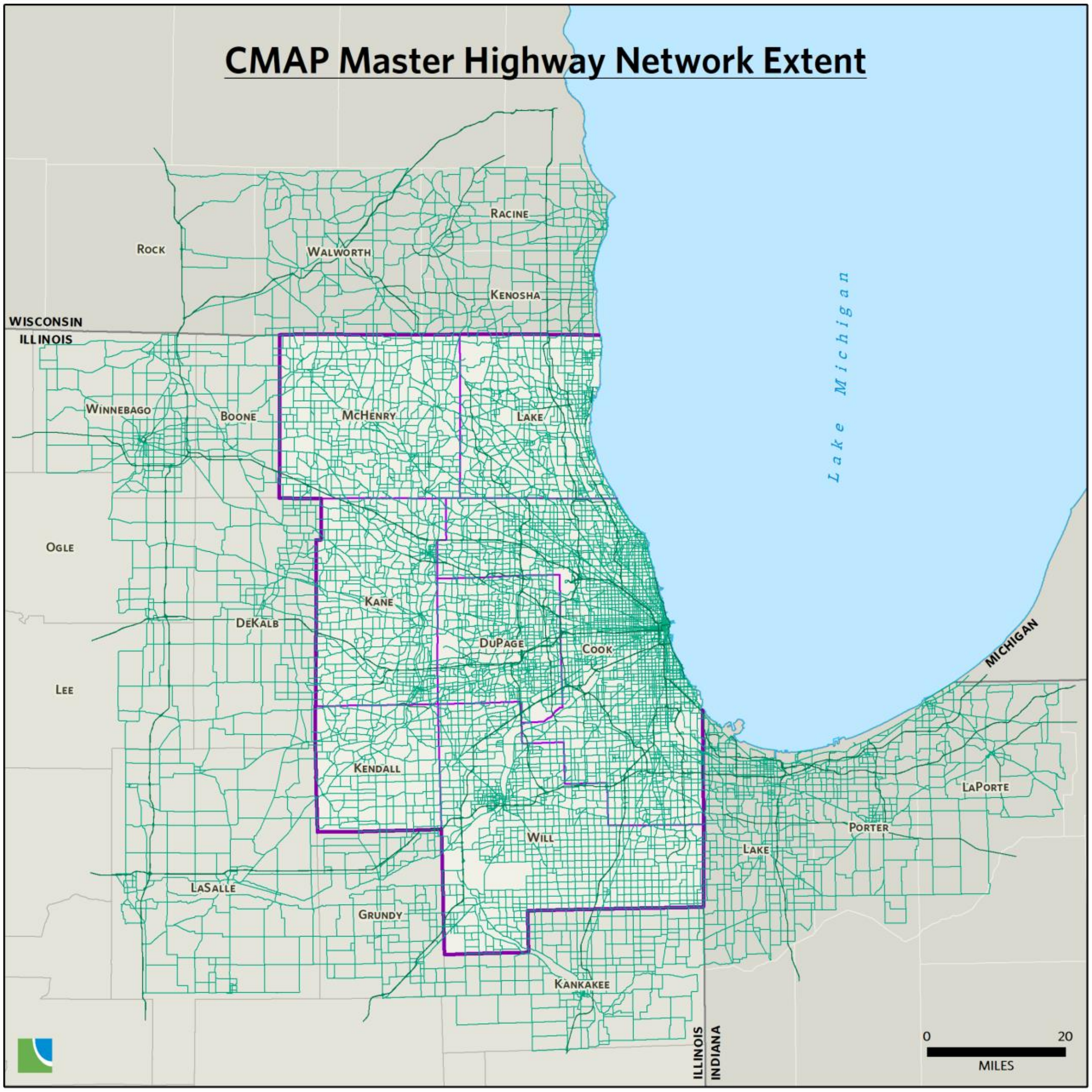
- *Illinois*: Twelve full counties (Boone, Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, McHenry, Will, and Winnebago) and three partial counties (LaSalle, Lee, and Ogle).

- *Indiana*: three full counties (Lake, LaPorte, and Porter – corresponding to the Northwestern Indiana Regional Planning Commission's planning area).
- *Wisconsin*: three full counties (Kenosha, Racine, and Walworth – the southern portion of the Southeastern Wisconsin Region Planning Commission's planning area) plus additional minimal roadway network extending into two other counties (Milwaukee and Rock).

The MHN is a collection of links and nodes representing roadway segments and intersections throughout the region. It contains information on more than 53,500 directional roadway segments and includes more than 19,300 nodes. The MHN is a comprehensive database for CMAP's regional travel demand modeling needs: it contains not only existing roadway segments and intersections, but also future planned facilities and improvements.

The MHN itself is edited and maintained using ESRI's ArcGIS® Geographic Information System (GIS) software. The MHN has a current base year of 2015, meaning that the roadway attributes on existing facilities represent the "on-the-ground" conditions from that year. It is a relational database (specifically, an ESRI file geodatabase) that maintains spatial and topologic relationships between features classes. The feature classes that define the roadway network in the MHN are arcs (also called links) and nodes. The projection of the data is State Plane Coordinate System, Illinois East zone, North American Datum of 1927. The unit of length is the U.S. Survey foot.

Figure 2. CMAP Master Highway Network



Network Arc-Node Topology

MHN arcs represent roadway segments located between intersections. Most arcs in the MHN are digitized as bi-directional links with the appropriate direction-specific attributes coded to the link. Expressways are digitized as a set of parallel single-direction links to replicate their limited-access characteristics.

Table 1 lists the highway network link variables contained in the arc attribute table that are relevant to CMAP's production modeling work. The attribute table also contains additional information not currently used for modeling purposes. As most links in the network represent bi-directional roadway segments, attributes must be included for each direction. Variable names ending in "1" describe attributes in the anode-bnode direction of the link (this is the "from-to" direction of a link, recognized by GIS software based on how the link was digitized). Those variable names ending in "2" represent attributes in the opposite direction. The directions variable indicates whether a link is a single or bi-directional segment and has three possible values, which determines how link attributes are coded:

- 1 – The link represents a single direction of travel; no second direction variables are coded (i.e., they equal 0).
- 2 – The link represents both directions of travel and all attributes are the same in both directions; no second direction variables require coding (except applicable parking restrictions).
- 3 – The link represents both directions of travel and at least one attribute differs between the two directions; all second direction variables require explicit coding.

The *baselink* variable identifies whether a segment represents an existing facility (value of one) or a future facility (value of zero, referred to as skeleton links). If *baselink*=0, only *anode*, *bnode*, *miles* and *directions* are coded on highway links. All other link attributes are fairly straightforward in their definition. Each link in the MHN is identified by a unique anode-bnode-baselink combination (variable *ABB*).

Table 1. Master Highway Network Link Attributes

Variable	Description
ANODE	Link's "from" node.
BNODE	Link's "to" node.
BASELINK	Link description flag: 0 = future project link ("skeleton" link), attributes added via highway project coding 1 = existing network link ("base" link), all attributes present
ABB	Unique arc ID, of the form "*ANODE-BNODE-BASELINK*".
MILES	Link length in miles.
TYPE1 & 2	Facility Type: 1=Arterial 2=Freeway (controlled-access) 3=Freeway-Arterial Ramp 4=Expressway (limited-access) 5=Freeway-Freeway Ramp 6=Centroid Connector 7=Toll Plaza 8=Metered Ramp
TOLLDOLLARS	Toll amount in dollars for autos with I-PASS. If link type is 7 (toll plaza), this is applied as a fixed-cost toll; for other link types, it is applied as a per-mile rate.
AMPM1 & 2	Time period restrictions: 1=open all time periods (1-8) 2=open a.m. periods (2-5) only, e.g. Kennedy reversible lanes inbound 3=open p.m. periods (1, 6-8) only, e.g. Kennedy reversible lanes outbound 4=open off-peak periods (1, 5) only
SIGIC	Signal interconnect flag: 0=no, 1=yes
POSTEDSPEED1 & 2	Posted speed limit (mph).
THRULANES1 & 2	Number of driving lanes. [This represents the most-restrictive capacity on the link, i.e. the fewest number of lanes present at any single point.]
PARKLANES1 & 2	Number of on-street parking lanes.
PARKRES1 & 2	Peak period parking restrictions, when on-street parking is not available and an extra through lane is available. *Coded separately for each direction on all 2-way links.* Code is text string of affected time periods (currently only 3 & 7). Default blank value means no peak period parking restrictions.
THRULANEWIDTH1 & 2	Average driving lane width (feet).
DIRECTIONS	Link directions flag: 1=one way 2=two way, attributes in both directions identical 3=two way, at least one attribute different in opposing direction
MODES	Modes permitted on link: 1=all vehicles 2=all vehicles (with truck restrictions from *TRUCKRES* applied) 3=trucks only 4=transit only (only called for transit networks) 5=HOV only
TRUCKRES	Detailed truck restriction codes, which translate into the following model coding:

	No restriction known/codeable: 0, 6, 15, 20, 22-24, 26, 28, 32, 33, or 36 No trucks: 1 or 18; also, 21 in time period 1 only No trucks except B-plates: 2-4, 9-11, 13, 25, 35, or 37; also, 12 in time period 1 only No medium or heavy trucks: 7, 8, 14, 16, 17, 19, 27, 29, 31, 34, 38-47, or 49 No heavy trucks: 5, 30, 45, 48
VCLEARANCE	Vertical clearance (inches). The following mode restrictions are applied for non-zero values: Clearance < 162": no heavy trucks Clearance < 150": no medium trucks Clearance < 138": no light trucks

Nodes in the MHN represent intersections between roadways or junctions where roadway segments converge/diverge, such as an entrance ramp merging into an expressway through lane. The arc-node topology enforced in the MHN is that nodes represent the end points of arcs and arcs with common end points are connected. CMAP's modeling staff maintains a set of scripts that automatically update network topology after edits have been made and populate a number of attribute fields.

Node attribute variables are listed in **Table 2**. These mostly serve to define the network arcs by providing values for *Anode* and *Bnode*. Values for the entire set of node variables listed are automatically populated through scripting. If desired, the unique node number may be manually edited, but all other node attributes are addressed through the scripts.

Table 2. Master Highway Network Node Variables

Variable	Description
NODE	CMAP network node number.
POINT_X	Auto-generated x-coordinate (NAD27 IL East State Plane feet).
POINT_Y	Auto-generated y-coordinate (NAD27 IL East State Plane feet).
SUBZONE09	Subzone ID from current CMAP modeling subzone system.
ZONE09	Zone ID from current CMAP modeling zone system.
CAPACITYZONE09	2009 Capacity Zone code: 1=Chicago Central Business District (2009 subzones 1-47) 2=Remainder of Chicago Central Area (2009 subzones 48-80) 3=Remainder of City of Chicago (2009 subzones 81-976) 4=Inner ring suburbs where Chicago street grid is generally maintained 5=Remainder of Illinois portion of the Chicago Urbanized Area 6=Indiana portion of the Chicago Urbanized Area 7= Other Urbanized Areas and Urban Clusters within the CMAP Metropolitan Planning Area plus other Urbanized Areas in northeastern Illinois 8=Other Urbanized Areas and Urban Clusters in northwestern Indiana 9=Remainder of CMAP Metropolitan Planning Area 10=Remainder of Lake County, IN (rural)

	11= External area 99= Points of Entry – not defined in the Capacity Zone system

Spatial and Geometric Accuracy

CMAP ensures that the MHN is spatially and geometrically accurate with respect to:

- Geocoding intersections to spatially accurate locations.
- Applying vertex coordinates to links in order to replicate roadway geometry.
- Ensuring expressway interchanges are fully-expanded to include ramps representing all possible traffic movements.

Figure 3 illustrates the network accuracy for one interchange in the MHN.

Figure 3. Master Highway Network Accuracy

I-57 at US-6

Highway Project Coding

The MHN includes links serving as placeholders for future planned facilities, identified by *baselink*=0. The Northeastern Illinois Transportation Improvement Program (TIP) database is the repository of project information for planned and programmed projects. Relying solely on the TIP database for project information provides a single direct link for reconciling model network coding with the planned improvement.

The MHN geodatabase stores highway project coding in a table containing detailed attributes and a line feature class containing the project ID, completion year and geographic extent. A group of network links is selected by their unique *ABB* values to define an individual highway project. The highway project line feature class contains summary information for each project, shown in **Table 3**. Each project is represented by a single multi-part line feature, which is automatically generated based on the links referenced in the detailed coding table. This data structure allows a single highway project to be associated with numerous MHN arcs and, by extension, allows a single MHN arc to be associated with multiple highway projects. The end result is that the project coding table contains one record for every arc referenced by every highway project.

Table 3. Master Highway Network Highway Project Line Feature Class Attributes

Variable	Description
TIPID	TIP project identification number.
COMPLETION_YEAR	Project completion year from TIP.

The project coding table is used to store link attributes that will be updated or applied when the associated highway projects are completed, and an action code that determines how the attributes for each link are processed. The list of section table variables is shown in **Table 4**; most directly correspond to MHN arc attributes. As with the arc attribute table, variables ending in "1" apply to the "from-to" direction of the link, while those ending in "2" apply to the "to-from" direction. During network processing, data from the arc attribute table are updated (overwritten) on-the-fly with project coding table entries to represent conditions after the project is implemented. Only those attributes changing due to project implementation are coded in the section table.

Project coding rules for parking lanes are slightly different than for other variables. The values for this attribute are added to (or subtracted from) arc table coding to yield the final result. This allows for these attributes to be increased, decreased or removed. This is necessary because there is no practical way to determine whether a zero in the section table represents no change in conditions or the removal of this particular attribute.

Four action codes control the link processing. Action code 1 modifies the coded attributes on links with existing attributes. Action code 4 is applied to new links (skeleton links), which have no attributes except *miles* and *directions*. Action code 2 is used when new links replace an old link without any change in its attributes, such as when a new intersection is introduced into the network. This action code requires that *replace_anode* and *replace_bnode* are filled in; these represent the nodes of the link where the attributes will be drawn from. Action code 3 deletes a link from the network.

Table 4. Master Highway Network Highway Project Coding Table Fields

Variable	Description
TIPID	TIP project identification number.
ABB	Reference to unique arc ID, of the form "*ANODE-BNODE-BASELINK*".
ACTION_CODE	CMAP action code: 1=modify (change an existing network link) 2=replace (replace an existing link with a new one but retain all attributes) 3=delete (remove a link from the network) 4=add (add a new link to the network)
NEW_TYPE1 & 2	New facility type number.
ADD_SIGIC	Add signal interconnect to link (code=1).
NEW_THRULANEWIDTH1 & 2	New average driving lane width (feet).
NEW_THRULANES1 & 2	New number of driving lanes.
NEW_POSTEDSPEED1 & 2	New speed limit (mph).
REP_ANODE REP_BNODE	*ANODE* and *BNODE* of MHN link providing attributes, ONLY for action_code=2.
NEW_TOLLDOLLARS	New I-PASS toll amount for autos (dollars). If link type is 7 (toll plaza), this is applied as a fixed-cost toll; for other link types, it is applied as a per-mile rate.
NEW_DIRECTIONS	New directions flag.
ADD_PARKLANES1 & 2	Add/remove parking lanes, coded number will be added to number in MHN arc attributes to calculate final lanes (code positive to add, negative to remove).
NEW_AMPM1 & 2	New time period restrictions.
NEW_MODES	New modes permitted.
TOD	Time-of-day code indicating specific time periods when changes are applied. Default of blank or 0 means changes applied to all periods. Code is text string of affected time periods: 1=8 PM – 6 AM (overnight) 5=10 AM – 2 PM (midday) 2=6 AM – 7 AM 6=2 PM – 4 PM 3=7 AM – 9 AM (a.m. peak) 7=4 PM – 6 PM (p.m. peak) 4=9 AM – 10 AM 8=6 PM – 8 PM

Storing the existing and future highway network components in a single database allows the analyst to ensure that project and base network information reconciliation is handled comprehensively, with all of the analysis networks for a particular application, at one step, existing in a single dataset. Storing the MHN in a GIS format also greatly simplifies project-coding tasks. The MHN structure allows for:

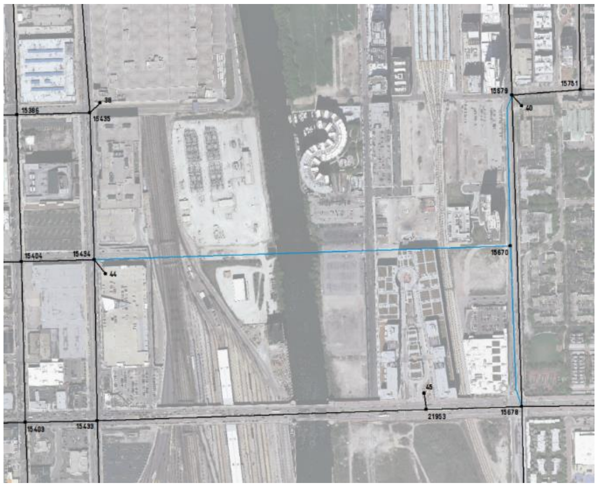
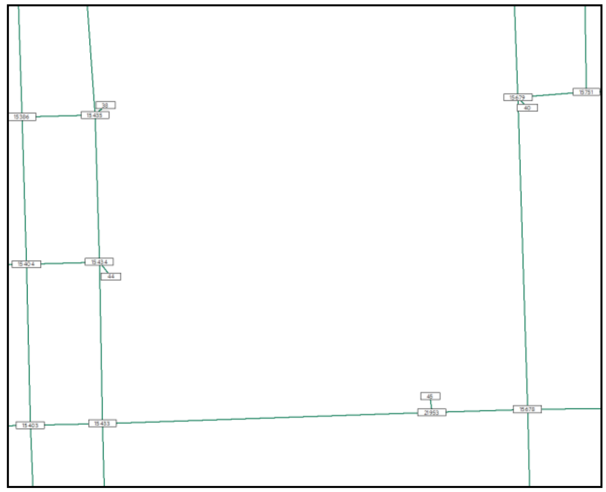
- Analysis into multiple future years – Assignable networks are produced that maintain consistent project coding into future years (e.g., a project that is built in an earlier year will be included in all subsequent networks).

- Analysis across multiple scenarios – Assignable networks are produced that maintain consistent project coding between differing analysis scenarios (e.g., a project that is included in one land use scenario will be identically coded in any other appropriate scenario).

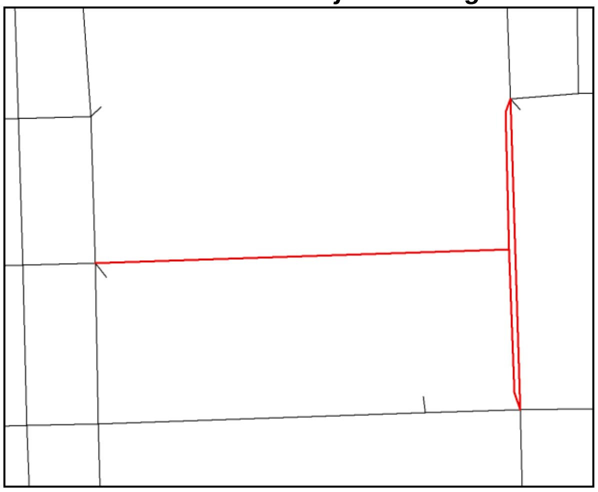
This topology was in direct response to the types of comparative evaluations that were necessary under the air quality conformity baseline/action rules. With approval of a State Implementation Plan budget, conformity analysis no longer entails a baseline/action test so a simpler hierarchy is utilized. Nonetheless, this ability is useful within any forecasting exercise where multiple time frames and scenarios are compared (e.g. land use/transportation interactions).

A list of modeled project TIP identification numbers and the year in which they are to be constructed is all that is required to create a set of highway network files for the travel demand modeling software (Emme®). The completion year is attached to each project and stored in the highway project line feature class. As complete project coding information exists in the feature class and associated coding table, simple database queries are able to select only those records needed to prepare the desired analysis year network. A set of scripts written in Python and SAS® process all of the project coding information, apply the attribute updates to the set of links comprising the scenario network, and create a set of time-of-day link and node attribute files suitable for import into Emme®. Figure 4 provides an illustration of this process.

Figure 4. Highway Network Coding Example

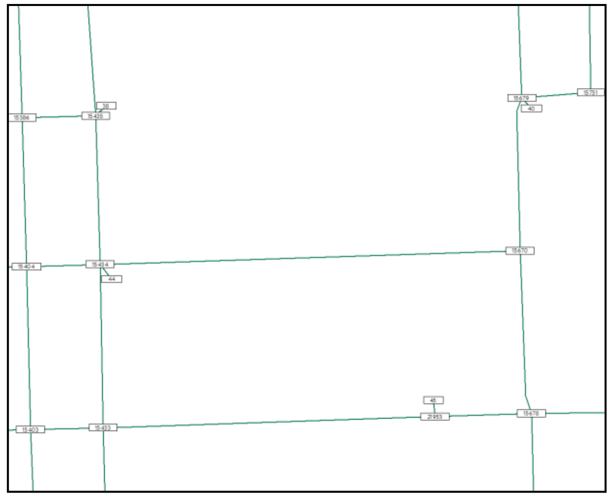
MHN Network	*Emme Network – Base Year Scenario*
	
Step 1. All existing roadway facilities (black) and a future planned facility (blue) are coded into the MHN. The future roadway extension will span a rail yard and a river, will tie into an existing intersection on the west and will create a new intersection on the east.	**Step 2.** An Emme base year scenario network is created. Since the roadway extension does not currently exist, it is not reflected in the model network.

MHN Network Project Coding



Step 3.
All links impacted by the project are associated with the project ID through a route system (red). The link coding contained in the route system's section table serves as a set of instructions on how to process each link. The coding identifies which links associated with this project to: (1) add to the network, (2) delete from the network and (3) replace with new links but apply the attributes of the old link.

Emme Network – Future Year Scenario



Step 4.
A future scenario modeling network includes the roadway extension and the new intersection.

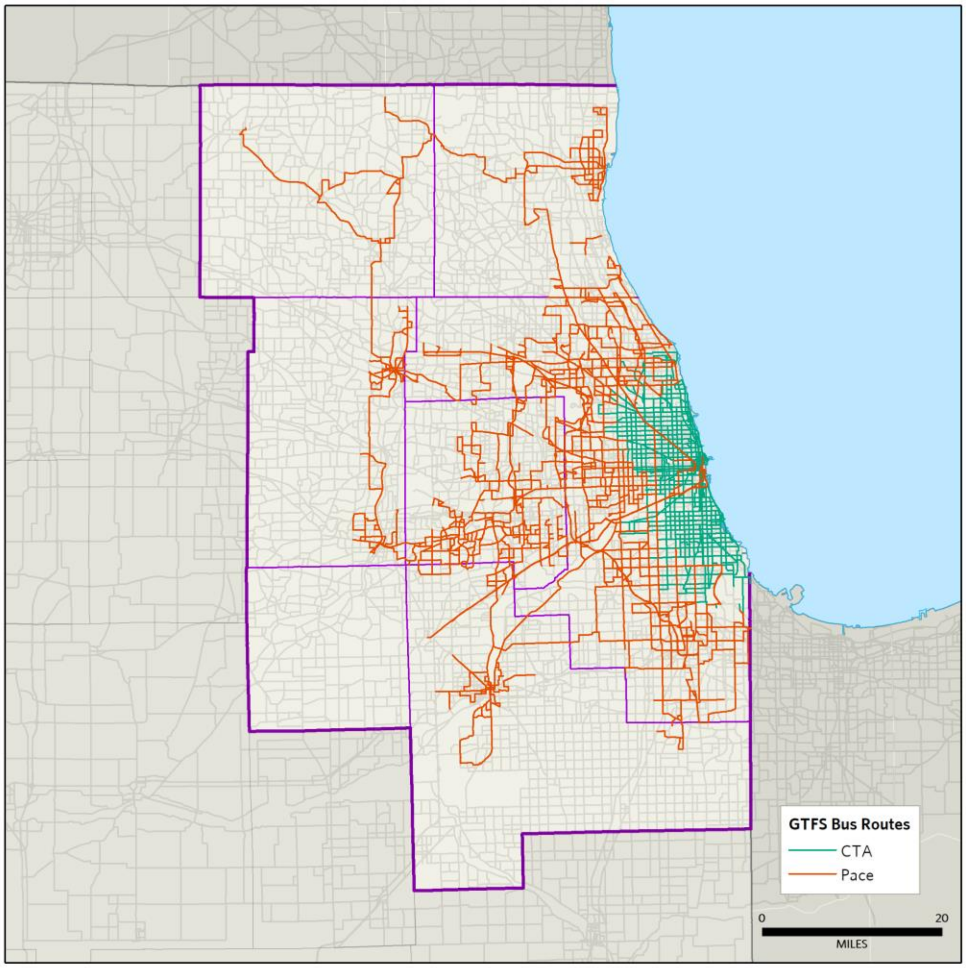
Bus Route Coding

The northeastern Illinois region has one of the most extensive public transportation systems in North America. Bus and rail service is provided by three local public operating agencies: the Chicago Transit Authority (CTA), Metra commuter rail and Pace suburban bus. Each of the three agencies has its own board, management and operating personnel. The agencies' service areas overlap to varying degrees and many riders' trips involve transfers between services provided by different operators.

The CTA operates bus service within the city of Chicago and several adjacent suburbs. Pace operates nearly exclusively in the suburbs, with some express service to downtown Chicago. Pace operates regular bus routes, feeder buses focused on providing connections to suburban Metra commuter rail and CTA rail stations, all paratransit service in the region, a vanpool program and some long distance express buses. Bus route coding maintained in the model networks includes publicly-operated fixed route service, and does not include vanpools, paratransit or subscription service.

Existing bus service coding is maintained as two separate pairings of a route feature class and an itinerary table within the MHN, very similar to the highway project coding structure. One pairing is for the base network, based on route data from 2015. Another is based on more current route data (currently 2016), which forms the basis for most future model networks. The data structure ensures that bus coding always reconciles with the underlying highway network arcs. Bus routes are forced to conform to the available MHN links: if a particular route uses local streets that are not included in the MHN, the coding for the route is altered accordingly so that it only uses MHN links. **Figure 5** shows the extent of the region's bus service.

Figure 5. Master Highway Network General Transit Feed Specification-Based Base Bus Coding, 2015



Bus coding in the MHN includes the complete itinerary (or node-by-node path) of the bus route and attributes associated with each itinerary segment. Bus routes are coded as single-direction runs. CMAP bus coding is derived from General Transit Feed Specification (GTFS) data files created by the transit operators. The GTFS files contain data on all runs of every bus during the entire week. As CMAP models weekday traffic, the bus coding data from the GTFS files are limited to a representative weekday (Wednesday).

Conversion of the GTFS data from its raw form into usable bus coding proceeds through a series of steps:

1. Geographic data are stored in MySQL. Python scripting is used to identify a group of potential MHN nodes that corresponds to each of the bus stop locations contained in the data files.
2. Using a set of rules, a MySQL query determines which stop(s) are assigned to specific MHN nodes. Bus run data are then reformatted into itineraries, which include departure and arrival times at each itinerary stop, calculated from the GTFS time associated with each stop. At this stage, the itineraries are somewhat independent of the MHN network: while they are constructed using MHN nodes, there is no guarantee that the itinerary segments formed correspond to actual network links, as defined by a specific *anode-bnode* combination. This is true because a particular bus may not stop at a consecutive set of connected nodes within the network, especially if it is express service.
3. Reconciliation with the network arcs is accomplished through a set of SAS and Python scripts. In instances where the segments do not align with a network arc, a shortest path algorithm is used to link the itinerary segment nodes together by building a useable path on the network. The segment attributes are then apportioned over the new sections appropriately and they are inserted into the bus route itinerary. Additional logical tests are performed and faulty data (such as an itinerary segment with the same node at both ends or a route with an initial departure time equal to the final arrival time) are corrected using a set of rules. The end result is a set of itineraries with all segments corresponding to MHN links. Automated procedures ensure logical coding is developed: for instance, coded buses are not allowed to travel the wrong direction on a one-way link.
4. The bus route and itinerary data are then imported into the MHN geodatabase by a Python script that automatically generates the line features representing each run from the underlying arcs.

As with the highway project coding, bus run details are stored in a set of related itinerary tables; these tables relate to the arc table in the same manner as the highway project coding tables. The bus run line features and itinerary tables are linked through the *transit_line* variable, which is a unique identifier given to each bus run.

Table 5 highlights the data fields maintained in the MHN that are used to describe bus route attributes. The variables shaded in blue correspond to header information Emme requires when reading in bus itineraries; others attributes are merely informational. Note that at this point the *headway* value only represents the total number of minutes in the time-of-day period within which the bus run occurs. The actual bus service headway is calculated at a later stage when individual runs are grouped into representative runs.

Table 5. Master Highway Network Base and Current Bus Run Feature Class Attributes

Variable	Description
TRANSIT_LINE	Unique CMAP bus run identifier. (Mode + 5-digit number, starting at 00000 for base, 50000 for current.)
DESCRIPTION	Real-world description of bus route (format: "*ROUTE_ID LONGNAME*: *DIRECTION* TO *TERMINAL*").
MODE	Bus mode code: B=CTA regular service E=CTA express service P=Pace regular service Q=Pace express service L=Pace local service
VEHICLE_TYPE	Bus vehicle type code (based on mode code): 1=mode B 2=mode E 3=mode P 4=mode Q 5=mode L
HEADWAY	Length of the time-of-day period (in minutes) within which the bus run falls, since every run is represented individually.
SPEED	Average bus route speed in MPH from GTFS data; minimum value of 15 allowed. [Not used in CMAP modeling but a non-zero value is required by Emme.]
FEEDLINE	Unique GTFS identifier for each run.
ROUTE_ID	Number of bus in route name (e.g. 52A, 112, X98).
LONGNAME	Proper name of bus in route name (e.g. Wentworth, Halsted/95th).
DIRECTION	Predominant direction of travel for bus run.
TERMINAL	Location of final stop on bus run.
START	Start time of bus run in seconds.
STARTHOUR	Start hour of bus run.
AM_SHARE	Proportion of run that occurs within the AM Peak period (7 AM - 9 AM). Simple count of itinerary segments; full segment must be covered within the time period.
CT_VEH	Extended transit vehicle types used for CT-RAMP.

The actual itinerary information for bus routes is contained in the itinerary table variables which are listed in Table 6. The itinerary provides the node-by-node path on the MHN that the bus follows. Again, most of these variables reflect information that Emme expects to receive when bus routes are imported.

Two GTFS-based bus coding route systems exist simultaneously in the MHN database:

- **Bus_base** – GTFS–based coding that corresponds to CMAP's model base year of 2015 (reflecting service at that time).
- **Bus_current** – Coding built from the most recent GTFS data files. This represents up-to-date coding and is used as the basis for future modeling scenarios.

Each of the bus route systems listed above contains over 25,000 bus runs comprising roughly 750,000 itinerary segments, representing one weekday of service. For travel demand modeling purposes, the bus runs are combined into representative bus routes. A script analyzes the runs of each particular bus route that occur during a time-of-day period, and uses the stopping pattern to determine which are similar enough to be collapsed into a "typical" directional bus route. The start times of all of the individual runs that are associated with a representative bus route are used to calculate the service headway that goes into the travel demand model.

Table 6. Master Highway Network Base and Current Bus Itinerary Table Fields

Variable	Description
TRANSIT_LINE	Unique CMAP bus run identifier. (Mode + 5-digit number, starting at 00000 for base, 50000 for current.)
ITIN_A	CMAP node number bus travels from.
ITIN_B	CMAP node number bus travels to.
ABB	Unique ID of the segment's corresponding MHN arc.
ITIN_ORDER	Order number of bus segment in itinerary, sequentially increasing from 1 for each run.
LAYOVER	Layover time in minutes applied to *ITIN_B*. Default=3.
DWELL_CODE	Code for stops (corresponding Emme code), applied to *ITIN_B*: 0=stop allowed (default time of 0.01 minutes) 1=no stop (#) *available for future use:* *2=alighting only (>)* *3=boarding only (<)* *4=boarding & alighting allowed (+)* *5=dwell time factor (*)*
ZONE_FARE	Incremental zone fare in cents.
LINE_SERV_TIME	Itinerary segment travel time in minutes.
TTF	Emme transit time function code: 0,1=1 2=2 (used for Bus Rapid Transit/Arterial Rapid Transit only)
DEP_TIME	Time departing node *ITIN_A* (seconds since midnight).
ARR_TIME	Time arriving at node *ITIN_B* (seconds since midnight).
LINK_STOPS	Number of stop locations from GTFS data that were combined into itinerary segment.
IMPUTED	Flag indicating segment was imputed by shortest path algorithm during import. 0=not applicable. 1=itinerary segment created by shortest path algorithm. 2=segment modified by logic to condense unreasonable vacillation in itinerary.

Table 7 lists the eight time-of-day (TOD) modeling periods used by CMAP. It also includes the selection rules used to determine which TOD period a particular bus run falls in, and shows the number of representative bus routes (from **bus_current**) used in the travel demand model. An additional TOD bus network (AM peak) is created to generate the transit level-of-service variables used to develop zonal generalized costs for the travel demand model.

The AM peak network is a bit more inclusive than the one included in time period 3, as illustrated by the selection rules. The representative routes comprising each TOD bus network are created “on-the-fly” when the networks are needed. While the regional travel demand model uses the AM peak and midday bus networks, the eight individual time-of-day bus networks are used in CMAP’s activity-based model.

Table 7. Time-of-Day Base Bus Routes

Time Period	Selection Rule	Number of Bus Routes
1 – (8 PM – 6 AM)	*Starthour* >=20 or *Starthour* <=5	606
2 – (6 AM – 7 AM)	*Starthour* =6	631
3 – (7 AM – 9 AM)	7<= *Starthour* <=8	698
4 – (9 AM – 10 AM)	*Starthour* =9	497
5 – (10 AM – 2 PM)	10<= *Starthour* <=13	503
6 – (2 PM – 4 PM)	14<= *Starthour* <=15	645
7 – (4 PM – 6 PM)	16<= *Starthour* <=17	653
8 – (6 PM – 8 PM)	18<= *Starthour* <=19	563
AM – (7 AM – 9 AM)	*Am_share* >=0.5	702

Future Bus Coding

While the GTFS data provide for existing bus service, future bus routes are also coded in the MHN to represent planned or programmed service. Consistent with GTFS bus runs, future bus routes are generally coded as single-direction service. While GTFS routes are coded on existing network links (*baselink*=1), future routes are coded to run on future highway network links (i.e., links that will be in the network in the horizon year of the projects being modeled). Thus it is very convenient to have the highway project coding information stored in the same database as the bus coding.

Table 8 lists the future bus route information stored in the line feature classes attribute table. Many of these variables provide the bus route information Emme requires to build transit routes and have the same definition as in the GTFS-based bus coding table. The *notes* field is used to store TIP project numbers or other useful information related to future bus service. The following variables provide instructions on how the future routes are processed:

- *Scenario* – identifies all of the specific modeling scenarios that individual bus routes should be included in.
- *Replace* – identifies the existing GTFS route(s) that will be replaced by the future route coding, if any.
- *TOD* – indicates which time-of-day networks will include the future bus service.

Table 8. MHN Future Bus Route Attributes

Variable	Description
TRANSIT_LINE	Unique CMAP bus route identifier. (Mode + 5-digit number, starting at 99000 for future.)
DESCRIPTION	Real-world description of bus route.
MODE	Bus mode code.
VEHICLE_TYPE	Bus vehicle type code.
HEADWAY	Average bus headway for Peak periods (TOD 3/7/AM) in minutes. This coded value will only be applied during those periods. *A value of zero indicates that the headway for the existing route coding from route flagged in REPLACE will be used (i.e., there will be no change in service frequency).*
SPEED	Average bus route speed in MPH; default value of 12 used. [Not used in CMAP modeling but a non-zero value is required by Emme.]
SCENARIO	Future scenarios bus line will be used in. Must include ALL scenarios that will contain route. May NOT be blank
REPLACE	Identifier of the existing bus route coding that will be replaced by the future project. A blank indicates the future route represents new service being added. Constructed as: Uppercase mode letter + "-" + route number. *Note: the replacement will only occur in the time periods identified in the TOD field.*
TOD	Time-of-day periods when the new coding will be implemented. As with SCENARIO, all applicable time periods must be listed. The route will be included in the AM network if TOD includes a value of 3. *A value of zero indicates that the new coding will be applied to all time periods.*
NOTES	TIP ID number (and possibly other descriptive information). Entries must be separated by colons. 30 character limit.

As with the highway project coding, CMAP modeling staff maintain a set of scripts that generate scenario-specific TOD transit network input files for the travel demand model. While processing of the base/current year bus routes is relatively straight-forward, the future bus routes require additional logic to process all of the changes correctly. The following rules are used to generate future scenario TOD transit network input files:

1) New routes only appear in the specific time periods identified in the *TOD* field, or in all periods if *TOD*=0. During processing, every future route with a TOD value that contains "3" will be included in the AM period, and every route with a TOD value that contains “5” will be included in the midday period.

2) The *replace* field identifies current bus routes that will be replaced by the future coding for the time periods in *TOD*. These current routes are deleted from the network. The routes are identified by the letter *Mode* code and the *Route_id* from the route table.

3) A number of potential values are used to determine future headways:

    a. Coded headway: this is the headway coded for future bus routes; it applies only to time periods 3, 7 and AM.

b. Factored headway: the value is Coded headway (if it's greater than zero) times a TOD multiplier [*2 for periods 2/4/6/8; 3 for period 5; 4 for period 1*]. This reflects a general service frequency reduction from the AM peak.

c. Replaced headway: the TOD headways for the bus routes being replaced by future service (this value is calculated when the bus runs are collapsed into representative routes). To avoid having to apply directional headways to the future service, this value is the minimum of the current directional headways.

d. Mode headway: the average headway for a time period for a given bus mode (B,E,P,L,Q) based on the existing bus routes, excluding those being replaced.

e. Last chance headway: a final future headway value if all other options fail; set to 90 minutes.

The logic used to determine the final TOD future headway for each future route is:

- *Priority 1*: If Replaced headway is nonzero and is less than Factored headway, use Replaced headway. If that does not apply, go to Priority 2.
- *Priority 2*: If Factored headway is nonzero, use Factored headway. If that does not apply, go to Priority 3.
- *Priority 3*: The future headway is the maximum of [Mode headway, Last chance headway].

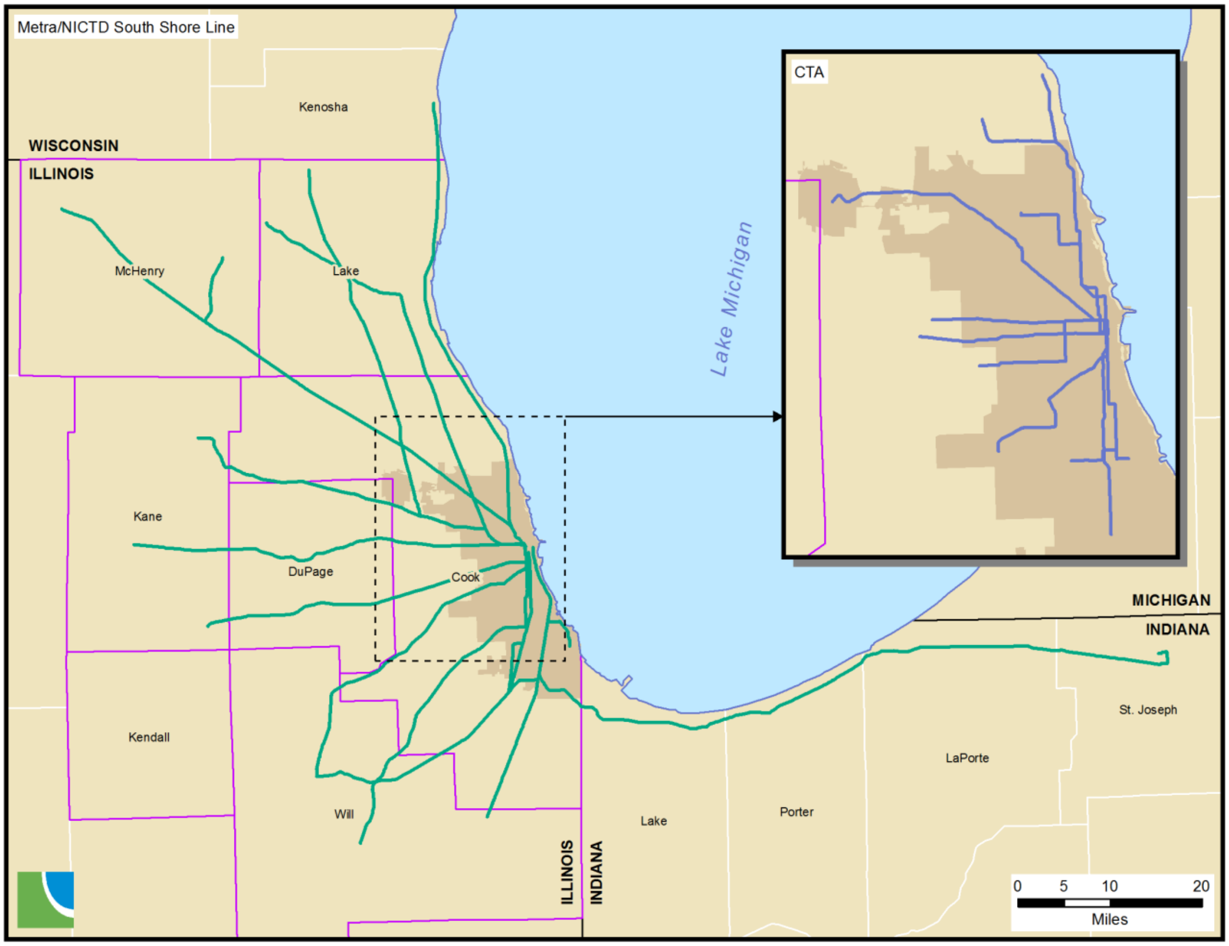
The final outcome is that the future headway for non-peak periods (1, 2, 4, 5, 6 and 8) cannot be less than the headway in the peak periods. Regardless of priority, headway is capped by the length of the time period the service is operating in.

2.4 Rail Network

The Master Rail Network (MRN) is stored in a file geodatabase, which contains all of the rail segments representing heavy and commuter rail service in northeastern Illinois. The geodatabase stores all of the feature class data needed to build rail transit networks for regional analyses: arcs, nodes, rail routes and itineraries. While it would be possible to combine the MHN and MRN into one relational database, the rail network has very few link attributes compared to the highway network and is much smaller in scope than the MHN. Thus it is easier to maintain them separately. The MRN is stored in the same projection as the highway network database so that they work together seamlessly.

In addition to bus service, the CTA operates heavy rail transit within the city of Chicago and several adjacent suburbs. Suburban commuters are served by Metra's radial rail services oriented between suburban areas and the central area. There are a number of Metra stations within the city of Chicago, and some Metra lines parallel CTA rail lines. Additionally, the Northern Indiana Commuter Transportation District operates commuter rail service between downtown Chicago and South Bend, Indiana. The extent of the MRN is illustrated in Figure 6.

Figure 6. Master Rail Network



Topology rules within the MRN are enforced programmatically by rebuilding the routes each time the network is updated or new routes are imported using the arc geometry. In addition to being an efficient way to process the data, this procedure also ensures that rail routes will always be coincident with the underlying arcs (which is necessary for selecting scenario-specific route coding).

Arc Fields

Table 9 lists the rail network link variables contained in the arc table and are the variables required by the travel demand modeling software. Most of the arcs represent the rail line segments that connect stations (either mode "C" for CTA rail or mode "M" for Metra). Two other kinds of links are included in the MRN on a limited basis: transfer links connecting different rail service and walk links providing access or egress to the service. These auxiliary links are discussed in further detail later.

Table 9. Master Rail Network Link Attributes

Variable	Description
ANODE	CMAP "From" node.
BNODE	CMAP "To" node.
MILES	Link length in miles.
MODES1	Modes permitted on anode-bnode direction of link (string of mode letters).
MODES2	Modes permitted on bnode-anode direction of link (string of mode letters); blank if link is only 1 direction.
DIRECTIONS	Link directions flag: 1=one-way, 2=two-way.

Node Fields

Node variables are listed in Table 10. The nodes represent rail stations or, in a few instances, rail line junctions that are not actual stations. Rail service does not stop at junction locations. In addition to a unique identifier for each station, the node table contains information on the availability of parking at the rail stations: *pspace* indicates the number of parking spaces available at the station and the cost of parking is stored in *pcost*. Both of these values represent conditions in the base year of the MRN, thus *pspace* equals zero if no parking is available and *pcost* equals zero if there is no fee.

Table 10. Master Rail Network Node Attributes

Variable	Description
NODE	CMAP node number; used to assign ANODE and BNODE values in arc table. CTA rail: uses range 30000-39999 Metra: uses range 40000-49999
LABEL	Node label (4-character station name).
PSPACE	Number of parking spaces at node in base scenario; zero if not used in base scenario.
PCOST	Parking cost at node in base scenario; zero if not used in base scenario.
FTR_PSPACE	Number of parking spaces at node in future scenarios. This text string uses the format "s1:p1:s2:p2: …" where s=the hundred's place value from CMAP's scenario numbering scheme and p=the number of parking spaces in the corresponding scenario. Each value must be separated by a colon.
FTR_PCOST	Parking cost at node in future scenarios; same format as *ftr_pspace*.

Future scenario parking information is also stored in the node attribute table in variables *ftr_pspace* and *ftr_pcost*. A *ftr_pspace* value of "4:150:6:200" is interpreted as follows: the node will have 150 parking spaces beginning in scenario 400 and 200 parking spaces beginning in scenario 600. The value is assigned through scenarios until a later scenario is specified, so the node will have 150 parking spaces in scenario 500 as well. While it is easier for the analyst to read this value if the scenarios are coded in chronological order, the processing programs do not require this in order to assign the correct value to each scenario. Values for *ftr_pcost* are coded using the same format.

Rail Route Coding

As with bus coding stored in the MHN, rail service coding in the MRN is built from GTFS data files for a representative weekday (Wednesday). Each individual run of every rail line is stored in the database, representing a single direction of travel. Processing of the GTFS rail service data into usable model coding follows the same set of procedures and logical reviews as bus route data. Rail service coding is stored in the geodatabase as a pair of related tables containing information on the rail run and its itinerary.

Table 11 lists the variables in the rail route table. As with bus route coding, the variables are a combination of header fields Emme requires when reading in rail itineraries (highlighted in blue) and GTFS fields maintained for clarity. These variables have the same definition in both the bus and rail route tables, although the values may differ. Special attention is given to the transit line name variable (*tr_line*) in the rail coding.

Table 11. Master Rail Network Rail Route Attributes

Variable	Description
TR_LINE	Unique CMAP rail run identifier (6 characters).
DESCRIPTION	Real-world description of rail run (20 characters maximum – limit imposed by Emme).
MODE	Rail mode code: C=CTA rail M=Metra/NICTD
VEHICLE_TYPE	Rail vehicle type code (based on mode code): 7=mode C 8=mode M
HEADWAY	Rail headway (in minutes). A value of 99 indicates headway will be set to the length of the time-of-day period within which the rail run falls. In future routes, headway values can be different if headway changes throughout day. In this case the value is in a colon delimited format with the TOD periods followed by the effective headway for those periods. (e.g. 234678am:6.7:5:11.3:1:19.2)
SPEED	Average rail route speed in MPH from GTFS data; minimum value of 15 allowed. [Not used in CMAP modeling but a non-zero value is required by Emme.]
FEEDLINE	Unique GTFS identifier for each run.
ROUTE_ID	For CTA: lists line (Blue, Red, etc.). For Metra: lists train run number.
LONGNAME	Lists the proper name of the train line (Blue Line, Union Pacific Northwest, etc.).
DIRECTION	Lists final stop on train run.
START	Start time of train run in seconds.
STARTHOUR	Start hour of train run.
AM_SHARE	Proportion of run that occurs within the AM Peak period (7 AM - 9 AM). Simple count of itinerary segments; full segment must be covered within the time period.
CT_VEH	Extended transit vehicle types used for CT-RAMP.

To allow for simple identification of runs on a specific rail line, the following rail route naming scheme is applied to the six-character *tr_line* variable:

- First character - lowercase Mode letter.
- Second and third characters - two letter line identifier (lowercase).
- Fourth through sixth characters - unique counter for each Mode-line combination, starting with '001' for base runs and '401' for current runs (automatically generated).

The three-character rail line coding prefixes are summarized in Table 12.

Table 12. Rail Line Coding Prefixes

Transit Agency	Line	Coding Prefix	Transit Agency	Line	Coding Prefix
CTA	Blue	cbl	Metra	BNSF	mbn
	Brown	cbr		Heritage Corridor	mhc
	Green (Ashland branch)	cga		Metra Electric	mme
	Green (Cottage Grove branch)	cgc		Milwaukee District North	mmn
	Orange	cor		Milwaukee District West	mmw
	Pink	cpk		North Central Service	mnc
	Purple	cpr		Union Pacific Northwest	mnw
	Red	crd		Rock Island District	mri
	Yellow	cye		SouthWest Service	msw
				Union Pacific North	mun
				Union Pacific West	muw
			NICTD	South Shore	mss

The itinerary information for rail lines is stored in a related data table, and the contents are listed in Table 13. These variables provide the same information as their counterparts in the bus itinerary tables. One variable of interest however is the zone fare variable (*zn_fare*). This value applies to commuter rail lines and is the marginal cost per ride (in cents) for traveling between fare zones. It is calculated as:

> [the difference between monthly pass costs from station zone to zone A] x [100 cents] / [40 (the average number of one-way rides for a monthly pass holder, assuming 20 workdays per month].

For example, a UP-N line monthly pass from Kenilworth (zone D) to Ogilvie (zone A) is $102.60 and a monthly pass from Wilmette (zone C) to Ogilvie is $90.45. The *zn_fare* on the link between Kenilworth and Wilmette is: [(102.60 - 90.45) x (100)]/40 = 30.38.

As with the bus coding, two GTFS-based rail coding route systems exist simultaneously in the geodatabase:

- all_runs_base – GTFS–based coding that corresponds to CMAP's model base year of 2015 (reflecting service at that time).
- all_runs – Coding built from the most recent GTFS data files. This represents up-to-date coding and is used as the basis for future modeling scenarios.

Both of the rail route systems listed above contain over 2,500 rail runs comprised of more than 76,000 itinerary segments, representing one weekday of service. For travel demand modeling purposes, the CTA rail runs are combined into representative rail routes; this is accomplished using the same script and "collapsing" logic that is applied to the bus run coding. All of the individual commuter rail runs are allowed to pass through to the travel demand model unchanged.

Table 13. Master Rail Network Itinerary Attributes

Variable	Description
TR_LINE	Unique CMAP rail line identifier (6 characters).
ITIN_A	CMAP node number of first node of link rail run travels on.
ITIN_B	CMAP node number of second node of link rail run travels on.
IT_ORDER	Order number of rail segment in itinerary.
LAYOVER	Layover time in minutes applied to *Itin_B*. Default=3.
DWELL_CODE	Code for stops (corresponding Emme code), applied to *Itin_B*: 0=stop allowed (default time of 0.01 minutes) 1=no stop (#) *available for future use:* *2=alighting only (>)* *3=boarding only (<)* *4=boarding & alighting allowed (+)* *5=dwell time factor (*)*
ZN_FARE	Incremental zone fare in cents.
TRV_TIME	Itinerary segment travel time in minutes.
DEP_TIME	Departure time at beginning of segment from GTFS data (in seconds).
ARR_TIME	Arrival time at end of segment from GTFS data (in seconds).
IMPUTED	Flag indicating segment was imputed by shortest path algorithm during import. 0=not applicable. 1=itinerary segment created by shortest path algorithm.

Future Rail Coding

As with the bus coding, there is a need to store future rail project information for use by the travel demand model. The route coding table for future rail service includes the same set of fields as the existing coding, as well as a few additional fields shown in Table 14 below. The *tod* variable identifies all of the specific time of day periods that individual future rail routes should be included in. The *scenario* variable identifies all of the specific modeling scenarios that individual rail routes should be included in. The *notes* variable contains the TIP identification number of the project and may include other descriptive information about the project. The *action* variable requires a more detailed explanation.

Table 14. Future Rail Route Additional Attributes

Variable	Description
TOD	Time of day periods that rail route will be used in. A string of ALL TOD periods (1–8 and am) that will contain the route. Applies to new service routes (ACTION=1) only.
SCENARIO	Future scenarios rail line will be used in. A string of ALL scenarios (first digit of three-digit code) that will contain route. May NOT be blank.
ACTION	Action code for the route.
NOTES	TIP ID number (and possibly other descriptive information). Entries must be separated by colons. 30 character limit.

Implementation of the GTFS-based rail coding required a reimagining of how future rail project coding would be handled. The desired outcome was to maintain the simple spreadsheet-based future service coding procedures employed at CMAP for years. To achieve this, an *action* code variable was added to the required attributes in the future route table. This value describes what type of service or improvement is being implemented and instructs the processing scripts on how to handle the data input. A brief description of the future rail *action* codes is provided in Table 15.

Table 15. Future Rail Coding Action Codes

Action Code	Meaning	Discussion
1	New line or service.	The entire itinerary must be coded.
2	Travel time reduction on selected links.	*Itin_A* and *Itin_B* define the nodes between which the travel times will be reduced (only the end points need to be coded). Code both directions of travel if applicable. The *Trv_Time* value represents the % reduction applied to the base year travel time (for instance 0.1 means a 10% reduction). To apply the travel time savings to the entire itinerary, code *Itin_A* and *Itin_B* as the beginning and ending nodes on the line and code *Layover*=99. If the time reduction applies to multiple lines, each must be coded separately.
3	New station.	*Itin_A* and *Itin_B* define the nodes between which the new station will be inserted. Store node number of new station in *Layover*. Code both travel directions if applicable.
4	Line extension.	Itinerary only contains the coding for the additional segments to be added to the base year runs. Code both directions of additional segments if applicable. For extension at ending terminal, code *IT_Order* values beginning with 1001. For extension at beginning station, use negative values.
5	Shift to different downtown station.	The SWS will switch from Union Station to LaSalle Street Station – essentially this is just swapping one link for another at the CBD end of the itinerary. In itinerary coding: *Itin_A* and *Itin_B* are the original nodes defining the link. *Layover* holds the new node number. *IT_Order* is used to identify which node is being replaced by the value in *Layover*: 1=*Itin_A* and 2=*Itin_B*. Code both travel directions if applicable.
6	Placeholder for TIP identification number.	When a future project reaches its time horizon and is implemented, it gets coded into the current routes. At this point the project could be removed from the future routes, except it is necessary to maintain the project's TIP ID in the future routes. To do this without affecting the network, the project is coded like an action code 2 with a 0% travel time reduction
7	New consolidated rail station.	Two existing rail stations are being consolidated and replaced with a new station. In itinerary coding: *Itin_A* and *Itin_B* are the remaining nodes between which the new station will be inserted. *Layover* holds the new station node number. Code both travel directions if applicable.

When the future rail coding is processed to create scenario transit networks, new lines/service (*action*=1) are added to the set of existing ones to increase the total number. For *action* codes 2-5 and 7, the changes described in the coding are applied to the existing transit routes (no actual processing is performed for *action*=6). Additionally, modified unique counters (characters four through six in *tr_line*) are used for future rail lines:

- For *action*=1 – the counter should be a 900 series (i.e., starting with '9' followed by two digits beginning with '01').
- For *action* codes 2-7 – the counter should start with two asterisks (one if the counter requires two digits) followed by a counter. For example, mri**1. This identifies the coding as a general improvement that will apply to all of the runs on the specified line.

Future rail itinerary coding contains the same fields as the existing itinerary coding, with the exception of the GTFS-derived fields. The use of the *action* code allows for a great deal of flexibility in coding the itineraries; CMAP staff uses this flexibility to rely upon one future rail coding template where the definitions of the itinerary fields are dependent upon the *action* code applied to the specific route. The benefit to the analyst of using this coding scheme is that only minimal future rail coding input is required to implement the desired changes; processing scripts perform all of the painstaking work.

2.5 Zone Systems

Three different zone systems are used in the regional travel demand model. The zone systems all serve different purposes within the regional travel demand model.

Trip Generation Zones

Trip generation zones (or subzones) are the smallest level of geography used in the travel demand model. Subzones are quarter-section sized geographies that CMAP uses for household and employment forecasting. The current edition of the subzones is known as "Subzone09" (identifying the year in which it was developed). This most recent improvement to the subzones included developing the quarter-section sized zones in Kendall County, IL and Aux Sable Township in Grundy County, Illinois. The CMAP modeling region comprises 16,819 subzones (shown in Figure 7).

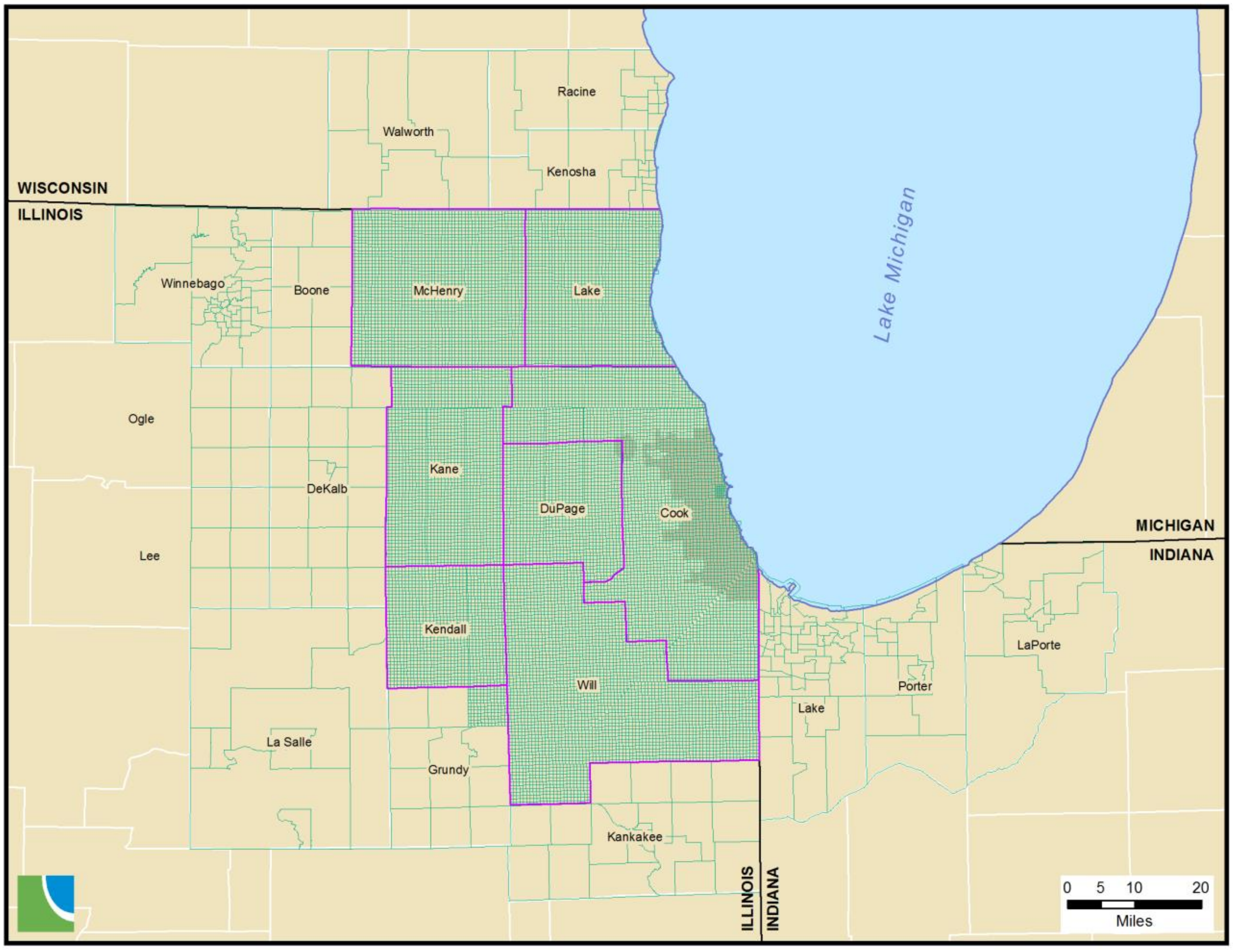
Quarter-sections are based on the Public Lands Survey System (PLSS) subdivision of land into township and range, and then into sections. Two of the major benefits of using this system as the basis for the subzones are:

- The geometry does not change (unlike Census-based geography).
- The PLSS sections conform in most cases to state, county, and township boundaries (unlike other referencing systems such as the U.S. National Grid).

As is apparent in Figure 7, subzones outside of the CMAP metropolitan planning area do not follow the same quarter-section based design. Subzones in the external modeling areas (the remainder of Illinois, and the relevant portions of Indiana and Wisconsin) are based on Census geography from the TIGER/Line file and are much larger in scope.

As indicated by their name, the trip generation zones are used to aggregate socioeconomic data into geographic units suitable for providing input to the trip generation model in order to generate trip productions and attractions. Trip generation zones serve as the base level for CMAP's modeling zone systems. The two remaining zone systems are created by aggregating the subzones into larger geographies. Thus the subzones always nest perfectly within the other zone systems.

Figure 7. CMAP Trip Generation Zones

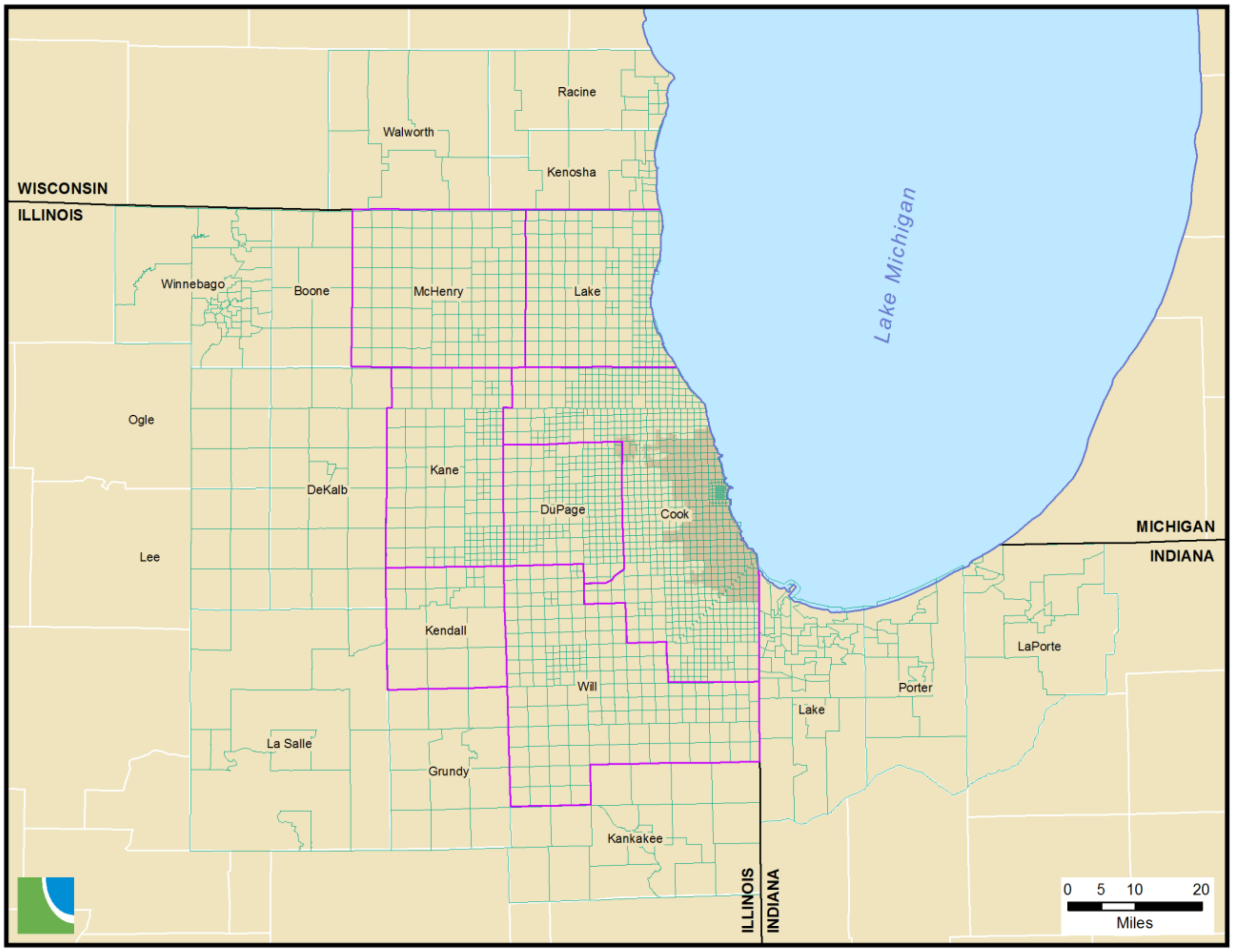


Modeling Zones

While the trip productions and attractions are generated in a zone system based on survey quarter-sections, this level of detail is not used for the remaining modeling processes. At this time, the space and computing capabilities required to complete calculations on matrices composed of nearly 17,000 trip generation zone origins and destinations (more than 282 million values) is not available. Therefore, the subzones are aggregated into the CMAP modeling zone system for the remaining three steps of the modeling process, trip distribution, mode choice, and assignment.

Figure 8 shows the 1,944 modeling zones for the CMAP region. These zones generally follow the survey township geography. Zones are either sections (approximately one square mile) or regular subdivisions of townships (4-square-mile ninths of townships 9-square-mile quarters of townships or whole townships). The modeling zones are equivalent to their underlying subzones outside of the CMAP planning area. Additionally, there are 17 external zones, or points of entry, that are not shown. These are arrayed around the outside of the pictured zone system, representing trips on major highways entering the region.

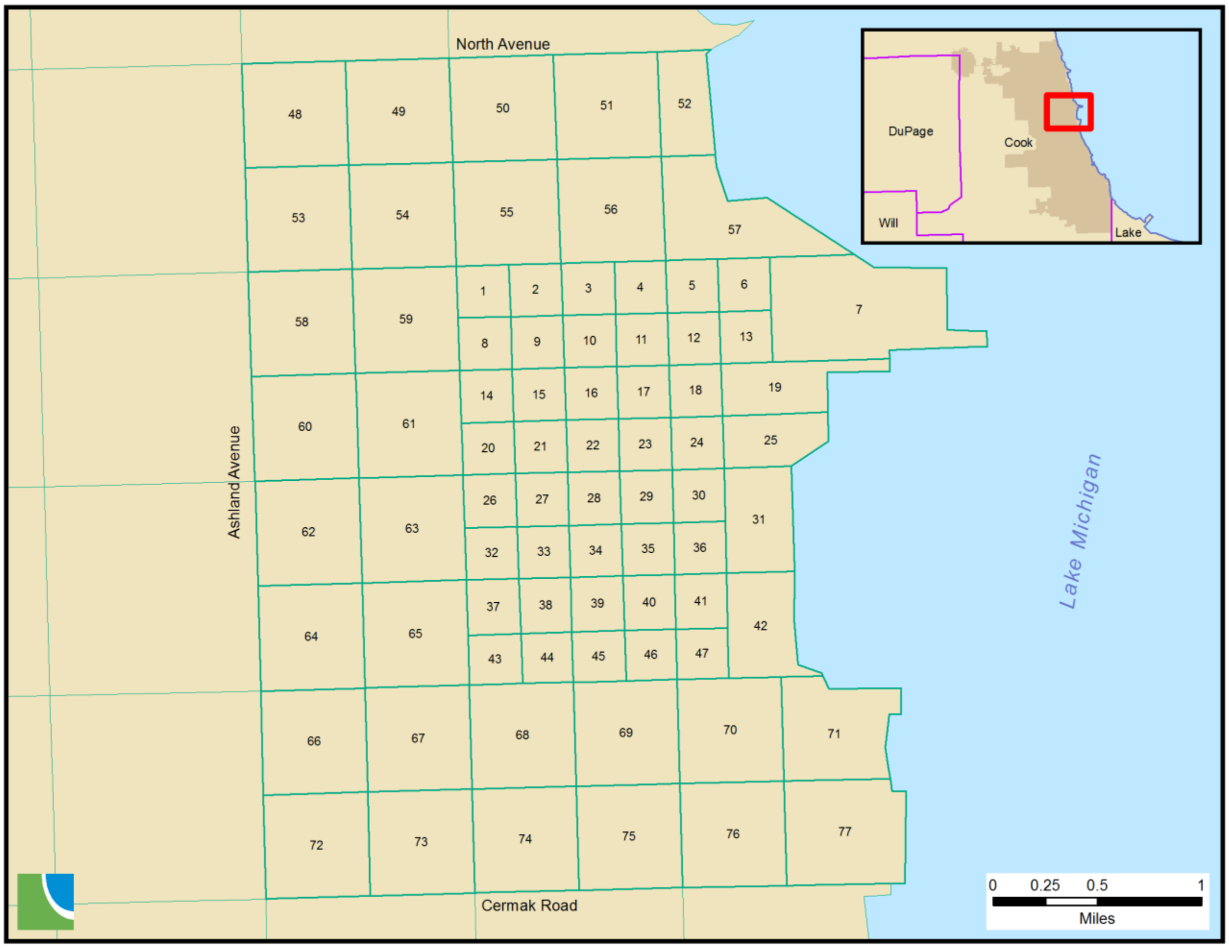
Figure 8. CMAP Modeling Zones



The density of the modeling zones (and by extension the subzones) increases within downtown Chicago. The Chicago Central Business District (CBD) is a pre-GIS convention established by CATS and NIPC based on boundaries set at Chicago Avenue, Halsted Street, and Roosevelt Road, and includes modeling zones 1 through 47. The larger Central Area was also established by CATS and NIPC prior to GIS to reflect the high density of trip making in this area and is based on the boundaries at North Avenue, Ashland Avenue, and Cermak Road. The Chicago Central Area is shown in Figure 9.

The Central Area includes modeling zones 1 through 77. Of the 77 zones, 30 are quarter-section sized zones (one-half mile by one-half mile). Most of the remaining modeling zones (representing the CBD) are quarter-quarter-section sized zones (one quarter-mile by one quarter-mile).

Figure 9. CMAP Central Area Zones



To simplify selecting discrete geographic areas, the modeling zones are numbered consecutively by county and township. The City of Chicago is consecutively numbered starting with the CBD (1-47), the Central Area (48-77), the Transit Hub (78-88) which provides a one-mile buffer around the Central Area, and then by townships for zones within the city limit. Table 16 lists the correspondence between subzones, modeling zones and geographic areas.

Table 16. CMAP Subzone-Zone Correspondence

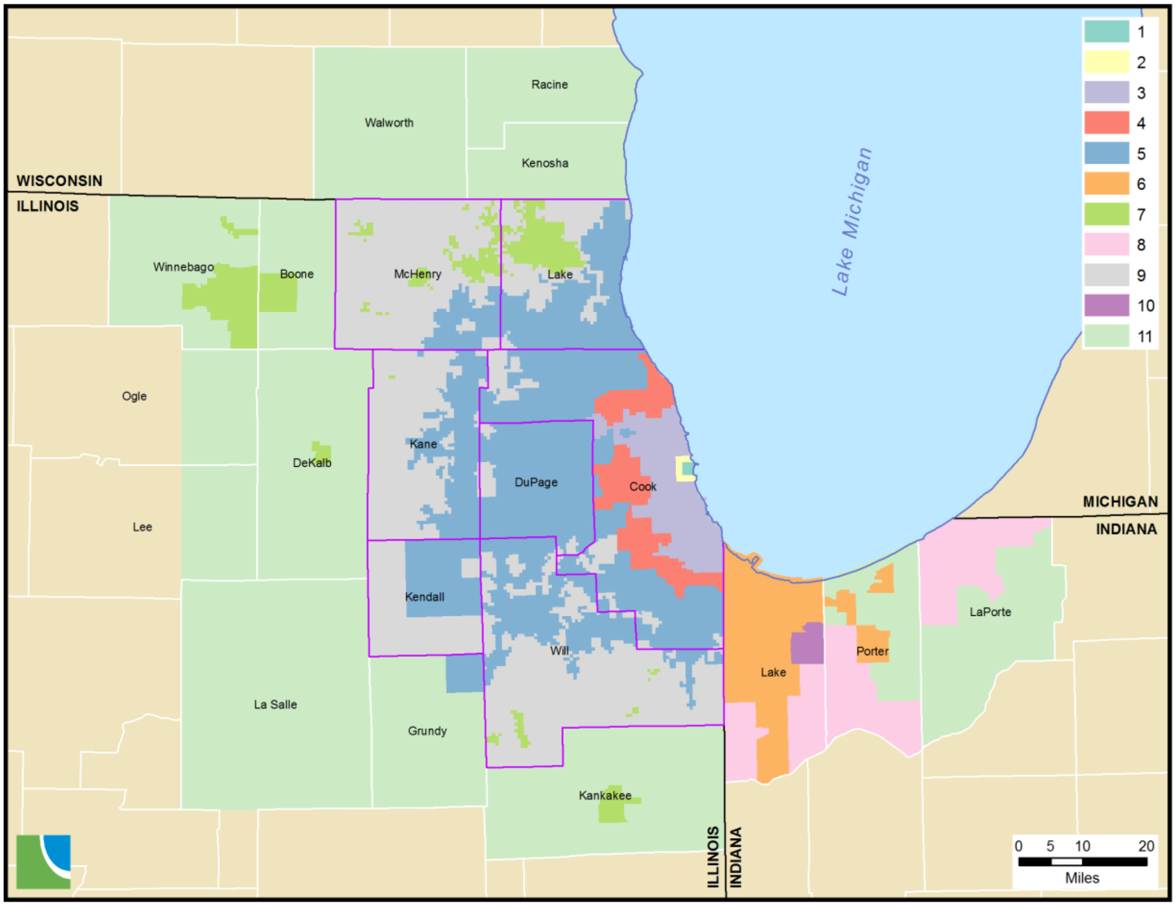
COUNTY		ZONE09		SUBZONE09	
FIPS Code	Name	First	Last	First	Last
	Chicago	1	309	1	976
	CBD	1	47	1	47
	Chicago Transit Hub	1	88	1	126
17031	Cook	1	854	1	3900
17111	McHenry	855	958	3901	6344
17097	Lake	959	1133	6345	8245
17089	Kane	1134	1278	8246	10405
17043	DuPage	1279	1502	10406	11763
17197	Will	1503	1690	11764	15147
17093	Kendall	1691	1711	15148	16443
17063	Grundy	1712	1723	16444	16598
17007	Boone	1724	1731	16599	16606
17037	DeKalb	1732	1752	16607	16627
17091	Kankakee	1753	1774	16628	16649
17201	Winnebago	1775	1811	16650	16686
17141	Ogle	1812	1817	16687	16692
17103	Lee	1818	1823	16693	16698
17099	La Salle	1824	1835	16699	16710
18089	Lake IN	1836	1882	16711	16757
18127	Porter IN	1883	1897	16758	16772
18091	LaPorte IN	1898	1909	16773	16784
55059	Kenosha WI	1910	1925	16785	16800
55101	Racine WI	1926	1938	16801	16813
55127	Walworth WI	1939	1944	16814	16819

Capacity Zones

The final zone system used in the regional travel demand model is the capacity zone system (displayed in Figure 10). As with the modeling zones, these zones are built by aggregating the subzones. The capacity zones are used to help estimate general roadway capacity for the highway assignment procedures. Some specific calculations that use the capacity zone value include:

- Calculation of an ordinal arterial functional class within the model.
- Calculation of the number of inbound approaches into an intersection.
- Estimation of traffic signal green-to-cycle ratios and signal cycle length for ramps connecting arterials and expressways.

Figure 10. CMAP Capacity Zones



The values of the capacity zone system are listed in Table 17 below. Within the travel demand model structure, the capacity zone values are stored as a node attribute in the highway network database. Thus the values in the table below correspond to the values of the *areatype* variable in the highway network node table discussed in Section 2.3.

Table 17. CMAP Capacity Zone Codes

Capacity Zone Value	Description
1	Chicago Central Business District (2009 subzones 1-47).
2	Remainder of Chicago Central Area (2009 subzones 48-80).
3	Remainder of City of Chicago (2009 subzones 81-976).
4	Inner ring suburbs where Chicago street grid is generally maintained.
5	Remainder of Illinois portion of the Chicago Urbanized Area.
6	Indiana portion of the Chicago Urbanized Area.
7	Other Urbanized Areas and Urban Clusters within the CMAP Metropolitan Planning Area plus other Urbanized Areas in northeastern Illinois.
8	Other Urbanized Areas and Urban Clusters in northwestern Indiana.
9	Remainder of CMAP Metropolitan Planning Area.
10	Remainder of Lake County, IN (rural).
11	External area.
99	Points of Entry – not defined in the Capacity Zone system.

2.6 Analysis Network Preparation

Preceding sections briefly discussed the procedures used to take the highway network and transit service information from the GIS databases and process it for use in modeling networks. Processing programs export data from the model network databases and update the highway network and transit service characteristics based on the scenario network being created. After all characteristics are updated, a set of text files suitable for importing into the travel demand software is created and contains the data defining the transportation network.

Highway Network

Separate import files are created for each of the time-of-day (TOD) highway networks, as well as for one all-inclusive highway network. Recall that the TOD networks contain time-period specific changes to links such as time-of-day parking restrictions and reversible lanes. Each TOD highway network has a set of four import files: two defining link attributes and two defining node attributes. The files contain the standard link and node attributes required by the travel demand software as well as extra attributes (denoted by "@") used within the travel demand model. The files are imported into the modeling software to create the TOD highway networks.

Highway network link attributes are shown in Table 18 with required attributes highlighted in blue. Link modes are defined to enable a multiple vehicle class highway assignment that matches the vehicle types used for emission calculations. Mode "A" is the primary auto mode and all other modes are secondary auto modes. No transit modes are included in the highway network because the transit network exists as a separate entity. This also means that no transit-only links (such as rail links or dedicated busways) are included in the highway network.

Secondary auto modes “S” for single occupancy vehicle (SOV) and “H” for high occupancy vehicle (HOV) allow high occupancy vehicle facilities to be represented in the network. For example, mode “S” would not be coded on HOV links. All links in the network allowing high occupancy vehicles would include mode code “H.”

Secondary auto mode “T” is a general truck mode coded on all network links that allow trucks. By excluding truck modes, commercial vehicles can be prohibited from facilities such as Lake Shore Drive, and the Kennedy and Dan Ryan express lanes. The additional truck modes “b,” “l,” “m,” and “h” permit more specialized coding of truck prohibitions to represent local restrictions or the testing of truck-only facilities based on weight classes.

Table 18. Model Highway Network Link Attributes

Variable	Description	Source
i	From node.	Batchin files
j	To node.	
len	Link length in miles.	
mode	Modes on link: A=primary auto; b= B plate truck S=single occupant auto (SOV); l=light truck H=high occupancy auto (HOV); m=medium truck T=general truck; h=heavy truck	
lanes	Number of driving lanes.	
vdf	Volume-delay function code. 1=arterial street; 5=freeway-freeway ramp 2=freeway; 6=zone centroids connector 3=freeway-arterial ramp; 7=link where toll is collected 4=expressway; 8=metered entrance ramp	
@speed	Speed limit or CMAP free speed.	
@parkl	Number of parking lanes along roadway.	
@sigic	Link with interconnected signals.	
@width	Driving lane width in feet.	
@toll	Toll amount in dollars.	
@ftime	Uncongested link travel time in minutes.	macros
@emcap	Level of Service E lane capacity on link.	
@artfc	Arterial link functional class: 1 = Principal Arterial; 3 = Minor Arterial 2 = Major Arterial; 4 = Collector	
@gc	Green time to cycle length ratio.	

A link’s volume-delay function (VDF) is based upon the five categories in CMAP's link capacity calculations: arterial, freeway, arterial-freeway ramp, expressway, and freeway-to-freeway ramps. Three additional volume-delay functions are included for links connecting zone centroids to the network, links where tolls are collected and metered freeway entrance ramps.

In addition to these standard variables required by the modeling software, some additional link attributes are included in the network. Many of these supplemental variables come directly from the MHN database. Other attributes used in the macros include the link's posted speed limit, as well as whether curb parking is allowed and the average width of driving lanes. For toll collection links, the amount of the toll is also included.

Table 19 lists the highway network node variables that are used. Standard node attributes are the node number and the x- and y-coordinates of the node. Node extra attributes are additional quantities associated with the node, including the zone number and area type (Capacity Zone value) at the node location. Area type definitions are listed in Table 17.

Table 19. Model Highway Network Node Attributes

Variable	Description	Source
i	Node number.	Batchin files
xi	x-coordinate (NAD27 IL East State Plane feet).	
yi	y-coordinate (NAD27 IL East State Plane feet).	
@zone	Modeling zone node resides in.	
@atype	Capacity Zone values (refer to Section 2.5).	
@napp	Number of approach links.	macros
@cycle	Traffic signal cycle length in minutes.	

After the TOD highway networks are imported into the travel demand software, two macros prepare the additional link and node attributes needed for the time period assignments. The first macro, *Ftime.Capacity*, calculates link lane capacities in vehicles per hour, and uncongested speeds based on link characteristics such as functional class, lane width, and posted speed limit. The network database also includes variables to flag those links that change characteristics depending on the time period, such as links that have peak period parking restrictions. These factors are also considered when link capacity is calculated.

The calculations in the *Ftime.Capacity* macro are generally consistent with the capacity procedures found in the 1985 Highway Capacity Manual and the 1994 update to the manual. The capacities of arterial street links reflect the type of signalized intersection located at the link's j-node, or downstream node. The macro first analyzes the links entering a node, and then estimates the capacity for each approach link based on generalized signalized intersection characteristics. Capacities for ramps between freeways and arterial streets ending at signalized intersections are determined in the same manner as arterial streets.

The concept behind this process is that link capacities and uncongested travel times must always be recalculated before an assignment is run, rather than be maintained as static network variables in the database. The capacities and uncongested travel time for links ending at a signalized intersection depend on the characteristics of all approach links into the intersection, not just the link of interest. As a result, link capacities and uncongested travel times depend on network topology. Adding, removing or modifying a link affects the capacities and uncongested travel times of all links that intersect it at a signalized intersection. Calculating these network quantities as part of the assignment procedure ensures that they are current when the assignment is carried out. This approach simplifies the introduction of certain types of improvements into the modeled network. The effects of parking restrictions, traffic control device improvements, signal progression, and intersection improvements can be modeled in the macro, eliminating lengthy manual adjustment of capacities and times on a link-by-link basis.

The *Ftime.Capacity* macro develops some extra link attributes, which are briefly described. Link uncongested travel time, @ftime, is calculated and is used in the volume-delay functions. It should be noted that this travel time does not contain any intersection delay, which is calculated separately by the volume-delay functions. Capacity values calculated by the macro, @emcap, are hourly lane capacities at level-of-service E. Link capacity for the time period, referenced within the volume-delay functions, is later obtained by multiplying @emcap by the number of driving lanes on the link and the number of hours in the assignment time period.

The second macro, *Arterial.Delay*, repeats many of the same calculations as *Ftime.Capacity*. It again evaluates approach links at signalized intersections and estimates signal cycle lengths at the j-nodes of arterial street links. It also estimates the proportion of the cycle length allocated to traffic on the link. These two quantities are retained in extra node and link attributes, @cycle and @gc respectively, for later use in the volume-delay functions that estimate intersection delays. An ad hoc functional class (@artfc) is also assigned to arterial street links based on the location of the link, its speed limit and number of driving lanes. This functional class is only used to allocate green time at signalized intersections, which depends on the cycle length and the number and types of conflicting approach links. The final link extra attribute in the table is the ratio of green time to cycle length, @gc, at the downstream node of a link. This value is used in the volume-delay functions.

Transit Network

The model uses coded transit networks reflecting transit service in the morning peak period (7:00 to 9:00 a.m.), and the midday period (10:00 a.m. to 2:00 p.m.). A transit network contains over 12,000 bus and rail mode links totaling nearly 5,700 miles in length. While the highway network data are all contained within the MHN database, the transit network comprises three separate components that must be integrated to create transit modeling networks:

1. **Bus route coding** – All current and future bus route coding is stored in the route systems of the MHN geodatabase. This coding includes the following transit modes: B (CTA regular bus service), E (CTA express bus), P (Pace regular service), L (Pace local service) and Q (Pace express service).

2. **Rail route coding** – All current and future rail route coding is stored in the rail route systems of the MRN geodatabase. This coding includes modes C (CTA rail) and M (Metra rail).
3. **Auxiliary links** – In addition to the transit coding itself, model transit networks require a system of auxiliary links to provide needed connections. Auxiliary links provide transfer links between different transit modes or lines that do not pass through the same nodes, walk access to transit service from zone centroids (trip beginning), and walk egress from transit service to zone centroids (trip end). A set of auxiliary links is created dynamically when the transit network files are generated. The procedures used to create the auxiliary links are discussed below. Zones requiring drive access are not provided with auxiliary dive access links. Drive access is handled by a matrix calculation that will be discussed later.

Table 20 lists the 12 auxiliary link modes included in the transit networks. Note that the transit network modes are case sensitive: all transit modes are uppercase and all auxiliary link modes are lowercase. The three types of auxiliary links are transfer links connecting transit lines to one another, access links to connect a zone centroid to transit service at the beginning of a trip and egress links connecting transit service to a zone centroid at the end of a trip. Transfer links are bi-directional while access and egress links only serve one direction of travel. In practice, access and egress links are generally bi-directional links with the appropriate mode assigned to the appropriate direction.

Table 20. Auxiliary Link Modes

Link Type	Mode	Description
Transfer	b	Bus-Bus walk.
	c	Bus-CTA rail walk.
	m	Bus-Metra walk.
	d	Metra-Metra walk.
	r	CTA rail-CTA rail walk.
	t	CTA Rail-Metra walk.
Access	u	Home-Bus walk.
	v	Home-CTA rail walk.
	w	Home-Metra walk.
Egress	x	Bus-Work walk.
	y	CTA rail-Work walk.
	z	Metra-Work walk.

Transfer links

There are six different transfer link modes, each identifying a connection between different types of transit service. Transfer links are needed when two services are physically separate because they don't share a station node. While Metra and CTA rail service are identified separately by the auxiliary links, no such distinction is made between CTA and Pace bus service: all bus service is combined into "bus." All of the transfer links are bi-directional so passengers can move in either direction between the transit lines. Transfer links "r," "t," and "d" are hard-coded in the MRN and are read directly into the final transit network via the rail.network file. The remaining transfer links are created as follows:

- Mode b – All highway network arterials (type=1 in the MHN) located in modeling zones 1-78, representing an area just slightly larger than Chicago's Central Area, are assigned mode "b." This allows trips to use "sidewalks" along arterial links for transfers. These links are included in the input file bus.network.
- Mode c – The Euclidean distance is calculated between CTA rail stops and all bus stops. A maximum distance of ⅛ mile (660 feet) is allowed between CTA rail stops in the CBD and bus stops. A maximum distance of ½ mile (2,640 feet) is allowed between bus stops and the remaining CTA rail stops. The shortest mode "c" link available to connect a CTA rail stop to each bus route is retained. As CTA rail stations may be served by multiple bus routes, there may be instances where more than one mode "c" link connects a bus route to the same CTA rail stop. This only occurs if the shared stop was not the shortest link from the CTA rail stop for all of the affected bus routes. These auxiliary links are stored in access.network.
- Mode m – Straight-line distances are calculated between Metra stops and all bus stops. Maximum distances of ¼ mile (1,320 feet) and 0.55 miles (2,904 feet) respectively are allowed between Metra stops and CTA bus stops, and Metra stops and Pace bus stops. Mode "m" links are attached to **all** bus stops determined to be within the allowable distance. There are no constraints on connecting a Metra stop to multiple stops on the same bus route, or on connecting a bus stop to multiple Metra stops. These auxiliary links are stored in access.network.

Access and Egress Links

Access and egress links are mode specific, so there are three access modes connecting zone centroids to different types of transit service and three egress modes connecting transit service to a centroid. Each of the access and egress modes applies to only one direction. For example, a centroid is connected to a Metra station by one mode "w" link from the centroid to the station, and one mode "z" link from the station to the centroid. In practice, this usually but not always results in a two-way link with different modes in each direction. The access and egress links are created as follows:

- Modes u and x, generic bus access and egress – The Euclidean distance between centroids and transit stops is calculated to determine access and egress link length. Bus stops are separated into CBD and non-CBD stops. A maximum distance of ¼ mile is allowed between centroids and CBD bus stops, while a maximum of 0.55 miles is allowed between centroids and the remaining bus stops. The access/egress links are merged with bus itineraries, thereby connecting multiple links per transit line to the same centroid. This allows for numerous access/egress connections between the same bus route-zone centroid pair if the itinerary varies by direction. Redundant access and egress links are eliminated, and links are grouped by centroid and sorted by link length in ascending order. A maximum of eight mode "x" links are kept for each CBD centroid. No more than two mode "x" links are retained for each non-CBD centroid. A maximum of three mode "u" links are saved per centroid. These auxiliary links are stored in access.network.

- Modes v and y, CTA rail access and egress – The straight-line distances are calculated between centroids and CTA rail stops. A maximum distance of 0.55 miles is allowed between CTA rail stops and zone centroids. By rule, each CTA rail station is connected to the centroid of the zone it resides in with an assigned distance of 0.55 miles if the link length exceeds 0.55 miles. The remaining access links are ranked in ascending order and are assigned to centroids until the maximum allowable number is reached. A maximum of three mode "v" links is assigned to each centroid in a zone with a CTA rail station. The same process is used for the egress links: maximums of seven and three mode "y" links are assigned to centroids in the CBD and outside the CBD, respectively, in addition to the connection to the station zone. These auxiliary links are stored in access.network.
- Modes w and z, Metra rail access and egress - Metra station access and egress links follow the same basic procedures as CTA rail station links. A maximum distance of 0.55 miles is allowed for these links. Metra stations are connected to the centroid of the zone they are within, and a length of 0.55 miles is assigned to the link if it exceeds the distance limit. Unlike with the other access and egress links, there is no constraint on the number of Metra access and egress links per centroid so **all** are put in the final network. These auxiliary links are stored in access.network.

Table 21 summarizes the processing rules used to develop the auxiliary links. When the processing is completed, the result is a set of scenario transit network files that are formatted to be imported into a single scenario of the travel demand software

Table 21. Auxiliary Link Processing Rules

Mode	Maximum Distance	Forced to Connect to Centroid?	Maximum Number of Links per Centroid
c	⅛ mile in CBD ½ mile outside CBD	No	N/A
m	¼ mile for modes BE 0.55 miles for modes PLQ	No	N/A
u, x	¼ mile in CBD 0.55 miles outside CBD	No	u – 3 x – 8 in CBD, 2 outside CBD
v, y	0.55 miles	Yes	v – forced + max. of 3 additional y – forced + max of 7 additional in CBD, forced + max of 3 additional outside CBD
w, z	0.55 miles	Yes	N/A

Zonal Impedances

A primary role of transit networks is to generate transit level of service variables for the generalized cost procedure used in the trip distribution and mode split models. Impedance matrices are created for zone-to-zone in-vehicle times, fares, first wait time and remaining out-of-vehicle time. In the logic of the CMAP models, the zone-to-zone quantities are all measured from the point where transit service is first boarded, rather than the actual trip origin. Access modes, times and costs are generated using Monte Carlo Simulation techniques. These techniques will be discussed later in the document.

Zone-to-zone impedances are built using the time and cost components of the transit network. Time components are weighted to reflect the relative disutility to the traveler. For instance, walking time is weighted at three times the rate of time spent within a transit vehicle. Similarly fares are weighted so they can be combined with times to create an overall measure of the impedance of a particular path.

A multi-path transit assignment is completed to provide transit impedances for zones that have walk access to a transit station. For zones with no walk access to a transit station, highway impedances from a complementary highway assignment are used to index the origin zone to a station zone that minimizes drive access and transit impedance to the destination. All cost components in the impedance matrix between the auto access zone with no walk access and the destination are replaced with cost components from the selected station zone to the destination. The result is, instead of the zone being disconnected, the origin to destination times and costs are populated with times and costs reflecting the selected station. In this application, a generalized parking cost is calculated to reflect on- and off-street parking availability and cost.

The transit network scenario is also used to generate travel districts based on a hierarchy of services present in the zone. This is analogous to CMAP's historic use of first, last and priority mode categorization. The mode matrices are constructed based upon the transit services likely to be utilized when moving between these zone groups.

The effects of roadway congestion on bus travel times are included in the transit skimming procedures. The modeled bus travel times start with scheduled times from the GTFS files produced by the transit service providers. The full model iterates five times (iteration 0 – 4). In iteration zero, the scheduled times are used in the AM peak and Midday transit scenarios. After each full model iteration, bus times in the AM peak and Midday scenarios are replaced with auto travel times when auto time is longer than scheduled time. The transit impedance matrices are recalculated with each iteration and maintain a consistent relationship with the auto travel times. This is important because the relationship between auto and transit travel times is an important determinant of the regional model results. An additional feature allows the schedule time to be retained by coding the transit travel time function as 2 where congested times should not be considered. This is helpful for scenarios that include bus rapid transit or other similar services that will not be impacted by prevailing traffic conditions.

2.7 Ancillary Data Input Files

In addition to the network datasets, there are several ancillary data files containing information on transit service levels, park-and-ride availability, CBD parking, and auto operating costs. These files are briefly described in this section.

M01 file

The M01 file stores several variables to provide the mode choice and distribution models with zonal transit availability and park and ride characteristic parameters. Some of the parameters are calculated using transit network characteristics and are specific to each scenario network. The contents of the M01 file are summarized in Table 22.

M01 files are created in two formats: one for Home-Based Work (HBW) trips and one for the other trip purposes. The pre-distribution (PD) and mode choice (MC) programs expect M01 files that are specific to the program and the trip type, thus the following PD and MC files are created:

Format1	***Format2***
MCHW_M01.TXT	MCHO_M01.TXT
PDHW_M01.TXT	MCNH_M01.TXT
	PDHO_M01.TXT
	PDNH_M01.TXT

Table 22. M01 File Attributes

Field Name and Position	Description
Zone Number (1)	Modeling zone number.
Zone Type (2)	1 – Chicago Central Area zone (1-77) 2 – Chicago zone outside of the Central Area (78-309) 3 – dense suburban CBD zone (more than 5,000 jobs per square mile) 4 – remaining suburban zones
Park and Ride Cost (3)	The cost of parking at the park and ride lot closest to the zone's geographic centroid. This represents the lowest rate of either the daily parking rate or the cost of a monthly parking pass divided by twenty work days.
Median zone household income (4)	The median household income in the zone (in $100s) from the 2007 ACS five percent Public Use Microdata Area data.
Park and ride availability (5)	A binary value indicating that the zone has park and ride access if there is a park and ride location within ten miles of the zone's geographic centroid.
Average waiting time for bus service in zone for home-work trips (6)	The average wait time for bus work trip (in minutes) for modes BEPQ. Calculated as the mean of (headway*0.5) for all bus stops served by selected modes within the zone during the AM peak period. To account for spatial inaccuracy, stops are buffered by 0.1 miles. *For HW files: maximum value is 99, default value of 99 used for zones with no bus service. For HO & NH files: maximum/missing values set to 999.*
Average waiting time for bus service in zone for non-work trips (7)	The average wait time for bus non-work trip (in minutes) for modes BEPQ. Double the wait for bus work trip (as a proxy for midday service). *For HW files: maximum/missing values set to 99. For HO & NH files: maximum/missing values set to 999*.
Average waiting time for feeder bus service in zone for home-work trips (8)	The average wait time for feeder bus work trip (in minutes) for mode L. Calculated as the mean of (headway*0.5) for all bus stops served by mode L within the zone during the AM peak period. To account for spatial inaccuracy, stops are buffered by 0.1 miles*. For HW files: maximum/missing values set to 99. For HO & NH files: maximum/missing values set to 999.*
Average waiting time for feeder bus service in zone for non-work trips (9)	The average wait time for feeder bus non-work trip (in minutes) for mode L. No feeder bus service in off-peak period, so: *For HW files: all values set to 99. For HO & NH files: all values set to 999.*
Home-work trip auto work end auto occupancy (10)	Zone vehicle occupancy rate for commuters (i.e., workers per vehicle), measured at destination (work) location. Calculated using data from Table 2-2 of the 2000 CTPP. *Included in HW M01 files only.*

DISTR file

The DISTR files contain zonal transit approach distribution parameters and are used by the pre-distribution and mode choice models. The parameters are calculated using transit network characteristics and are thus specific to each scenario network. The following table (Table 23) describes the DISTR file fields.

Table 23. DISTR File Attributes

Mode Category	Field Number	Description
	1	CMAP modeling zone number.
Commuter rail (fields 2-4) CTA rail (fields 5-7) Park and Ride (fields 14-16)	2,5,14	Mean distance in miles to station (or park and ride). *Calculation*: A distance calculation is performed to find the rail station closest to each subzone centroid. The closest station distances are then aggregated to the zonal level to determine the mean distance weighted by subzone households. The maximum mean distance is set to 19.95 miles. The analysis is performed separately for the commuter rail stations, rapid transit stations and park and ride locations.
	3,6,15	Standard deviation of distance to station (or park and ride). *Calculation*: The standard deviation is calculated as the square root of the sum of [the zonal variance calculated above and a subzone variance, estimated to be 0.042].
	4,7,16	Type of Mode Choice distribution. 101 (default) = normal distribution. 102 = exponential distribution.
Bus (fields 8-10) Feeder Bus (fields 11-13)	8, 11	Minimum bus stop distance (miles). *Calculation*: A set of bus stop buffers (incremented by 0.1 miles from 0.1 up to 1.1 miles) are created. The buffers are overlaid with the zone system to determine the proportion of each zone covered by each buffer. The minimum bus stop distance is determined by the size of the smallest buffer that covers any part of the zone. The value is set to 999 for zones that are not covered by any portion of the largest buffer. The analysis is performed separately for bus (modes BEPQ) and feeder bus (mode L) stops.
	9, 12	Maximum bus stop distance (miles). *Calculation*: The maximum bus stop distance is determined by the size of the smallest buffer that covers the entire zone (for practical reasons the threshold is 97% of the zone). The value is set to 999 for zones with a minimum distance of 999 or is set to 1.1 if no buffer meets the coverage threshold and the minimum distance is not 999.
	10, 13	Proportion of the zone within minimum walking distance. *Calculation*: This value is calculated as the area of the zone covered by the minimum distance buffer divided by the area of

		the zone covered by the maximum distance buffer. This value is set to 999 for zones with a minimum distance of 999.

As with the M01 file, two separate formats of the DISTR file are created: one for home-based work trips and one for the other trip purposes. The only difference between the formats is that the feeder bus fields (11-13) are all set to 999 for the home-based other and non-home based files. The DISTR files use the same naming convention as noted above with the M01 files.

Household Vehicle Ownership File

This file (MCHW_HH.TXT) is automatically generated by the trip generation model as a fixed-width file and is used as input by the mode choice model. Within the mode choice model, home-work auto person trips are allocated to drive-alone, two person rideshare and three or more person carpools. The sub-mode choice model includes independent variables for the proportions of households within each zone at differing levels of vehicle ownership. As this information is already estimated by the trip generation model, creation of this file ensures that the mode choice model uses internally consistent data. The following table identifies the attributes included in this file.

Table 24. Household Vehicle Ownership File Attributes

Variable	Location in File
CMAP modeling zone	1-5
Households with One or More Low Income Workers	
Share of Households without Vehicles	6-17
Share of Households with One Vehicle	18-29
Share of Households with Two or More Vehicles	30-41
Households with One or More High Income Workers	
Share of Households without Vehicles	42-53
Share of Households with One Vehicle	54-65
Share of Households with Two or More Vehicles	66-77

Low income workers are defined as having earnings below the regional median. Conversely, the earnings of high income workers exceed the regional median. Note that the set of household proportions under each income category sums to one.

M023 file

The M023 file contains transit fare and auto operating cost data used by the pre-distribution and mode choice models. The cost data reflect 2009 values. Separate files are created for each trip purpose, although the file contents are identical. The file is composed of six records:

1. CTA fares;
2. Pace feeder bus fares;

3. Pace regional bus fares;
4. Auto operating costs in 5 mile per hour increments for speeds between 0-40 miles per hour;
5. Auto operating costs in 5 mile per hour increments for speeds between 40-80 miles per hour;
6. Average auto operating costs per mile by zone type used to estimate transit access/egress costs.

The CTA fares used in the M023 file are:

- Bus boarding fare is $2.00
- Rail transit boarding fare is $2.25
- First transfer is $0.25
- Link-Up pass per ride is $0.95 (approximately equal to $39 monthly cost divided by 40 trips per month)

The Pace fares used in the M023 file are:

- Feeder bus boarding is $0.95 (assumes Link-Up pass).
- CBD feeder bus fare is $0.00 (fare calculations revised and no longer used).
- Pace current regular fare is $1.75.
- Pace first transfer is $0.25.

Auto operating costs were updated to reflect current fuel consumption and the current costs of tires, maintenance, and gasoline. These costs were derived from two sources. A publication by AAA[4] was the source for the per mile costs of auto maintenance and tires. Figures on the average gasoline consumption per mile were obtained from an Oak Ridge National Laboratory publication.[5] A $3.00 per gallon gasoline cost was assumed to convert the gasoline consumption into a cost per mile. The resulting costs per mile for auto travel are listed in Table 25.

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[4] AAA, "Your Driving Costs: 2009 Edition" (2009).

[5] West, B.H., R.N. McGill, J.W. Hodgson, S.S. Sluder and D.E. Smith, "Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models" (1999, March).

Table 25. M023 File Auto Operating Costs

		Cents per Mile			
Miles/Hour	Fuel Used Gallon/Mile	Gasoline (@$3.00/Gal)	Tires	Maintenance	Total
0-5	0.064	19.17	0.77	4.56	24.50
5-10	0.052	15.67	0.77	4.56	21.00
10-15	0.044	13.25	0.77	4.56	18.58
15-20	0.038	11.47	0.77	4.56	16.80
20-25	0.034	10.27	0.77	4.56	15.60
25-30	0.032	9.65	0.77	4.56	14.98
30-35	0.032	9.54	0.77	4.56	14.87
35-40	0.032	9.65	0.77	4.56	14.98
40-45	0.032	9.58	0.77	4.56	14.91
45-50	0.031	9.38	0.77	4.56	14.71
50-55	0.031	9.26	0.77	4.56	14.59
55-60	0.031	9.40	0.77	4.56	14.73
60-65	0.033	9.90	0.77	4.56	15.23
65-70	0.036	10.71	0.77	4.56	16.04
70-75	0.039	11.63	0.77	4.56	16.96
75-80	0.042	12.71	0.77	4.56	18.04

The last record in the file contains the average per mile auto operating cost for each of the four zone types (defined in the M01 file). The M023 data is collapsed into six records, which are shown in Table 26. All values are reported in cents.

Table 26. M023 File Layout

								Field Locations
	1-5	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**31-35**	**35-40**
CTA Fares	200	225	25	95				
Feeder Bus Fares	95		0					
PACE Fares	175		25					
Auto Operating Costs by 5 MPH	2450	2100	1858	1680	1560	1498	1487	1498
	1491	1471	1459	1473	1523	1604	1696	1804
Auto Operating Costs by Zone Type	2000	1700	1500	1500				

CBD Parking File

CBD parking costs are also important to the mode choice and distribution models. A database of selected central area parking facilities is used to provide parking cost distribution information to the composite cost and mode choice models. The specification of the variables and fields is described in CATS Working Paper 95-01. Files are generated for use by both the Pre-Distribution and Mode Choice models. The parking supply database is currently treated as a fixed input, unless a scenario is testing the effect of downtown parking costs on regional mode choice.

Two different sets of records are included in the CBD parking file. The first set identifies the parking supply characteristics of each CBD zone that contains parking. Each zone in this set has five records with the following information:

- CBD parking zone number.
- The probability of finding parking within the zone at the threshold parking cost (this value must be 100 percent in each zone's fifth record).
- The threshold parking cost in cents per hour.
- The savings in parking costs in cents per hour determined by subtracting the threshold parking cost from the maximum parking cost in the zone.
- The amount of time needed to walk one block in the CBD (180 seconds).

A sample of the parking supply records for CBD zone 5 is displayed in Table 27. Note that the maximum cost to park in this zone was identified as $4.13 ($33.00 per eight hour day).

Table 27. CBD Parking File Sample Parking Supply Records

CBD Parking Zone	Parking Probability (0.000)	Threshold Cost (cents/hour)	Cost Savings (cents/hour)	Walk Speed (seconds/block)
5	2222	350	63	180
5	4444	225	188	180
5	6667	200	213	180
5	8889	163	250	180
5	10000	150	263	180

The parking supply records were updated using the following procedures. A website for downtown parking availability (chicago.bestparking.com) provided data for these values. Off-street parking facilities were organized by CBD parking zones. The least costly daily rate for each facility was determined using either the daily rate or a monthly rate divided by 20 workdays. Facilities were then ordered by daily rate from most to least expensive and the cost savings compared to the most expensive facility calculated. Each parking facility in a zone was assumed to have the same selection probability. Cumulative probabilities were then totaled, again from most to least expensive parking facility. Five parking supply records were created from the parking probabilities and threshold costs. In zones with many off-street parking locations, threshold costs were selected so as to yield nearly equal probability intervals.

User characteristics are important to the cost paid for parking, and they were updated in 2010 using data from the Travel Tracker survey. These characteristics include the percentage of people who have access to free parking, and the percentage of trips by auto occupancy. Both of these characteristics are stratified by income. While it may seem curious to input quantities that are actually estimated by the models, these travel characteristics are needed in order to compute the free versus pay CBD parking and the parking costs per person. Given their role in the cost calculations they need only be rough estimates based on observed travel.

The user characteristics are included in the second set of records in the CBD parking file – these correspond to the final five records in the file. These records are ordered by household income ranges and include the following variables for CBD commuters:

- The upper value of the household income quintile range (last record is the lower bound of the highest quintile).
- The percentage of CBD auto commuters with free parking.
- The percentage of all CBD workers taking transit to CBD.
- The percentage of CBD auto commuters in single occupant vehicles.
- The percentage of CBD auto commuters ridesharing in two person vehicles
- The percentage of CBD auto commuters carpooling in three person vehicles.
- The percentage of CBD auto commuters carpooling in four or more person vehicles.

The user characteristics are shown in Table 28. Note that most of the values do not change with income – this is due to the limited sample of CBD parkers found in Travel Tracker.

Table 28. CBD Parking File User Characteristics

			Auto Occupancy			
Income Quintile	**Park Free**	**Transit**	**One**	**Two**	**Three**	**Four or More**
22800	77.1	67.3	75.8	20.2	3.0	1.0
43900	77.1	67.3	75.8	20.2	3.0	1.0
68000	77.1	67.3	75.8	20.2	3.0	1.0
104000	67.1	67.3	75.8	20.2	3.0	1.0
104001	67.1	67.3	75.8	20.2	3.0	1.0

3 Population Synthesis

As part of the development of the agency's Activity Based Model (ABM), CMAP acquired population synthesis software (PopSyn) originally developed for the Atlanta Regional Commission. The population synthesizer creates a base year distribution of population which is drawn from the 2000 Census, more specifically from Summary File 1, Summary File 3 and the Census Transportation Planning Package. Rather than maintain two separate processes to develop an enumeration of households in the region (one to support the ABM and one to support the trip-based model), CMAP has developed an integrated system where subzone-level controls developed for the trip-based model are used to guide development of the synthetic population. The final synthesized population then provides the necessary input data to support both models, ensuring that they each are using entirely consistent synthetic populations (even though the models have different data requirements).

A seed matrix is required to inform the synthetic distribution – this includes zonal shares of regional households delineated by various household attributes. The following table lists the five household attributes that are used in the development of the CMAP household distribution. Note that a non-family household is defined by the Census Bureau as one where an individual lives alone or with others who are not related either through birth, marriage, or adoption. This delineation of households is intended to develop categories of households that have distinctly different travel patterns and needs.

Table 29. Population Synthesis Household Attributes

Variable	Description
HOUSEHOLD INCOME	Household income in 1999 dollars (nine categories) 1 – under $10,000 2 – $10,000 to under $20,000 3 – $20,000 to under $30,000 4 – $30,000 to under $40,000 5 – $40,000 to under $50,000 6 – $50,000 to under $60,000 7 – $60,000 to under $75,000 8 – $75,000 to under $100,000 9 – $100,000 or more
HOUSEHOLD SIZE	Household size category (five categories) 1 – 1 household member 2 – 2 household members 3 – 3 household members 4 – 4 household members 5 – 5 or more household members
HOUSEHOLD WORKERS	Number in household employed part time or full time (four categories) 0 – 0 in household employed PT or FT 1 – 1 in household employed PT or FT 2 – 2 in household employed PT or FT 3 – 3 or more in household employed PT or FT
FAMILY HOUSEHOLD	Family household flag 1 – nonfamily household 2 – family household
HOUSEHOLDER AGE	Age of householder 1 – under 65 2 – 65 and older

After creating the household distribution, the tool samples PUMS household records to create a fully-enumerated representation of the population. As the current version of the software relies on somewhat dated Census data, the 2007-11 ACS data were used to update the marginal distribution of households within the categories. An additional adjustment was made to the marginal distribution to reflect the increase in non-family households that occurred in the CMAP region between 2000 and 2010, especially within the City of Chicago. The seed distribution used by the iterative proportional fitting (IPF) process in PopSyn reflects a more current household distribution. The IPF procedures attempt to match 272 household categories, listed in Table 30. Note that each row in the table represents multiple household categories which are differentiated by the number of workers in the household.

Table 30. Synthetic Population Household Categories

Household Category	HH Subcategories (row 3 shows PopSyn HH variables defining subcategory)				
ID	*hinccat2*	*Hsizecat*	*hwrkrcat*	*hfamily*	*hhagecat*
1	1-4	1	0 | 1	2	1
3	1-4	2	0 | 1 | 2	2	1
6	1-4	3	0 | 1 | 2 | 3	2	1
10	1-4	4	0 | 1 | 2 | 3	2	1
14	1-4	5	0 | 1 | 2 | 3	2	1
18	5-6	1	0 | 1	2	1
20	5-6	2	0 | 1 | 2	2	1
23	5-6	3	0 | 1 | 2 | 3	2	1
27	5-6	4	0 | 1 | 2 | 3	2	1
31	5-6	5	0 | 1 | 2 | 3	2	1
35	7-8	1	0 | 1	2	1
37	7-8	2	0 | 1 | 2	2	1
40	7-8	3	0 | 1 | 2 | 3	2	1
44	7-8	4	0 | 1 | 2 | 3	2	1
48	7-8	5	0 | 1 | 2 | 3	2	1
52	9	1	0 | 1	2	1
54	9	2	0 | 1 | 2	2	1
57	9	3	0 | 1 | 2 | 3	2	1
61	9	4	0 | 1 | 2 | 3	2	1
65	9	5	0 | 1 | 2 | 3	2	1
69	1-4	1	0 | 1	1	1
71	1-4	2	0 | 1 | 2	1	1
74	1-4	3	0 | 1 | 2 | 3	1	1
78	1-4	4	0 | 1 | 2 | 3	1	1
82	1-4	5	0 | 1 | 2 | 3	1	1
86	5-6	1	0 | 1	1	1
88	5-6	2	0 | 1 | 2	1	1
91	5-6	3	0 | 1 | 2 | 3	1	1
95	5-6	4	0 | 1 | 2 | 3	1	1
99	5-6	5	0 | 1 | 2 | 3	1	1
103	7-8	1	0 | 1	1	1
105	7-8	2	0 | 1 | 2	1	1
108	7-8	3	0 | 1 | 2 | 3	1	1
112	7-8	4	0 | 1 | 2 | 3	1	1
116	7-8	5	0 | 1 | 2 | 3	1	1
120	9	1	0 | 1	1	1
122	9	2	0 | 1 | 2	1	1
125	9	3	0 | 1 | 2 | 3	1	1
129	9	4	0 | 1 | 2 | 3	1	1
133	9	5	0 | 1 | 2 | 3	1	1
137	1-4	1	0 | 1	2	2
139	1-4	2	0 | 1 | 2	2	2

142	1-4	3	0 | 1 | 2 | 3	2	2
146	1-4	4	0 | 1 | 2 | 3	2	2
150	1-4	5	0 | 1 | 2 | 3	2	2
154	5-6	1	0 | 1	2	2
156	5-6	2	0 | 1 | 2	2	2
159	5-6	3	0 | 1 | 2 | 3	2	2
163	5-6	4	0 | 1 | 2 | 3	2	2
167	5-6	5	0 | 1 | 2 | 3	2	2
171	7-8	1	0 | 1	2	2
173	7-8	2	0 | 1 | 2	2	2
176	7-8	3	0 | 1 | 2 | 3	2	2
180	7-8	4	0 | 1 | 2 | 3	2	2
184	7-8	5	0 | 1 | 2 | 3	2	2
188	9	1	0 | 1	2	2
190	9	2	0 | 1 | 2	2	2
193	9	3	0 | 1 | 2 | 3	2	2
197	9	4	0 | 1 | 2 | 3	2	2
201	9	5	0 | 1 | 2 | 3	2	2
205	1-4	1	0 | 1	1	2
207	1-4	2	0 | 1 | 2	1	2
210	1-4	3	0 | 1 | 2 | 3	1	2
214	1-4	4	0 | 1 | 2 | 3	1	2
218	1-4	5	0 | 1 | 2 | 3	1	2
222	5-6	1	0 | 1	1	2
224	5-6	2	0 | 1 | 2	1	2
227	5-6	3	0 | 1 | 2 | 3	1	2
231	5-6	4	0 | 1 | 2 | 3	1	2
235	5-6	5	0 | 1 | 2 | 3	1	2
239	7-8	1	0 | 1	1	2
241	7-8	2	0 | 1 | 2	1	2
244	7-8	3	0 | 1 | 2 | 3	1	2
248	7-8	4	0 | 1 | 2 | 3	1	2
252	7-8	5	0 | 1 | 2 | 3	1	2
256	9	1	0 | 1	1	2
258	9	2	0 | 1 | 2	1	2
261	9	3	0 | 1 | 2 | 3	1	2
265	9	4	0 | 1 | 2 | 3	1	2
269	9	5	0 | 1 | 2 | 3	1	2

The socioeconomic data developed from the regional forecast and LAA provide the subzone-level control values for all ON TO 2050 model scenarios. CMAP has greatly enhanced the functionality of PopSyn to enforce these controls and generate a distribution of enumerated households. While the software matches the number of households at the regional level, further analysis of the data revealed that the number of households within each zone was not being strictly controlled and that without additional controls in place the synthetic population was generally larger than the forecast, sometimes by as much as 500,000 people. Additionally, CMAP develops subzone-level data that define the region, which were not reflected in the synthetic population.

As a result additional procedures were developed to constrain the synthetic population to the subzone-level controls. PopSyn is run to develop a synthetic population and then an extension to the software is run to perform the following tasks:

- The initial synthetic distribution is used as a seed distribution that is resampled to match a number of subzone-level controls.
- The number of households in a subzone is strictly enforced. For each household available within a subzone, the number of adults is synthesized from eligible values drawn from the seed distribution, meaning that only values present in the PUMS data are actually selected. This process is conducted iteratively until the sum of adults synthesized in the subzone matches the control total.
- The number of household workers are synthesized next. Based on the number of adults in a given household, the number of workers is synthesized based on eligible values in the seed distribution. Again the procedures work to meet the subzone total.
- Once the combination of adults and workers in each household is set, the process finds eligible values for the number of children so that the total in the households conforms to the subzone total.
- Finally the procedures use the combination of household adults, workers and children to determine the household income value while attempting to conform to the subzone income index value -- this constraint is loosely enforced compared to the ones on adults, workers and children. As the trip-based model expects values in 2010 dollars, the household income values from Census 2000 (1999 dollars) are adjusted to account for inflation.

Two files used by the trip generation model are also read by the synthetic population procedures. Geographic areas are entered through a file named GEOG_IN.TXT. Within the synthetic population process, the primary purpose of this file is to provide a correspondence between subzones, zones and PUMAs. The variables in the file are listed in the following table. The file HH_IN.TXT, whose variables are listed in

Table 32, provides the subzone-level control totals for households, adults, workers and children used in the synthetic distribution.

Once the synthetic distribution has been developed, an output file (**POPSYN_HH.TXT**) is created that provides the relevant information needed by the Trip Generation model. The variables in this file are listed in Table 33. This file provides the household information that the Trip Generation model will use to create trips for each enumerated household.

Table 31. GEOG_IN.TXT Input File

Variable	Description	Format
SUBZONE	The trip generation subzone, which must be in sequence in the file from low to high values.	Integer (1-25000)
COUNTY	A five digit code identifying the county where the subzone is located. The first two digits are the state Federal Information Processing Standards (FIPS) code for the state and the remaining three digits are the county FIPS code. (Example: DuPage County is 17043).	Integer (1-99999)
COUNTY NAME	Ten character county name enclosed in double quotes.	Alphanumeric
STATE	Two character state code enclosed in double quotes.	Alphanumeric
ONE PERCENT PUMA	Five digit numeric code for Census 2000 one percent PUMAs or other large area.	Integer (1-99999)
FIVE PERCENT PUMA	Five digit numeric code for five percent PUMAs.	Integer (1-99999)
ZONE	Modeling zone.	Integer (1-5000)
CHICAGO	Variable is set to 1 when trip generation subzone is inside Chicago; 0 elsewhere.	Integer (0 or 1)
CBD	Variable is set to 1 when trip generation subzone is inside the Chicago CBD; 0 elsewhere. The first forty-seven trip generation subzones presently make up the Chicago CBD.	Integer (0 or 1)
ROW-COLUMN	Variable identifies the portion of the region that previously provided the tables of cross-classified households for the procedure to disaggregate households within smaller trip generation subzones. 1 = Inner Chicago 2 = Outer Chicago and Inner Suburbs 3 = Mid Suburban 4 = Fringe and External Areas	Integer (1-4)
AREA	Area of the trip generation subzone in square miles.	Real Number

Table 32. HH_IN.TXT Input File

Variable	Description	Format
SUBZONE	The trip generation subzone, which must be in sequence in the file from low to high values.	Integer (1-25000)
SUBZONE HOUSEHOLDS	Number of households in the trip generation subzone.	Integer
AVERAGE ADULTS PER HOUSEHOLD	Average adults (sixteen and older) per household in the subzone.	Real number
AVERAGE WORKERS PER HOUSEHOLD	Average adult workers per household in the subzone.	Real number
AVERAGE CHILDREN PER HOUSEHOLD	Average children (fifteen and younger) per household in the subzone.	Real number
INCOME QUARTILE INDEX	This index is defined as the average subzone household income divided by the regional median household income.	Real number
AGE OF HOUSEHOLDER INDEX	This index is the average householder code for the subzone.	Real number
PRIVATE AUTO COMMUTE MODE SHARE	This is the ratio between the workers in the subzone who commute by auto (single occupant vehicles, carpool, and taxi) divided by the workers in the subzone.	Real number
PEDESTRIAN ENVIRONMENT FACTOR	A means of quantifying the pedestrian-friendliness of a subzone, described in the Socioeconomic Data section.	Real number

Table 33. POPSYN_HH.TXT Output File

Variable	Description
SUBZONE	The trip generation subzone.
HHTYPE	Household type code for the synthetic household – one of 624 values based on the combination of Adults-Workers-Children-Age of Householder and Income Index (see Trip Generation section).
VEHICLES	Number of vehicles available in the synthetic household.
SERIALNO	Unique identifier assigned to the household in the ACS data.
STPUMA5	Concatenation of the State FIPS code and the 5% PUMA number.
ROWCOL	Variable identifying the location of the synthetic household in the region: 1 = Inner Chicago 2 = Outer Chicago and Inner Suburbs 3 = Mid Suburban 4 = Fringe and External Areas
ADULTS	Number of adults in the synthetic household.
WORKERS	Number of workers in the synthetic household.
CHILDREN	Number of children in the synthetic household.
INCOME_QUARTILE	Income quartile for synthetic household: 1 = $30,200 or less 2 = $30,201 - $59,400 3 = $59,401 - $100,900 4 = above $100,900
AGE_INDEX	Age of head of householder index for synthetic household: 1 = householder age 16-34 2 = householder age 35-64 3 = householder age 65+
HHVTYPE	Household vehicle type code for the synthetic household – one of 624 values based on the combination of Adults-Workers-Children-Age of Householder and Vehicles Available (see Trip Generation section).
INCOME	Household income of the synthetic household (in 2010 dollars).

While PopSyn can be used to develop group quarters population, CMAP does not use this functionality and instead develops this information through the regional socioeconomic forecasting process. PopSyn would treat each group quarters resident as a one-person household and they would be processed in the same manner as any other household. Due to differences in Census geographies between the 2000 and 2010 Census data, the software has not yet been revised to use more recent Census files. CMAP is currently developing a land use model in the UrbanSim platform which has an integrated population synthesizer. Once the land use model is operational, the synthetic households developed by it will be used for CMAP modeling and PopSyn will be retired.

4 Trip Generation

Trip generation is the first of the four sequential steps utilized by CMAP to forecast travel behavior. It is the means by which land use planning/zoning quantities such as households and employment are converted into trip origins and destinations that serve as measures of transportation demand. The trip generation process links the region's current and forecasted socioeconomic characteristics, the variables which drive travel demand, with the remaining sequential steps used to estimate choices of a trip destination and its mode and route.

Trip generation is based upon an enumeration of all households in the study area. Each trip generation subzone is fully populated with specific households drawn from the CMAP Travel Tracker Survey to meet desired criteria. Since the household sample is small relative to total regional households, a survey household may appear multiple times in the same subzone. Trips reported by these households are used instead of the typical trip generation methodology based upon trip generation rates. This approach eliminates the intermediate step of estimating trips generated per person or household.

As the trip generation model software executes, it creates temporary files of households tabulated by composition, income, and vehicle ownership. These files have value beyond their role in trip generation. For example, these household files might prove useful in studies dealing with issues of social and economic justice related to alternative transportation investments. The code was revised to allow users to save these intermediate datasets.

4.1 Model Processing Steps

The revised trip generation model has a linear logic identical to past versions of the model. This logic also corresponds to subroutines in the model's FORTRAN code. The main processing steps in the model are briefly summarized:

Model Control Keywords

A number of important parameters (displayed in the following table) are supplied to the FORTRAN code through the file **TG_INPUT.TXT**. These keywords are read from the file and control the operation of the program, including whether to generate trips or only populate the trip generation subzones with ACS PUMS households. The keywords are checked for internal consistency, and the report file **TG_OUTPUT.TXT**, which generates reports as the program executes, is opened.

Table 34. Trip Generation Input File Parameters

Variable	Description	Model Run Values
TITLE	An 80 character name identifying the model run enclosed in single quotes	
SUBZONES	Number of trip generation subzones in the study area	16819
PUMA5	Number of Census 2000 five percent sample PUMAs in the modeled study area	69
PUMA1	Number of Census 2000 one percent sample PUMAs in the modeled study area	20
ZONES	Zones used in the remaining CMAP models for trip distribution (linking of trip ends into trips between zones), mode choice (allocation of trips to travel modes), and assignment (allocation of trips to highway and transit routes)	1944
COUNTIES	Number of counties in the study area	21
TRIPGEN	A true/false variable: When true the program will populate trip generation subzones with CMAP survey households and estimate trip productions and attractions	True
HHENUM	A true/false variable: When true the program will populate trip generation subzones with ACS PUMS households without estimating trips	False
SAVE_FILE	A true/false variable that causes all intermediate program files to be retained after the model run is completed	True
EXP_TTYPE	A true/false variable: When true, all files and reports include 49 trip types based upon trip purposes in the CMAP household travel survey. When false, files and reports have the eleven trip types formerly used by CMAP	True
SYNTH_VEH	A true/false variable: When true, the available household vehicles developed through the population synthesizer are used. When false, the vehicle availability submodel is used to estimate vehicles available for each household	True
MODE_CHOICE	A true/false variable: When true, creates a file used by the Mode Choice model.	True
IN_EMPFACT	Employment in Indiana is multiplied by this factor. This variable and the following one for Wisconsin are included to offset possible systematic differences in employment definitions and estimation methods between CMAP and neighboring MPOs	1.0
WI_EMPFACT	Employment in Wisconsin is factored by this value	1.0
RNSEED	The program uses random numbers in the process that selects households to populate subzones. This keyword allows the user to repeat the same sequence of random numbers when set to a positive value	221

Study Area Geography

The geographic input file **GEOG_IN.TXT**, used in the population synthesis process, is also used by the trip generation model to define various geographies. Arrays defining the study area geography – trip generation subzones, zones, Public Use Microdata Areas (PUMAs), counties, etc. – are loaded and cross-referenced.

Household Type Table

Within the trip generation model households are classified by one of 624 different categories (HHTYPE) defined by the composition of the household. Households are initially cross-classified by:

- Adults [1, 2, 3, 4 or more adults];
- Workers [0, 1, 2, 3 or more workers],
- Children fifteen years and younger [0, 1, 2, 3 or more children],
- Income quartiles, and;
- Age of householder [16-34, 35-64, or 65 and older categories].

Workers include all employed persons (classes of worker 1 through 8 in the 2006-10 PUMS person file) including a small number of family business or farm unpaid workers. Six hundred twenty-four different types of households are possible with this scheme. Note that this is less than all possible combinations of the household stratifying variables because of the constraint that households must have a number of adults that is equal to or greater than the number of workers, thus there are only thirteen possible combinations of adults and workers (rather than sixteen) as shown in the following table.

Table 35. Adult-Worker Household Types

		Adults in Household			
		1	2	3	4 or more
Workers in Household	0	1	2	3	4
	1	5	6	7	8
	2		9	10	11
	3 or more			12	13

The 13 adult-worker categories provide a key to the numbering of all 624 categories: the adult-worker categories are nested within the other stratifying variables of age of householder, income quartile and number of children. The following table shows the complete list of household type definitions.

Table 36. Household Type Definitions

16 ≤ Householder ≤ 34			35 ≤ Householder ≤ 64			Householder ≥ 65		
Household Type	Children	Income Quartile	Household Type	Children	Income Quartile	Household Type	Children	Income Quartile
1-13	0	1	209-221	0	1	417-429	0	1
14-26	1	1	222-234	1	1	430-442	1	1
27-39	2	1	235-247	2	1	443-455	2	1
40-52	> 3	1	248-260	> 3	1	456-468	> 3	1
53-65	0	2	261-273	0	2	469-481	0	2
66-78	1	2	274-286	1	2	482-494	1	2
79-91	2	2	287-299	2	2	495-507	2	2
92-104	> 3	2	300-312	> 3	2	508-520	> 3	2
105-117	0	3	313-325	0	3	521-533	0	3
118-130	1	3	326-338	1	3	534-546	1	3
131-143	2	3	339-351	2	3	547-559	2	3
144-156	> 3	3	352-364	> 3	3	560-572	> 3	3
157-179	0	4	365-377	0	4	573-585	0	4
170-182	1	4	378-390	1	4	586-598	1	4
183-195	2	4	391-403	2	4	599-644	2	4
196-208	> 3	4	404-416	> 3	4	612-624	> 3	4

The file **PUMS_HHTYPE_IN.TXT** is read into the trip generation model and is used to define the 624 household types. Household income quartiles for study area households were estimated from the combined 2006-10 ACS PUMS household files. Yearly household-income distributions are factored to 2010 dollars using the inflation adjustment factors in the PUMS household files.

Table 37. PUMS_HHTYPE_IN.TXT Input File

Variable	Description	Format
HOUSEHOLD TYPE	Code indicating cross-classification of household (as per numbering in Table 3).	Integer (1-624)
ADULTS IN HOUSEHOLD	Coded 1, 2, 3, or 4 with code 4 equal to 4 or more.	Integer (1-4)
WORKERS IN HOUSEHOLD	Coded 0, 1, 2, or 3 with code 3 equal to 3 or more.	Integer (0-3)
CHILDREN IN HOUSEHOLD	Coded 0, 1, 2, or 3 with code 3 equal to 3 or more.	Integer (0-3)
HOUSEHOLD INCOME QUARTILE	Coded 1, 2, 3, or 4 from low to high income quartile (in 2010 dollars). 1 = $30,200 or less 2 = $30,201 - $59,400 3 = $59,401 - $100,900 4 = above $100,900	Integer (1-4)
AGE OF HOUSEHOLDER CODE	Age of head of householder index: 1 = householder age 16-34 2 = householder age 35-64 3 = householder age 65+	Integer (1-3)

Load Synthetic Households

The synthetic households developed by PopSyn are read into the program, populating each subzone with a list of unique households identified by household type. These are stored in POPSYN_HH.CSV.

Household Vehicle Availability

The household vehicle ownership sub-model is applied to estimate the vehicle ownership levels for each household. This effectively adds an additional dimension (vehicles available in the household) to cross-classification of households. Household types are redefined with vehicle availability replacing income quartile. Note that the default run mode of the trip generation model uses the number of household vehicles developed through the population synthesis process rather than implementing the vehicle ownership sub-model. Nevertheless, a complete discussion of the household vehicle availability model is provided, as utilizing it only requires changing one flag (SYNTH_VEH) in TG_INPUT.TXT.

The household vehicle availability sub-model is a discrete choice logit model similar to models that predict mode choice behavior. There are three or four possible vehicle level choices for each household depending on the number of adults (workers plus nonworking adults) in the household. Single-adult households may have zero, one, or two or more vehicles; larger households have the alternatives of zero, one, two, or three or more vehicles.

Each vehicle availability level has an associated utility. In these logit models, utilities are weighted linear combinations of household and subzone variables that have been entered or developed in earlier steps. Model estimation consists of determining which variables best explain observed vehicle availability levels and the relative importance of these variables in the utility expressions. The utilities may also include bias constants that indicate preferences toward certain vehicle availability levels that are not otherwise accounted for by the utility expressions.

The vehicle availability sub-models have the following general form:

$$\text{Prob}\{\text{Vehicle Availability Level } i\} = \frac{e^{u_i}}{\sum_i e^{u_i}}.$$

Where u_i is the utility of household vehicle availability level i, which is computed by the linear equation:

$$u_i = \sum_j \alpha_{ij} H_j + \beta_i.$$

For these utility equations:

1. The model coefficient α_{ij} is the weight attached to the j'th independent household variable for household vehicle availability level i.
2. H_j is the j'th independent household variable (number of workers in household, household income quartile, etc).
3. The constant β_i is the bias toward vehicle availability level i, and it must equal zero for at least one alternative.

Model coefficients for the sub-models were estimated with data from the CMAP household travel survey. After completing estimation, several incremental changes to the sub-models were introduced: (1) some model coefficients were similar for different levels of vehicle availability and the utility equations were modified to replace these multiple coefficients with a single coefficient across utility equations; (2) a few marginally significant model coefficients became insignificant and were dropped, and; (3) a complete set of bias coefficients for location and age of householder were estimated.

Model calibration was completed by adjusting bias coefficients so that estimated and observed levels of household vehicle ownership matched within the study area. Additional bias constants were also included to account for the new age of householder household variable. The modified vehicle availability sub-models were finally coded into the CMAP trip generation model code.

The following table lists the coefficients in the logit equation utilities that comprise the household vehicle availability sub-model. Separate models were estimated and calibrated for three different sized households defined by the total adults (workers plus nonworking adults) in the household. Each line in the table lists the model coefficients for estimating the utility attached to that level of vehicle availability for one of the three household type models.

Table 38. Vehicle Availability Sub-Model Coefficients

Variable	One Adult Household Vehicle Availability			Two Adult Household Vehicle Availability				Three or More Adult Household Vehicle Availability			
	0	1	≥ 2	0	1	2	≥ 3	0	1	2	≥ 3
Pedestrian Environment Factor (Maximum=40)	0.06165	0.03188		0.1280	0.06309	0.03359		0.1703	0.06586	0.06586	
Workers?											
≥ 1 (0/1)		0.4731	0.4731			0.6940	0.6940		1.114	1.114	1.114
≥ 2 (0/1)						0.5198	0.5198			0.7934	0.7934
≥ 3 (0/1)											1.389
Income Quartile?											
≥ 2 (0/1)		1.182	1.766		1.702	2.466	2.466		0.9492	1.487	1.487
≥ 3 (0/1)		0.9910	1.690			0.8650	0.8650			0.8723	1.571
= 4 (0/1)			0.4668			0.4517	0.8827			1.390	1.834
Commute Auto Mode Share		4.677	4.677			5.284	5.284			4.959	4.959
Nonworking Adults											0.1491
Children?											
≥ 1 (0/1)						0.2218					
Household Location Bias											
1. Inner Chicago		-2.600	-5.077		2.018	-2.827	-4.393		2.806	-1.836	-1.631
2. Rest of Chicago and Inner Suburbs		-2.676	-4.823		2.259	-2.637	-3.944		2.552	-2.139	-1.789
3. Mid-Suburbs		-2.869	-4.914		2.151	-2.728	-4.126		1.547	-2.783	-2.668
4. Far Suburbs and Fringe		-3.082	-4.984		1.925	-3.144	-4.302		2.272	-2.430	-2.278
Age of Householder Bias											
16-34		0.392	0.394		0.392	0.394	0.403		0.392	0.394	0.403
35-64		0.401	0.465		0.401	0.465	0.574		0.401	0.465	0.574
≥ 65		0.249	0.218		0.249	0.218	0.007		0.249	0.218	0.007
Goodness of Fit Measures											
ρ2 with respect to zero	0.384			0.391				0.448			
ρ2 with respect to constants	0.169			0.166				0.222			

The vehicle availability sub-model is applied to each of the enumerated households. The household type variable is then revised to include household vehicle availability (HHVTYPE). It has the same structure as the original household type variable listed in Table 36, except that four levels of vehicle availability (0, 1, 2 or 3 or more vehicles) replace the income quartile value.

Household Trip Productions and Attractions

The subzones have been populated with the households from the population synthesis. The next step is to pair each one with a comparable household from the Travel Tracker survey so that actual trips can be assigned to specific households. Household trip generation can then be accomplished without the intermediate step of computing trip generation rates. The following table defines the 49 trip purposes recognized in the trip generation model.

Table 39. CMAP Expanded Trip Purposes

Origin Activity	Destination Activity	Trip Code
Worker		
Home (P)	Workplace-Low Income (A)	1
Home (P)	Workplace-High Income (A)	2
Home (P)	Work-Related (A)	3
Home (P)	School (A)	4
Home (P)	Non-home/Work at Residence (A)	5
Home (P)	Non-home/Work Not at Residence (A)	6
Home (P)	Shop (A)	7
Work (P)	Non-home/Work at Residence (A)	8
Work (P)	Non-home/Work Not at Residence (A)	9
Work (P)	Shop (A)	10
Work (O)	Work (D)	11
Non-home/Work at Residence (O)	Non-home/Work at Residence (D)	12
Non-home/Work at Residence (O)	Non-home/Work Not at Residence (D)	13
Non-home/Work at Residence (O)	Shop (D)	14
Non-home/Work Not at Residence (O)	Non-home/Work at Residence (D)	15
Non-home/Work Not at Residence (O)	Non-home/Work Not at Residence (D)	16
Non-home/Work Not at Residence (O)	Shop (D)	17
Shop (O)	Non-home/Work at Residence (D)	18
Shop (O)	Non-home/Work Not at Residence (D)	19
Shop (O)	Shop (D)	20
Nonworking Adult	School (A)	21
Home (P)	Non-home at Residence (A)	22

	Non-home Not at Residence (A)	23
	Shop (A)	24
Non-home at Residence (O)	Non-home at Residence (D)	25
	Non-home Not at Residence (D)	26
	Shop (D)	27
Non-home Not at Residence (O)	Non-home at Residence (D)	28
	Non-home Not at Residence (D)	29
	Shop (D)	30
Shop (O)	Non-home at Residence (D)	31
	Non-home Not at Residence (D)	32
	Shop (D)	33
Child 12-15	School (A)	34
Home (P)	Non-home at Residence (A)	35
	Non-home Not at Residence (A)	36
	Shop (A)	37
School (P)	Non-home at Residence (A)	38
	Non-home Not at Residence (A)	39
	Shop (A)	40
Non-home at Residence (O)	Non-home at Residence (D)	41
	Non-home Not at Residence (D)	42
	Shop (D)	43
Non-home Not at Residence (O)	Non-home at Residence (D)	44
	Non-home Not at Residence (D)	45
	Shop (D)	46
Shop (O)	Non-home at Residence (D)	47
	Non-home Not at Residence (D)	48
	Shop (D)	49

A file of survey households is read from **HI_HHENUM_IN.TXT.** This file has a serial number identifying the household, the household type, characteristics of the household, and trips made by the household during the weekday surveyed. Trips in this input file were tabulated in exactly the same manner as in earlier versions of the program. Trip files that were the basis for trip generation rates were simply resumed by household. Trip purpose definitions are unchanged and rules for the linking of trips are the same as in previous versions.

The end result is 48 different trip purposes: 19 for workers, 13 for nonworking adults, and 16 for children between the ages of 12 and 15 as listed in the preceding table. Note that in the input file **HI_HHENUM_IN.TXT** there are 49 trip purposes to allow for the splitting of home productions-work attractions into home-work trips by low and high income workers by the trip generation model. The first trip purpose in the file includes all home productions to work attractions, while the second trip purpose serves as an empty placeholder.

Each synthetic household is matched to a survey household using the following process which encompasses four mutually-exclusive methods:

- If there are five or more survey households with the same vehicle-based household type (HHVTYPE) within the resident PUMA, then one of these households is randomly selected as the match (match category 1).
- If there are less than five survey households in the PUMA based on HHVTYPE, then they are combined with households of the same type in the ring of adjacent PUMAs around the central PUMA. If this results in at least five households of the specific type, then one of these households from the adjacent geography is randomly selected as the match (match category 2).
- If there are less than five survey households of the same type in the adjacent geography, but five or more in the full study area, then one of these households is randomly selected as the match (match category 3).
- If there are less than five survey households of the same type in the full study area, then a final match category (match category 4) ensures that all remaining households find a match in the survey households, regardless of how small the likelihood is that the household occurs. Households are initially categorized into thirteen groups, which correspond to the combinations of Adults and Workers in the households. These groups are then subdivided based on the absence or presence of children in the household. Groups with fewer than 30 households are recombined based on the Adult-Worker combination and ignoring the children/no-children dichotomy. The end results is 23 household categories that all have a minimum of 30 households to randomly select from.

Table 40. HI_HHENUM_IN.TXT Input File

Variable	Description	Format
PUMA	A six digit code with the first two digits equal to the FIPS county code and the last four digits equal to the PUMA.	Integer (172300-551900)
HHVTYPE	The revised household type code based on vehicle availability in the survey household.	Integer (1-624)
SERIAL NUMBER	An eight digit code with the seven character serial number assigned to the household in the Travel Tracker Survey followed by the one character code for day of week (weekdays only).	Integer
ADULT	Number of adults in survey household.	Integer
WORKER	Number of workers in survey household.	Integer
NONWORKER	Number of non-workers in survey household.	Integer
CHILD	Number of children aged 0-15 in survey household.	Integer
CHILD 12-15	Number of children aged 12-15 in survey household.	Integer
VEHICLES	Number of vehicles available in survey household.	Integer
TRIPS1	Household's home production-work attraction trips.	Integer
TRIPS2	Empty placeholder.	Integer
TRIPS3	Household's home production-work related attraction trips.	Integer
….	….	….
TRIPS49	Household's shop-shop trips by child 12-15.	Integer

The processing of the survey households into match categories is handled outside of the trip generation model, and the results are read into the model via two files. HHID_choices1.csv provides the following information: a household type code that is the concatenation of the PUMA and the vehicle type household category, the match category used (for tracking purposes) and the number of survey households in the match category. The second file (HHID_choices2.csv) includes a listing of the survey household serial numbers and a flag of whether or not the household exhibits very rare (i.e., higher than the 98th percentile) trip characteristics for either worker trips, non-worker trips or trips for children as 12-15. The number of households within each category (provided in the first file) is used to store the specific households in the appropriate arrays during the matching process.

Table 41. HHID_choices1.csv Input File

Variable	Description	Format
HOUSEHOLD CODE	A household type code that is the concatenation of PUMA (from HI_HHENUME_IN.TXT) and the HHVTYPE code, i.e., PUMA*1000+HHVTYPE.	Integer
MATCH CATEGORY	A numeric code identifying the household match methodology used to match the enumerated household with a survey household: 1 = household in PUMA 2 = household in adjacent PUMA 3 = household in region 4 = final match category	Integer (1-4)
CHOICES	Identifies the number of survey households available to match against.	Integer

Each of the enumerated households is processed as follows to develop the trip productions and attractions:

- The household code for the enumerated household is matched to the travel survey data stored in HHID_choices1.csv.
- One household serial number is randomly selected from among the available choices. If a household is identified as being rare, it has a reduced probability of being selected compared to non-rare households and the choice may be resampled. This is done to prevent extremely rare households from being over-represented in the final household distribution.
- Once a serial number is selected, it is matched to the survey household and the associated trips are attached to the enumerated household.

Table 42. HHID_choices2.csv Input File

Variable	Description	Format
HOUSEHOLD IDENTIFIER	An eight-digit code with the seven character serial number assigned to the household in the Travel Tracker survey followed by the one character code for day of week (weekdays only).	Integer
RARE	A flag indicating whether or not the survey household exhibits extremely rare trip characteristics.	Integer (0|1)

Enumerated survey households are written to the fixed-width output file **HI_HHENUM_TRIP_OUT.TXT** as they are selected. Trip productions and attractions are summed by subzone and are now organized and reported as in previous versions of the trip generation model.

Table 43. HI_HHENUM_TRIP_OUT.TXT Output File

Variable	Description	Format
SUBZONE	The trip generation subzone, which must be in sequence in the file from low to high values.	Integer (5 Characters)
PUMA	A six digit code with the first two digits equal to the FIPS county code and the last four digits equal to the PUMA.	Integer (7 Characters) (172300-551900)
HHTYPE	The original income quartile household type code.	Integer (4 Characters) (1-624)
HHVTYPE	The revised vehicle availability household type code.	Integer (4 Characters) (1-624)
IN_VEHICLES	Modeled household vehicle availability	Integer (2 Characters)
ROW-COLUMN	Geographic identifier. 1 = Inner Chicago 2 = Outer Chicago and Inner Suburbs 3 = Mid Suburban 4 = Fringe and External Areas	Integer (2 Characters)
SERIAL NUMBER	An eight digit code with the seven character serial number assigned to the household in the Travel Tracker Survey followed by the one character code for weekdays..	Alphanumeric (8 Characters)
ADULT	Number of adults in survey household.	Integer (3 Characters)
WORKER	Number of workers in survey household.	Integer (3 Characters)
NONWORKER	Number of non-workers in survey household.	Integer (3 Characters)
CHILD	Number of children aged 0-15 in survey household.	Integer (3 Characters)
CHILD 12-15	Number of children aged 12-15 in survey household.	Integer (3 Characters)
OUT_VEHICLES	Number of vehicles available in survey household.	Integer (3 Characters)
TRIPS1	Household’s home-work trips by low income worker.	Integer (3 Characters)
TRIPS2	Household’s home-work trips by high income worker.	Integer (3 Characters)
TRIPS3	Household’s home production-work related attraction trips.	Integer (3 Characters)
….	….	….
TRIPS49	Household’s shop-shop trips by child 12-15.	Integer (3 Characters)

Group Quarters Trip Generation

The CMAP survey did not gather travel data from any group quarters residences. The ACS does collect some limited information on persons in group quarters, including institutionalized and non-institutionalized persons. For trip generation, it is assumed that institutionalized persons do not travel independently, which means that group quarters trip generation applies only to individuals in dormitories, military barracks, group homes, and the like. A second assumption is that all children in group quarters are in institutions and do not travel independently.

The four types of group quarters residents that remain to be considered are:

- Persons in military barracks
- Persons in college/university dorms
- Persons aged 16 to 64 in other types of group quarters
- Persons aged 65 or more in other types of group quarters

A trip generation subzone input file, **GQ_IN.TXT**, containing workers and nonworking adults in non-institutionalized group quarters is read by the program.

Table 44. GQ_IN.TXT Input File

Variable	Description	Format
SUBZONE	The trip generation subzone, which must be in sequence in the file from low to high values.	Integer (1-25000)
GQ MILITARY	Persons in military barracks	Integer
GQ UNIVERSITY	Persons in college/university dormitories	Integer
GQ OTHER (16-64)	Persons in other group quarters aged 16 to 64	Integer
GQ OTHER (≥ 65)	Persons in other group quarters aged 65 and older	Integer

Group quarters trip rates and fractions of group quarters persons commuting by non-motorized means are now hardcoded in the model; the values used for these rates are listed in the following table. Home-work trip rates were developed from the 2006-10 ACS PUMS person file, which provided the worker per person in group quarters, the home-work trip rate, and the fraction of home-work trips by vehicle modes. Trip rates for non-work trips are the previously developed rates for workers and non-workers in single person, low income, zero vehicle households. Vehicular trip rates for non-work trips are assumed to equal the rates for home-work trips.

Table 45. Group Quarters Trip Generation

Group Quarters	Worker per GQ Person	Home-Work Trip Rate	Non-Work Trip Rates	Fraction of Trips by Vehicle
Barracks	1.00	1.95	Single person trip rates	0.14
Dormitories	0.88	0.90		0.15
Other GQ (16-64)	0.50	1.10		0.30
Other GQ (≥65)	0.18	1.10		0.26

Allocation of Non-Home Trip Ends

At this point in the logic of the CMAP trip generation model, all trips generated by persons residing inside the modeled study area -- both in households and group quarters -- are accounted for. What remains to be determined is where the non-home trip ends are located. These are allocated to trip generation subzones in this step of the model.

To perform the allocation an attractiveness share, a function of employment or households (depending on the trip's purpose) is calculated for each subzone. Since the Chicago CBD is atypical in its mix of employment, subzones within the CBD are weighted differently from non-CBD subzones. After totaling the shares for all subzones, trip ends are then proportionally allocated to subzones by these shares. The input ATTR_IN.TXT is read into the model to supply the employment values necessary for the allocation.

Table 46. ATTR_IN.TXT Input File

Variable	Description	Model Run Values
SUBZONE	The trip generation subzone, which must be in sequence in the file from low to high values.	Integer (1-25000)
RETAIL EMPLOYMENT	Retail employment in the trip generation subzone.	Integer
TOTAL EMPLOYMENT	Total employment in the trip generation subzone.	Integer
FRACTION OF HIGH EARNERS	The fraction of workers working in the subzone with earnings above the regional median worker earnings.	Real Number

The two employment quantities in ATTR_IN.TXT are prepared by CMAP as part of the regional socioeconomic forecast. The fraction of higher income workers working in the subzone was estimated from the 2006-10 CTPP. Employment figures for Indiana and Wisconsin are factored by the control variables **WI_EMPFACT** and **IN_EMPFACT** immediately after the file is read.

Weights for the allocation of non-home productions or origins are listed in Table 47 below. Table 48 is a similar table listing the weights used for allocating non-home attractions or destinations. After workplace attractions are allocated, they are factored into workplace attractions for workers with above and below median earnings by the factors in the **ATTR_IN.TXT** input data set.

Table 47. Allocation Weights for Origin Non-Home Trip Ends

				Employment Category					
		Households		Retail		Non-Retail		Total	
Origin Activity	**Destination Activity**	**CBD**	**Non-CBD**	**CBD**	**Non-CBD**	**CBD**	**Non-CBD**	**CBD**	**Non-CBD**
Worker									
Work (P)	Non-home/Work at Residence (A)							0.018	0.018
	Non-home/Work Not at Residence (A)							0.399	0.217
	Shop (A)							0.087	0.070
Work (O)	Work (D)							0.093	0.140
Non-home/Work at Residence (O)	All Destinations (D)	0.109	0.062						
Non-home/Work Not at Residence (O)				1.591	1.356	0.017	0.064		
Shop (O)				0.684	1.070				
Nonworking Adult									
Non-home at Residence (O)	All Destinations (D)	0.050	0.053						
Non-home Not at Residence (O)				1.047	1.531	0.006	0.015		
Shop (O)				0.472	1.119				
Child 12-15									
School (P)	All Attractions (A)				0.786		0.022	0.011	
Non-home at Residence (O)	All Destinations (D)	0.019	0.036						
Non-home Not at Residence (O)					0.786		0.022	0.011	
Shop (O)				0.042	0.346				

Table 48. Allocation Weights for Destination Non-Home Trip Ends

Origin Activity	Destination Activity	Households		Employment Category: Retail		Employment Category: Non-Retail		Employment Category: Total	
		CBD	Non-CBD	CBD	Non-CBD	CBD	Non-CBD	CBD	Non-CBD
Worker									
Home (P)	Workplace (A)							1.307	0.975
	Work-Related (A)			0.592	0.559	0.054	0.074		
	School (A)			3.340	3.879	0.068	0.216		
	Non-home/Work at Residence (A)	0.363	0.170						
	Non-home/Work Not at Residence (A)			3.340	3.879	0.068	0.216		
	Shop (A)			0.891	2.127				
Work (P)	Non-home/Work at Residence (A)	0.129	0.025						
	Non-home/Work Not at Residence (A)			0.456	0.924	0.327	0.117		
	Shop (A)			1.224	0.454				
Work (O)	Work (D)							0.093	0.140
All Origins (O)	Non-home/Work at Residence (D)	0.109	0.062						
	Non-home/Work Not at Residence (D)			1.591	1.356	0.017	0.064		
	Shop (D)			0.684	1.070				
Nonworking Adult									
Home (P)	School (A)				3.550		0.266	0.190	
	Non-home at Residence (A)	0.100	0.197						
	Non-home Not at Residence (A)				3.550		0.266	0.190	
	Shop (A)			0.545	2.218				
All Origins (O)	Non-home at Residence (D)	0.050	0.053						
	Non-home Not at Residence (D)			1.047	1.531	0.006	0.015		
	Shop (D)			0.472	1.119				
Child 12-15									
Home (P)	School (A)			0.644	3.346	0.006	0.233		
	Non-home at Residence (A)	0.152	0.134						
	Non-home Not at Residence (A)			0.644	3.346	0.006	0.233		
	Shop (A)			0.073	0.820				

School (P)	Non-home at Residence (A)	0.019	0.036						
	Non-home Not at Residence (A)				0.786		0.022	0.011	
	Shop (A)			0.042	0.346				
All Origins (O)	Non-home at Residence (D)	0.019	0.036						
	Non-home Not at Residence (D)				0.786		0.022	0.011	
	Shop (D)			0.042	0.346				

External Trip Ends

After accounting for all trips made by study area residents, the next step is to factor out trip ends for trips with one trip end outside the modeled study area. In the model, only home-workplace trips for households are factored in this manner. This is largely due to data limitations. The CMAP survey sample is far too small for any reliable estimation of these factors and only the CTPP commuting data are available. Additionally, home-workplace trips are lengthier than other trip purposes and more likely to have one trip end outside the area modeled. Trips by persons residing in group quarters are not factored for external trip ends.

A summary home-workplace table was first developed from the 2000 CTPP Table 3.1. This table contains the home to workplace commutes for workers by five percent PUMAs. After removing workers who work at home, the table has three components for workers who travel to work and who: (1) live and work inside (internal-internal) the modeled study area; (2) live outside (external) the study area, but work inside (internal) inside the study area, and; (3) live inside (internal) the study area, but work outside (external) the study area.

External trip factors to adjust the home productions and workplace attractions in a five percent PUMA were developed from the table in the following manner. The home production factor is the fraction of all trips from internal households (internal-internal plus internal-external) linked to external workplaces (internal-external), and the workplace attraction factor is the fraction of all trips to internal workplaces (internal-internal plus external-internal) that are linked to external households (external-internal). Home productions in five percent PUMS are factored first followed by workplace attractions. Finally, workplace attractions are factored at the regional level to equal home productions. These external trip factors are entered in an input file named **EXT_IN.TXT.**

Table 49. EXT_IN.TXT Input File

Variable	Description	Format
FIVE PERCENT PUMA	Six digit numeric code for five percent PUMAs (two digit county FIPS code plus four digit code for five percent PUMA).	Integer
EXTERNAL PRODUCTION FACTOR	Fraction of home productions in home-workplace trips linked to external workplace attractions.	Real Number
EXTERNAL ATTRACTION FACTOR	Fraction of workplace attractions in home-workplace trips linked to external home productions.	Real Number

Non-motorized Trips

Following trip generation, the remaining steps in the trip-based model only address person trips using motorized modes. However the trip generation model does create non-motorized person trips. The non-motorized sub-models are all binary choice models that forecast the proportion of trip productions/origins that will be completed by non-motorized modes. It is assumed that non-motorized trips take place within a subzone or more generally non-motorized productions/origins equals non-motorized attractions/destinations in the subzone.

Expanded trips from the CMAP survey were tabulated by vehicular and non-motorized modes by trip purpose for five percent PUMAs and the Chicago CBD. Independent variables suspected of affecting non-motorized-vehicular mode choice were added, including: (1) households and employment variables; (2) zero vehicle households; (3) weighted average pedestrian environmental factor, and; (4) area in square miles for computing household and employment densities. The weighted average pedestrian environmental factor was calculated by weighting the subzone pedestrian environmental factors within a PUMA by their area.

Aggregate logit models were then estimated from the quantities in these spreadsheets. The combined home-workplace and home-work related non-motorized sub-model was also re-estimated using non-motorized commuting proportions tabulated from the ACS PUMS data. While there proved to be little difference between the two work sub-models estimated with CMAP survey and ACS data, the ACS sub-model was coded into the trip generation model due to its larger sample of households.

The non-motorized sub-models plus their non-motorized utility coefficients and vehicular bias are listed in the following table. Bias constants were adjusted to account for the revised block definitions used in the 2010 Census.

Table 50. Utility Variables in the Non-Motorized Sub-models

		Non-Motorized Utility Variables							
		Employment/ Sq. Mile (1000's)	PEF	No Vehicle Households/ All Households	Households/ Sq. Mile (1000's)	CBD Veh. Bias	Non-CBD Veh. Bias	ρ^2 (zero)	ρ^2 (constant)
Worker									
Home	Workplace Work-Related	0.0799	0.0129	2.598		4.133	4.363	0.797	0.081
	Non-work	0.0023	0.0724	2.398		4.283	4.901	0.632	0.131
Work	Non-home	0.0089	0.0850			4.504	4.855	0.577	0.343
Non-home or Work	Non-Home/Work	0.0082	0.0380		0.1380	3.889	3.965	0.656	0.224
Nonworking Adult									
Home	Non-home		0.0551	1.530		4.566	3.968	0.546	0.077
Non-home	Non-home	0.0024	0.0855		0.0831	4.173	4.742	0.638	0.204
Child 12-15									
Home	Non-home		0.0535			2.418	2. 418	0.314	0.045
Non-home	Non-home		0.0625			2.454	2.454	0.498	0.059

As noted, these sub-models are binary choice models (non-motorized versus motorized) applied at the geographic level of subzones. They also are applied to fewer aggregate trip types, partly to increase the non-motorized observations used for estimating each sub-model. Independent variables are as follows:

- The two density variables in the non-motorized utility are average total employment and households per square mile within the subzone.
- The pedestrian environment factor was input into the model in an earlier step.
- The no vehicle household fraction is determined internally within the model by the sub-model for household vehicle availability.
- The utility for the vehicular choice is a constant in all the models and is essentially treated as bias toward the motorized choice. It varies by CBD or non-CBD location in all but the child 12 to 15 sub-model.

The non-motorized sub-models implemented in the trip generation code are also bounded by the highest observed percentages of non-motorized trips which is the average non-motorized fraction of trips in the Chicago CBD.

Create Final Vehicle Trip Output File

The last subroutine in the trip generation model code creates an output file (**TRIP49_PA_OUT.TXT**) for use in the remaining CMAP models. This file contains the final vehicular trip ends for internal trips for all residents in the modeled study area.

Table 51. TRIP49_PA_OUT.TXT Output File

Variable	Description	Format
SUBZONE	Trip generation subzone (1-25000) (6 characters)	Integer (I6)
ZONE	Modeling zone number (1-5000) (6 characters)	Integer (I6)
TRIP TYPE	Trip type (1-11 when EXP_TTYPE= false, or 1-49 when EXP_TTYPE= true). (2 characters)	Integer (I2)
HH PRODUCTIONS	Household trip productions/origins for trips within the modeled study area. (9 characters, 1 decimal place)	Real Number (F9.1)
HH ATTRACTIONS	Household trip attractions/destinations for trips within the modeled study area. (9 characters, 1 decimal place)	Real Number (F9.1)

A final procedure of the trip generation model creates TG_HHENUM_OUTPUT.TXT, a file that lists the subzone and zone of each enumerated household, as well as the HHVTYPE. This file is subsequently used in the Mode Choice model.

Table 52. TG_HHENUM_OUTPUT.TXT Output File

Variable	Description	FORMAT
SUBZONE	Trip generation subzone.	Integer
ZONE	Modeling zone number.	Integer
HOUSEHOLD VEHICLE TYPE	Household type code based on vehicle availability.	Integer

CMAP currently writes out the 49 purposes and further processes the results, combining the trip purposes and aggregating the trip ends to the modeling zone system used in the remainder of the modeling process. The final four files used in the trip distribution and mode choice models are home-based work low income, home-based work high income, home-based other, and non-home based trips.

5 Trip Distribution

The trip distribution model links the trip productions with the trip attractions. The model is applied between trip generation and mode choice in the trip-based model. The process estimates the destination choices of motorized person trips, regardless of mode, by converting zone trip production and attraction vectors produced by the trip generation model into movements between zones. This results in trip tables which are two dimensional matrices. During this process, the intervening opportunity trip distribution model is used to distribute person trips using composite impedance reflecting the relative ease of travel provided by both the highway and transit networks. The resulting person trip tables are then input into the mode choice model.

In addition, the resulting home-based person trip tables (home-based work, home-based other) are in a special format referred to as "Production-Attraction" format. This means that all trips are represented as being produced from the home/production end and attracted to the destination end. The effect is that a trip from home to work and one from work to home again are both represented as trips leaving home to the work destination. Care must be taken to keep this in mind if the trip tables are used for other purposes. One advantage of this format for analysis is that it provides an indication of the direction of daily travel. One knows that the origin side is the home, and the destination is not. For example, if one looked at the daily travel to any location in origin/destination format, one would find that approximately the same number of people traveled to a particular zone as left it, but it would not be possible to determine if that zone was the home or work location.

The CMAP trip distribution takes the form of a gravity model, with the additional consideration of "intervening opportunities" that consider the probability of a traveler selecting a particular destination based on the number of destination opportunities it offers. The inputs needed for this model are the person trip productions and attractions from the trip generation model, an estimate of each zone's accessibility calculated using generalized cost "utility functions," an array of L-values to influence trip length from the origin end, and transit offset value to influence trip length to the CBD. This model is discussed in further detail.

5.1 Doubly-Constrained Intervening Opportunities Model

The intervening opportunity model of trip distribution was originally formulated in the late 1950s. It is based on two simple premises. First, travelers try to minimize travel time and cost, and secondly, there is some constant probability that a traveler will find a potential destination acceptable. To illustrate, a person making a shopping trip does not always stop at the nearest store, they first consider whether the nearest store is acceptable or not; if not, they move on to the next closest store, and so on, until an acceptable destination is found.

These premises can be restated as follows in terms of the analysis zones and trip attractions and trip productions that are built into the model. The probability that a trip production will end in a particular destination zone is the product of two probabilities, the probability that the trip has not already terminated nearer the origin zone multiplied by the probability that an acceptable attraction exists in the destination zone. Mathematically, this probability can be expressed as:

$$\Delta P = (1 - P) * L * \Delta A$$

Where P equals the probability that the trip is completed before the destination zone is reached; ΔP is the marginal probability of completing the trip due to the added attractions (ΔA) of the destination zone. Finally, L is the constant probability of stopping at any single attraction.

Applying this simple model raises a number of complex questions. What is meant by nearest zone and in what sequence are attractions considered by the traveler? Is proximity determined by the shortest travel time or least cost mode/route, or by some measure that reflects the alternative modes and routes available between origin and destination zones? Even more fundamental model questions are associated with the L-values, including how travel and traveler characteristics affect these quantities, and how they change over time?

The balance of this section discusses how the intervening opportunity trip distribution model is applied by CMAP. The major change introduced into the model since its earliest applications is the use of a combined measure of transit and highway cost to rank zones in order of increasing cost from the origin zone.

The model was calibrated to data from the Travel Tracker survey for home-other and non-home based trips; home-based work trips are calibrated using trip lengths from the 2000 CTPP. L-values are calibration constants used in the model that measure how selective travelers are in accepting opportunities (destinations). In general, lower L-values lead to longer trips (because the traveler is more selective), and higher L-values lead to shorter trips. L-values are calculated based on the generalized cost of the transportation system and the available opportunities within a specific cost cutoff. Thus the L-values are responsive to both land use and transportation system changes. The L-values were calibrated and then smoothed into a monotonic function of accessible attractions. This function is used to estimate future L-values. Regression relationships were developed to estimate L-values as a function of the attractions that are accessible within a particular combined transit-highway cost from the origin zone. This approach to L-value calibration allows the cost and time characteristics of the highway and transit networks, as well as trip productions and attractions, to influence the trip distribution.

The intervening opportunity trip distribution model is a member of the gravity model family of trip distribution models. After some algebra, the above relationship indicates that trips between zones are proportional to the trip productions in the origin zone and attractions at the destination zone, and inversely proportional to the difficulty of traveling between the two zones. This is the well-known general formulation of the gravity model. In most gravity models, the difficulty of traveling between zones (i.e., the impedance faced by the traveler) is related to the travel time or travel cost between zones. However in the intervening opportunity model, impedance also is a function of the attractions, or intervening opportunities, the traveler encounters while journeying between zone pairs.

The doubly constrained intervening opportunity model consists of the following set of equations. To solve these equations, travel impedance is first determined, and then the remaining equations are simultaneously solved using an iterative matrix balancing algorithm:

$$1.\ T_{ij} = \alpha_i \beta_j F_{ij}$$

$$2.\ P_i = \alpha_i \sum_j \beta_j F_{ij}$$

$$3.\ A_j = \beta_j \sum_i \alpha_i F_{ij}$$

$$4.\ \alpha_i, \beta_j, F_{ij} \geq 0$$

Where:

T_{ij} = the estimated trips between a production/origin zone *i* and attraction/destination zone *j*.

P_i = production/origin trip ends in zone *i*.

A_j = attraction/destination trip ends in zone *j*.

α_i = production/origin zone *i* balancing coefficient.

β_j = attraction/destination zone *j* balancing coefficient.

F_{ij} = a measure of the interaction affinity between zones that is inversely related to the difficulty or impedance (time, cost, etc., noted below as I_{ij}) associated with travel between zones *i* and *j*.

The $\alpha_i s$ and $\beta_j s$ in these equations are determined through a matrix balancing procedure (also known as iterative proportional fitting) given the $P_i s$, $A_j s$ and $F_{ij} s$. The equations above are the actual trip distribution model that links together trip productions and attractions. Zone trip productions and attractions produced by the trip generation model are converted into movements between zones, or trip tables. There is one distribution equation for every origin zone - destination zone pair.

In Metropolitan Planning Organization practice, a functional relationship between F_{ij} and travel impedance $I_{i,}$ is first assumed, then the coefficients in these relationships are calibrated using observed travel, with the objective of matching modeled travel time/cost trip frequency distributions or average travel times/costs to observed data. The CMAP distribution model is a negative exponential form with the difficulty of travel dependent on the number of closer work attractions.

$$T_{ij} = \alpha_i \beta_j e^{-LV_{ij}}$$

Where:

$L =$ CMAP distribution model calibration coefficient, which may vary by trip purpose or location.

$V_{ij} =$ intervening attractions/destinations (attractions nearer production/origin zone *i* than attraction/destination zone *j*, including those in zone *i* and but not those in zone *j*).

Previous model development work at CMAP/CATS estimated relationships between the *L* value calibration coefficient and the number of attractions within the average travel cost. The general form of these relationships is shown below.

$$L = \frac{\lambda}{(V_\$)^\gamma}$$

Where:

$L =$ CMAP distribution model calibration coefficient.

$V_\$ =$ intervening attractions/destinations nearer production/origin zone than some predetermined cost.

$\lambda, \gamma =$ additional model calibration parameters.

In the current version of the CMAP Trip Distribution model, the above equation is expanded into a gamma function with an added calibration parameter (μ). This revised function can fit a wider range of distributions than the original.

$$L = \frac{\lambda}{(V_\$)^\gamma} e^{\mu V_\$}$$

The practical effect of this change is to establish lower bounds for the *L*-values. The extra parameter does not, however, change the approach to calibration since the log of the function is still a linear equation that can be fit to observed data with least squares regression. New calibrations of the distribution model were completed and are discussed in the next section.

In the doubly constrained version of the intervening opportunity model, two sets of equations restrict the total trips distributed from an origin zone to the zone's trip productions, and the total trips received by a destination zone to the zone's trip attractions. These equations ensure that the row sums of the trip table equal trip productions and the trip table's column sums equal trip attractions. There is one production constraint equation for each origin zone and one attraction constraint equation for every destination zone.

To gain some sense of the magnitude of the calculations required for trip distribution, consider that there are nearly 7,600,000 equations in the above model that need to be solved for each trip purpose. This figure applies to the 1,944 internal modeling zones addressed by Trip Distribution; the 17 external zones are treated separately. The Trip Distribution model is also applied separately for four trip purposes:

- home productions to work attractions for workers earning less than the regional median annual wage (low income workers),
- home productions to work attractions for workers earning more than the regional median annual wage (high income workers),
- home productions to non-work attractions, and
- non-home productions to non-home attractions.

5.2 Model Calibration

Calibration of any trip distribution model usually means fitting the model's average trip lengths, or trip length distribution, to observed trip characteristics. The CMAP trip distribution model is calibrated to average trip lengths for outbound trips from subareas in the region, and to the average trip length for trips received by the central area. In the calibration process, the L-values primarily control the trip lengths for trips sent, while a transit offset value regulates the length of trips received by the central area.

The trip distribution model calibration, therefore, has two stages. L-values are calibrated to average sent trip lengths, and then the relative importance of transit and highway modes in the distribution generalized cost is calibrated from the trip lengths of trips received by the central area. In all of the calibration calculations, the trips referred to are person trips made in any vehicle, auto or transit. Non-motorized modes such as walking and bicycling are not included. The calibration calculations are repeated for each of the four trip purposes modeled. As stated, the L-values control the lengths of trips sent from areas while highway and transit offset values are used to control the length of trips to the central area. After the final coefficients were determined for the HBW trips, it was necessary to iteratively adjust the highway offset to achieve the desired trip length for work trips to the central area.

The calibration steps used for each of the four trip purposes can be summarized as follows:

1. The average low and high income home-work sent and received straight-line trip distances were tabulated by five percent PUMAs from the 2000 CTPP. This was done

using the tract level records of Table 3-7. As Table 3-7 is based on household income rather than worker salaries, workers in households in the lower two categories of household income were assumed to be representative of workers with less than median salaries, and workers in the upper two household income categories were assumed to be high income workers. Trip lengths for "low" and "high" income workers were then estimated from Table 3-7. Data suppression in Table 3-7 was addressed by factoring both worker income trip lengths by the ratio of unsuppressed (Table 3-2) to suppressed (Table 3-7) trip lengths for all workers. All trip distances were calculated using the geographic centroids of tracts, which are roughly similar to the CMAP modeling zones. Comparable average trip lengths for home-other and non-home sent and received trips are obtained from the CMAP survey. These distances were directly calculated from trip end coordinates in the survey.

2. Beginning with an estimate of the average L-value calibration coefficient for each and every PUMA, the zone-level distribution was run with these PUMA averaged L-values and the average PUMA trip lengths were compared to observed values. PUMA L-values were factored by the inverse ratio of observed to simulated trip lengths (as decreased L-values yield increased trip lengths and vice versa) and distribution was rerun until satisfactory closure with the observed trip lengths was attained. An attempt was made to match both sent and received trip lengths; however, priority was given to matching sent trip lengths and Chicago Central Area work received trip lengths. The result is a set of "observed" L-values for PUMAs.
3. A pre-distribution zone-to-zone generalized cost matrix was developed.
4. The median travel costs for all trips was estimated using an historic base year trip distribution and the generalized costs from step 3.
5. The attractions/destinations reachable within the median travel costs were calculated for each zone and averaged by PUMAs (these are the PUMA level $V_{\$}$s).
6. A relationship was estimated between the PUMA "observed" L-values from step 2 and the attractions/destinations within the median cost (the PUMA $V_{\$}$s) from step 5.
7. Trips were distributed at the zonal level using L-values estimated by the "smoothed" relationship from step 6 and the results were evaluated by again comparing simulated and actual trip lengths.

The model was calibrated to develop new coefficients for each of the four trip purposes, which are presented in Table 53.

Table 53. Trip Distribution Calibration Coefficients

Trip Purpose	Median Cost	Fitted Parameters						R^2
		λ	"t" Statistic	γ	"t" Statistic	μ*10^7	"t" Statistic	
Home-Work								
Low Income	3.11	10.065	13.5	-0.739	-11.0	8.661	3.3	0.86
High Income	3.24	11.203	16.5	-0.830	-13.5	8.084	3.4	0.91
Home-Other	2.94	16.192	5.3	-1.211	-4.6	25.93	3.6	0.31
Non-Home	3.06	15.390	9.2	-1.196	-7.6	40.54	4.2	0.68

Source: Parsons Brinckerhoff, "Adapting the Chicago Metropolitan Agency for Planning's Travel Demand Models for the I-290 Eisenhower Expressway Reconstruction Traffic Forecasts" (Unpublished Draft) (2011, February 9): 29.

More on Trip Distribution model trip lengths can be found in the 2017 and 2011 versions of the CMAP Travel Demand Model Validation Report.

5.3 Generalized Highway-Transit Cost Estimation

Travel time and cost are not explicitly included in the impedances (F_{ij}s), but they enter the model through the ranking of trip attractions from the origin zone. In the CMAP regional model, a generalized cost of travel across modes is used for ranking zones. This generalized cost reflects the cost and time of travel by both transit and auto, and is calculated in a process referred to as pre-distribution.

The generalized highway and transit costs between trip interchanges are key influencers of travel behavior, and are used as inputs to both the trip distribution and mode choice models. The pre-distribution generalized cost calculations use largely the same coefficients as the CMAP Mode Choice model version. While the distribution model uses the combined costs of highway and transit to represent the general difficulty of traveling between zone pairs, the mode choice model uses the driving and transit costs separately to compare the relative difficulty of driving to the destination versus using public transportation. Line-haul costs and times for travel by transit and auto are determined by the modeled network paths between zones, but the costs and times required to reach or depart line-haul facilities are simulated through Monte Carlo simulation models which estimate central area parking costs and transit access characteristics.

The cost calculation routine with Monte Carlo simulations is run before applying the trip distribution model and estimates the generalized travel cost of driving or transit. One hundred person trips are simulated for each trip interchange between zones, taking advantage of the Monte Carlo simulation's ability to limit common modeling error caused by the use of average values rather than modeling probabilities. The transit and highway costs and times for these trips are estimated in the same manner as in the mode choice, but the mode choice calculations are not completed. The interchange's transit and highway costs are then calculated from the average of the characteristics of the 100 trips simulated for each zonal interchange.

Costs used in the pre-distribution procedures were previously discounted to 1970 dollars. The current version of the procedures uses current costs (measured in 2010 dollars). The coefficients were adjusted using the Historical Consumer Price Index for all Urban Consumers, which indicated that a 1970 dollar would be worth $5.55 in current dollars. The Pre-Distribution cost coefficients were, therefore, reduced to 18 percent ($\frac{\$1.00}{\$5.55}$) of their previous levels.

Variables in the generalized cost calculation and their weights are listed in Table 54. This table represents the subset of Mode Choice coefficients used in Pre-Distribution. The work trip high income utility functions are used to estimate costs to Central Area destinations for all trip purpose; the non-work purpose utility functions are not used. For work trips not destined to the Central Area, the low income work utility calculation is used. For all remaining home-based other and non-home based trips, the respective destination utility functions for trips not destined to the Central Area are used.

Note that transit bias is not included in this generalized cost calculation for the distribution model. The transit bias included in the mode choice model is a constant that does not vary with the ease or difficulty of travel between zones. Transit bias in the mode choice model accounts for uncaptured quantities leading travelers to choose transit over auto more or less than expected, given information about the traveler and comparative times and costs of highway and transit. The transit bias constants are not included in the utility functions, as the relative importance of transit compared to highway is considered when the generalized costs are combined for auto and transit into one term.

The separate auto and transit utility values $\sum_i \omega_i V_i^{auto}$ and $\sum_i \omega_i V_i^{transit} + \tau$ for each zone pair, must be combined into one generalized term. The utilities are combined using the following formula:

$$C^{auto,transit} = -Ln\left\{e^{-\sum_i \omega_i V_i^{auto}} + e^{-\sum_i \omega_i V_i^{transit} + \tau}\right\}$$

The combined multi-mode generalized cost can also be interpreted as the cost belonging to some abstract mode "auto-transit" whose service characteristics are equivalent to those of a joint transit-highway alternative. A key characteristics is that all else being equal, a trip interchange should be more accessible if it offers a choice of both highway and transit than if it offers only highway service.

Table 54. Pre-Distribution Model Coefficients

Pre-Distribution Variable (V_i)	Weight (w_i)
Home to Central Area Work Trips High Income	
Auto and Transit In-Vehicle Time (in minutes)	0.01590
Auto and Transit Cost (in cents)	0.00153
Auto and Transit Excess Time for Access/Egress (in minutes)	0.04860
Transit Bias	0.00000
Transit Out-of-Vehicle Time (in minutes)	0.02900
Transit First Wait Time (in minutes)	0.01730
Home to Non-Central Area Work Trips Low Income	
Auto and Transit In-Vehicle Time (in minutes)	0.01860
Auto and Transit Cost (in cents)	0.00130
Auto and Transit Excess Time for Access/Egress (in minutes)	0.05840
Transit Bias	0.00000
Transit Out-of-Vehicle Time (in minutes)	0.03990
Transit First Wait Time (in minutes)	0.08110
Home to Other Trips, Non-Central Area Destinations	
Auto and Transit In-Vehicle Time (in minutes)	0.01140
Auto and Transit Cost (in cents)	0.00592
Auto and Transit Excess Time for Access/Egress (in minutes)	0.06630
Transit Bias	0.00000
Transit Out-of-Vehicle Time (in minutes)	0.05890
Transit First Wait Time (in minutes)	0.06100
Non-home to Non-home, Non-Central Area Destinations	
Auto and Transit In-Vehicle Time (in minutes)	0.01140
Auto and Transit Cost (in cents)	0.00592
Auto and Transit Excess Time for Access/Egress (in minutes)	0.06630
Transit Bias	0.00000
Transit Out-of-Vehicle Time (in minutes)	0.05890
Transit First Wait Time (in minutes)	0.06100

In addition to the coefficient updates noted above, several default parameters hard-coded into the pre-distribution code were also updated:

- Average auto occupancy rates for home-other and non-home trips were revised to 1.66 and 1.19 respectively, based on the Travel Tracker survey.
- The minimum median household income is now $10,000 per year.
- The household income used to simulate non-home trips (i.e., the home zone is unknown) is $59,300, the ACS median household income for the Chicago Consolidated Metropolitan Statistical Area in 2010 dollars.
- The parameters used in the transit access/egress cost were updated: in-vehicle time was set to $0.20 per minute, out-of-vehicle time was set to $0.40 per minute, and kiss and ride auto driver costs were assumed to be double the one-way costs for auto passengers.

5.4 Distribution Model Processing Steps

The CMAP distribution model is unique enough that some find a description of the calculation steps helpful to understand how the model actually works. The following description includes information on several additions to the original CMAP trip distribution macros that were recently implemented: (1) calculations to estimate the number of attractions/destinations within the median travel cost were revised to include partial zones; (2) attractions/destinations that result in very short trips that are inappropriate for motorized travel are not considered, and; (3) intra-zonal trips are now explicitly determined. The following is an annotated outline of the sequence of calculations that implement the CMAP trip distribution models; the distribution of each of the four trip purposes is generally similar.

1. Compute the combined auto-transit general cost matrix from the input auto and transit cost matrices. The combined auto-transit cost equals the sum of the individual mode utilities in the CMAP mode choice model.
2. The next set of steps describes the computations used to calculate the L-values.

   2.1. Locate the corners of the receiving zone based on the area of the zone and the x- and y-coordinates of the zone's geographic centroid. Zones are assumed to be approximately square in shape.

   2.2. Estimate the cost to reach each receiving zone corner. This is calculated by:

$$\frac{Dist_{Cent-Cor}(\$_{Auto-Transit})}{Dist_{Zone-Zone}}$$

Where:

$Dist_{Cent\text{-}Cor}$ = the x-y distance between the zone centroid and a zone corner.
$Dist_{Zone\text{-}Zone}$ = the x-y distance between the sending and receiving zone centroids.

$\$_{Auto\text{-}Transit}$ = the travel cost between the sending and receiving zone centroids.

These corner costs are trip interchange specific; that is; there are four receiving zone corner costs for each zone to zone interchange.

2.3. Find the minimum and maximum cost corners for the interchange.

2.4. Compute the opportunities that should not be considered for motorized travel. This is estimated to equal $\frac{0.5(ZoneAttractions)}{ZoneArea}$. The 0.5 in this equation is the area that can be reached within 0.5 miles x-y distance from the beginning of the trip.

2.5. Compute trip attractions/destinations within the median cost of all potential destinations. The first part of this calculation can have the following outcomes for each zone:

- The maximum cost corner is less than the median cost and all of the zone's attractions/destinations are included.
- The median cost is between the zone's maximum and minimum cost corners and a cost-prorated portion of the zone's attractions/destination are included.
- The minimum cost corner is greater than the median cost and the zone's attractions/destinations are not included.

After all zones are considered, the excluded opportunities from step 2.4 (.i.e., trips too shot to be motorized) are subtracted from the total attractions/destination inside the median cost.

2.6. Compute the L-values using calibrated relationships and attractions/destinations inside the median cost from step 2.5.

3. Compute the matrix of intervening attractions/destinations. A two stage matrix operation is required. The zones nearer in cost to the sending zone are first identified, and then the attractions/destinations for the subtended zones are added together. The excluded opportunities from step 2.4 are lastly subtracted from the total.
4. Compute the initial matrix of travel impedances $e^{-LV_{ij}}$ with the intervening attractions/destinations from step 3 (includes attractions/destinations within the sending zone).
5. Adjust all zonal attractions/destinations to potential trip attractions/destinations for vehicular travel. Subtract the excluded opportunities calculated in step 2.4 from all attractions/destinations in the zone, leaving attractions/destinations for both intra-zonal and inter-zonal trips for personal vehicular travel.
6. Run the initial trip distribution (matrix balancing) for both inter-zonal and intra-zonal trips. The attractions/destinations equal the zonal attractions/destinations from step 5 and total productions/origins are factored to equal attractions/destinations.

7. Factor the intra-zonal trips from step 6 by the ratio of zone trip productions/origins to sent trips.
8. Adjust the original zone productions/origins and attractions/destinations by removing intra-zonal productions/origins and attractions/destinations.
9. Zero the impedance matrix ($e^{-LV_{ij}}$) for all intra-zonal movements because intra-zonal trips cannot occur in the subsequent redistribution of trips.
10. Redistribute only inter-zonal trips using the zone productions/origins and attractions/destinations calculated in step 8 and the impedance matrix from step 9.
11. Combine the intra-zonal (step 7) and inter-zonal (step 10) trips into the final total trip table.

5.5 Work Trips to Greater Milwaukee

A well-established issue for the CMAP trip-based model is the fact that the Milwaukee metropolitan area lies just north of the zone system used in the model. As Milwaukee proper does not exist as a zone within the modeling system, the result is that home-work trips from the Wisconsin counties included in the model that in reality travel to the Milwaukee area are forced to find destinations in Illinois in far greater numbers than are supported by observed data. CMAP has implemented a unique solution to ameliorate this issue:

- The Point-of-Entry production file (see 7.1 Special Trip Handling) includes the number of work trips from the 2006-2010 CTPP originating from Kenosha, Racine and Walworth counties (residence location) and destined to the counties of Milwaukee, Ozaukee, Washington and Waukesha (work location). This value is scaled back to represent the number of home-work trips made in the year 2000, consistent with the other special trip handling procedures.
- Procedures factor the number of Milwaukee work trips to the appropriate year and subtract double that amount (to account for both productions and attractions) from the Milwaukee POE zone (1946) in the external trip generator.
- During trip distribution, POE 1945 is used as a proxy for Milwaukee -- this zone is used for convenience in order to process a continuous block of zones during the distribution procedures.
- The generalized cost values for low-income work trips between POE 1945 and all other zones are synthesized by borrowing the corresponding values from an adjacent zone ad increasing them by five percent. The normal trip distribution procedures are then applied. Once the final trip table is developed, all trips with an origin or destination of zone 1945 are zeroed out and the values are moved to the auto POE matrix. However, they are slotted with zone 1946 as the origin or destination (rather than 1945) to reflect travel to Milwaukee. Note that these trips are entered into the auto POE matrix in Origin-Destination format, not Production-Attraction format.

- The same process is repeated for high-income work trips.

6 Mode Choice

The CMAP Mode Choice model uses two analysis techniques: the logit model and the Monte Carlo simulation model. Each of these techniques will be described in this section. The Mode Choice model equation is of the logit form. A Monte Carlo simulation of central area parking costs, transit access times, and traveler's income is used to provide some of the input to the logit equation. The Monte Carlo simulation decreases the aggregation error found in other urban mode choice models. The Mode Choice model generates the estimated transit and highway trips originating from each of the analysis areas and destined to each of these areas. The Mode Choice model is applied to the person trips resulting from the Trip Distribution model, and divides the four distributed trip types into eight modal person trip tables:

1. Home-based work high income auto mode
2. Home-based work low income auto mode
3. Home-based work high income transit mode
4. Home-based work low income transit mode
5. Home-based other auto mode
6. Home-based other transit mode
7. Non-home based auto mode
8. Non-home based transit mode

6.1 Logit Model Structure

The multinomial logit formulation is the most commonly used model form for mode choice models in the United States. The multinomial logit model is expressed mathematically as follows:

$$P_{g,i} = \frac{\exp[U_{g,i}(x_{g,i})]}{\sum_{g,m} \exp[U_{g,m}(x_{g,m})]}$$

Where:

$P_{g,i}$	is the probability of a traveler from group *g* choosing mode *i*,
$x_{g,m}$	are the attributes of mode *i* that describe its attractiveness to group *g*,
$U_{g,m}(x_{g,m})$	is the utility of mode *m* for travelers in group *g*, and
$\Sigma_{g,m}$	indicates the summation of utilities over all available alternatives
exp( )	is the exponential function

Typically, the utility function for each alternative takes the form:

$$U_{g,m}(x_{g,m}) = a_m + b_m LOS_m + c_{g,m} SE_g + d_m TRIP$$

Where:

LOS_m	represents the variables describing levels-of-service provided by mode m,
SE_g	represents the variables describing socioeconomic characteristics of group g,
$TRIP$	represents the variables describing characteristics of the trip (e.g., CBD trips)
b_m	is a vector of coefficients describing the importance of LOS_m variables,
$c_{g,m}$	is a vector of coefficients describing the importance of each $SE_{g,m}$ characteristic of group g with respect to mode m,
d_m	is a vector or coefficient describing the importance of each trip characteristic with respect to mode m, and
a_m	is a constant specific to mode m that captures the overall effect of any variables missing from the expression (comfort, safety, and so forth).

The CMAP regional Mode Choice models are applied for four trip purposes:

1. Home-Based Work Low Income: Trips from home to work made by workers earning less than the regional median annual wage;
2. Home-Based Work High Income: Trips from home to work made by workers earning more than the median regional wage;
3. Home-Based Non-Work: Trips made between home and all non-work locations (shopping and other); and
4. Non-Home-Based: Trips that neither begin nor end at the traveler's home.

The mode choice models begin with person trips from the distribution model. These person trips tables are composed of all trips made by any "motorized" mode, that is, by transit, or as an automobile driver or passenger. The logit formulation is then used to separate the person trips into transit trips and highway person trips. There is a separate mode choice model for each trip purpose and each is stratified by location at the destination end of the trip. This stratification is between Central Area zones and non-Central Area zones. The work trip model is also stratified by low and high income travelers.

Table 55 presents the coefficients used in each of the Logit models. As noted in the Pre-Distribution discussion, all cost values reflect 2010 dollars. Different transit bias constants were calibrated for person trips by purpose, and by income level for home-work trips. Separate coefficients are associated with each of the components of transportation system time and costs:

1. *In-vehicle travel times*. This is the time spent in the vehicle (either auto or transit) for a trip. For transit trips that include auto access to a service, the auto access and transit in-vehicle times are combined.

2. *Cost*. This is the cost of making a trip. For a transit trip, this includes the fare and station parking cost. For an auto trip, this includes the cost of operating the vehicle and parking costs.
3. *Walk time*. The time spent walking to and from transit service and the time spent walking from a parking spot at the destination end of the trip to the ultimate trip destination, if it occurs within the Central Area.
4. *Transit bias*. Constant to capture attributes causing trips to choose transit more or less frequently than expected based on known information about the traveler, times and costs.
5. *Transit out-of-vehicle travel times*. This is the time one would spend transferring between transit routes.
6. *Wait time of first transit line boarded*. This is the time spent waiting to board the first transit vehicle, calculated as one-half of the service headway.

Table 55. Mode Choice Model Coefficients

Mode Choice Variable (V_i)	Weight (w_i)	
Home to Central Area Work Trips	**Low Income**	**High Income**
Auto and Transit In-Vehicle Time (in minutes)	0.01590	0.01590
Auto and Transit Cost (in cents)	0.00153	0.00153
Auto and Transit Excess Time for Access/Egress (in minutes)	0.04860	0.04860
Transit Bias	-0.43640	-0.71210
Transit Out-of-Vehicle Time (in minutes)	0.02900	0.02900
Transit First Wait Time (in minutes)	0.01730	0.01730
Home to Non-Central Area Work Trips	**Low Income**	**High Income**
Auto and Transit In-Vehicle Time (in minutes)	0.01860	0.01860
Auto and Transit Cost (in cents)	0.00130	0.00130
Auto and Transit Excess Time for Access/Egress (in minutes)	0.05840	0.05840
Transit Bias	-0.97300	-2.06070
Transit Out-of-Vehicle Time (in minutes)	0.03990	0.03990
Transit First Wait Time (in minutes)	0.08110	0.08110
Home to Other Trips	**Non-Central Area Destinations**	**Central Area Destinations**
Auto and Transit In-Vehicle Time (in minutes)	0.01140	0.01590
Auto and Transit Cost (in cents)	0.00592	0.00153
Auto and Transit Excess Time for Access/Egress (in minutes)	0.06630	0.04860
Transit Bias	-0.44820	-0.55070
Transit Out-of-Vehicle Time (in minutes)	0.05890	0.02900
Transit First Wait Time (in minutes)	0.06100	0.01730
Non-home to Non-home	**Non-Central Area Destinations**	**Central Area Destinations**
Auto and Transit In-Vehicle Time (in minutes)	0.01140	0.01590
Auto and Transit Cost (in cents)	0.00592	0.00153
Auto and Transit Excess Time for Access/Egress (in minutes)	0.06630	0.04860
Transit Bias	-1.14030	-1.62750
Transit Out-of-Vehicle Time (in minutes)	0.05890	0.02900
Transit First Wait Time (in minutes)	0.06100	0.01730

The Mode Choice model uses the following components of the transportation system to analyze modal costs. These matrices are estimated by the travel demand software transit and highway network assignment algorithms:

1. Transit in-vehicle travel times: The time spent in the vehicle for a transit trip. For transit trips that include auto access to a service, the auto access and transit in vehicle times are combined.
2. Transit out-of-vehicle travel times: This includes walking, waiting, and transfer times.
3. Headway of first transit line boarded: This attribute provides information on the level of transit service available at the origin of the trip.
4. Transit fare: Fare paid to ride transit. When cost is calculated in the remainder of the model, the parking cost at the origin is also included if applicable.
5. Highway travel times: This is highway in-vehicle time and is the time spent in the vehicle for a trip.
6. Highway travel distances: This is used to calculate auto operating costs. When auto trip costs are calculated for the model, parking costs at the destination are also included.
7. First transit mode boarded.
8. Last transit mode used.
9. Transit priority mode (ranked in the following order: Metra rail, CTA rail, and bus).

Minimum cost routes are determined between zone centroids using cost component weights that are generally consistent with the pre-distribution and mode choice model coefficients. The quantities in the matrices are obtained by tracing these minimum cost routes. As network travel conditions vary throughout the day due to highway congestion and transit service levels, separate sets of travel characteristics matrices are modeled for the AM peak and midday time periods. The AM peak period is selected because all trips with a home purpose are modeled in pre-distribution, distribution, and mode choice as though the trip is produced at home. Therefore all home-work trips are estimated assuming AM peak period travel conditions to be consistent with the home production of these trips. Home-other and non-home trip purposes are paired with midday travel conditions. A CBD parking sub-model estimates auto parking costs and walking distances for zones; this sub-model is restricted to home-work travel.

The specific logit model formulation for the Chicago model is the binary model formulation that is a derivation of the general logit model formulation. This formulation is as follows:

$$P_t = \frac{e^{C_i V_i}}{1 + e^{C_i V_i}}$$

Where:

P_t is the probability that the trip will be a transit trip

C_i is the coefficient for variable i
V_i is the value of variable i for the movement being investigated

The coefficients for the logit model are reasonable and "correspond" to normal mode choice procedures. The ratio of the out-of-vehicle time coefficients to the in-vehicle time coefficient, for work trips, ranges from 1.09 for travel to the Central Area, to 4.36 for the travel to non-Central Area destinations. While the "classical" value for this ratio is 2.5, the variation in the Chicago model is logical and rational. The Central Area destined trips are more sensitive to the in-vehicle travel time than the non-Central Area destined trips and to transfer time. For Central Area destined trips the walk time and the transfer time is more sensitive (the coefficients are higher) than the initial headway time, while for the non-CBD trips the reverse is true with the first headway being the most sensitive of all variables. For the non-work trips the ratio of out-of-vehicle time to in-vehicle time ranges from 5.17 for transfer time to 5.82 for walk time. It is normal that non-work trips "emphasize" out of vehicle time rather than in-vehicle time. Typically there is minor highway congestion during the time most non-work trips occur (non-peak periods) and the transit service levels, in terms of headways and coverage, tend to be worse during these times.

The implied value of time for work trips range from $1.12 for in-vehicle time to CBD destinations to $6.76 for headways to non-CBD destinations. The value of time for the in-vehicle times ($1.12 and $1.55) are very similar to other urban areas. For example the Los Angeles model has a value of time of $1.12, the Washington region's value of time is $2.08, and Seattle's value of time is $2.09. The value of time for the non-work model is much lower, ranging from twenty-one cents for in-vehicle time to $1.21 for walk time. The sharp decrease in value of time for non-work trips is typical of mode choice models. A summary of the value of time and the out-of-vehicle time to in-vehicle time ratios (OVT/IVT) for the models is shown below:

Value of time and OVT/IVT ratio for Work Trips with CBD destinations

	In-vehicle time	headway time	transfer time	walk time
Value of time (dollars per hour)	$1.12	$1.22	$2.05	$3.30
OVT/IVT	N/A	1.09	1.82	2.94

Value of time and OVT/IVT ratio for Work Trips with Non-CBD destinations

	In-vehicle time	headway time	transfer time	walk time
Value of time (dollars per hour)	$1.55	$6.76	$3.32	$4.87
OVT/IVT	N/A	4.36	2.15	3.14

Value of time and OVT/IVT ratio for Non-Work Trips				
	In-vehicle time	headway time	transfer time	walk time
Value of time (dollars per hour)	$0.21	$1.11	$1.07	$1.21
OVT/IVT	N/A	5.35	5.17	5.82

Table 56 presents examples of using the Mode Choice model for work trips for a low income traveler. These examples are presented to illustrate the actual calculations used in the model. The examples also show that for a given set of travel times and costs, there will be a higher usage of transit to the Central Area than to the other areas of the region. This is, again, a logical property of the mode choice model.

Table 56. Example Application of the Home-Based Work Trip Model

Example using Central Area coefficients (Low Income)					
Variable	Highway	Transit	Difference	Coefficient	diff.*coeff.
in-vehicle time	25	45	-20	0.0159	-0.3180
first headway	0	5	-5	0.0173	-0.0865
transfer time	0	10	-10	0.0290	-0.2900
walk time	5	7	-2	0.0468	-0.0936
Cost	200	100	100	0.00153	0.1530
Modal Coefficient				-0.4364	-0.4364
Sum Difference of values times the coefficients					-1.0715
exp(equation)					.3425
1+ exp(equation)					1.3425
transit probability	(exp(equation)/ (1.0+exp(equation))				0.2551

Example using non-Central Area coefficients (Low Income)					
Variable	Highway	Transit	Difference	Coefficient	diff.*coeff.
in-vehicle time	25	45	-20	0.0186	-0.3720
first headway	0	5	-5	0.0811	-0.4055
transfer time	0	10	-10	0.0399	-0.3990
walk time	5	7	-2	0.0584	-0.1168
Cost	200	100	100	0.0013	0.1300
Modal Coefficient				-0.9730	-0.9730
Sum Difference of values times the coefficients					-2.1363
exp(equation)					0.1181
1+ exp(equation)					1.1181
transit probability	(exp(equation)/ (1.0+exp(equation)				0.1056

6.2 Auto Submode Model for Work Trips

The sequence of CMAP travel demand models includes a mode choice model that allocates auto person trips into drive alone, two persons ride-sharing, and three or more persons carpooling sub-modes. This auto sub-mode choice model contains independent variables for the proportions of households within a zone at different levels of vehicle ownership. Since the household vehicle ownership sub-model in the CMAP trip generation model estimates these proportions (the previously discussed MCHW_HH.TXT file), the same values of household vehicle ownership should be used in both trip generation and mode choice for consistency. The relevant parameters for running the work trip auto sub-model (as read by the FORTRAN code via a Namelist file) are listed in Table 57.

Table 57. Work Trip Auto Submodel Parameters

Variable	Description	Variable Options
HW	Home productions and work attractions are simulated	True/False
HNW	Home productions and non-work attractions are simulated	True/False
OTH	Origins and destinations without a home or work trip end are simulated	True/False
HOV2	Two or more person vehicles are modeled with the HOV travel times and distances	True/False (Valid only if **HW** is true and must be false if **HOV3** is true)
HOV3	Only three or more person vehicles are modeled with the HOV travel times and distances	True/False (Valid only if **HW** is true and must be false if **HOV2** is true)
LOW_INC	Home-work trips for mode split are for low income workers	True/False (Valid on if **HW** is true and must be false if **HI_INC** is true)
HI_INC	Home-work trips for mode split are for high income workers	True/False (Valid on if **HW** is true and must be false if **LOW_INC** is true)
ASM_ZONES	Parameters that control the simulation of distance from trip end to line-haul transit service are input by zone (DISTR input file)	True (Regional defaults are used when **ASM_AREA** and **ASM_ZONES** are both false)
INCOST	Modal travel costs are input by area type and not set to program defaults	True (M023 input file has auto/transit user costs)

When **HOV2** or **HOV3** is true, an additional **NAMELIST** named **AUTOTAB** is required for home-work trips. It contains the bias constants for the auto sub-mode model and the numbers of the matrices that are used as the input and output tables needed to split auto trips by occupancy level. These are summarized in Table 58.

Some clarification of how the auto sub-mode bias constants are applied is warranted. The auto sub-mode model first splits auto person trips into drive alone and shared ride person trips using two added bias constants, HOV_CBDBIAS(2) and HOV_BIAS(2). These are included in the shared ride utility function. The shared ride person auto trips are then split into two person and three or more person auto person trips. The HOV_CBDBIAS(1) and HOV_BIAS(1) bias constants are included in the three or more person auto utility at this choice level.

Table 58. AUTOTAB Variables for Work Trip Auto Sub-Mode Choice

Variable	Description	Values
HOV_CBDBIAS(1)	Three or more persons auto sub-mode bias for CBD work trips	a. 2.51(Low income bias) b. 2.51(High income bias) c. 2.51 (All worker bias)
HOV_CBDBIAS(2)	Two or more persons auto sub-mode bias for CBD work trips	a. 0.499 (Low income bias) b. -0.0448 (High income bias) c. 1.59 (All worker bias)
HOV_BIAS(1)	Three or more persons auto sub-mode bias for non-CBD work trips	a. 2.09 (Low income bias) b. 2.09 (High income bias) c. 2.09 (All worker bias)
HOV_BIAS(2)	Two or more persons auto sub-mode bias for non-CBD work trips	a. 0.247 (Low income bias) b. 0.4430 (High income bias) c. 1.15 (All worker bias).
TABLE_SOV_TIME	Highway travel time	Emme input matrix numbers
TABLE_SOV_DIST	Highway distance traveled	
TABLE_HOV_TIME	Highway travel time	
TABLE_HOV_DIST	Highway distance traveled	
TABLE_SOV1	Drive alone auto person trips	Emme output matrix numbers
TABLE_HOV2	Two occupant auto person trips	
TABLE_HOV3	Three or more occupant auto person trips	

Two CTPP Part 3 (worker flows) tables were used to estimate the auto sub-mode bias constants. The two or more occupant bias constant (drive alone versus shared ride) was based on regional totals from Table 3-7, which cross-tabulates household income and work mode choice. Auto mode choice in this table, however, is restricted to drive alone or two or more persons, only the higher level auto sub-mode choice. The household income ranges in this table allow worker salaries to be roughly approximated, and low income and high income bias constants for this choice can, as a result, be reasonably estimated. The three or more auto occupant bias constant (two persons in vehicle versus three or more) was estimated from the regional totals from Table 3-2, which contains more detailed auto sub-mode details but no household or worker income data. Therefore, the two versus three or more occupant choice model has to be independent of income.

6.3 Auto Submode Model for Non-Work Trips

The determination of vehicle occupancy for non-work trips is handled differently. Many argue that auto occupancies for non-work trip purposes are largely determined by household characteristics rather than by travel time and cost considerations. These non-work trips fulfill essential household needs or are for recreation and often times include only persons from the household. Non-work trips are also typically much shorter than work commutes so time and cost savings from sharing rides are unlikely to be a factor in intra-household travel decisions. A household's non-work travel behavior is likely similar to a mathematical programming formulation where the objective is to efficiently carry out daily household activities subject to constraints such as auto availability.

Therefore, the model estimates non-work auto occupancies based on household types and their non-work trip behavior as reported in the CMAP Travel Tracker survey. Non-work trips are not simply factored into trips by auto occupancy; instead, the model makes use of a file identifying the types of households within trip generation subzones built by the household enumeration version of the CMAP trip generation (TG_HHENUM_OUTPUT.TXT). Enumerated households are linked to a second file of auto trips built from the CMAP survey that are organized by trip purpose and auto occupancy within each type of household (HH_VTYPE_TRIPS_IN.TXT). Thus non-work trip auto occupancies respond to changes in household characteristics but not travel costs within the modeling procedures.

Table 59. HH_VTYPE_TRIPS_IN.TXT Input File

Variable	Description	Format
HOUSEHOLD TYPE	Household vehicle type definition.	Integer (1-624)
HOUSEHOLD	Number of households of HHVTYPE from travel Tracker. Only households with weekday auto trips are included; each day surveyed counts as an observation.	Integer
HW1	Total drive alone home-work person trips.	Integer
HW2	Total two person auto home-work person trips.	Integer
HW3+	Total three or more person auto home-work person trips.	Integer
HO1	Total drive alone home-other person trips.	Integer
HO2	Total two person auto home-other person trips.	Integer
HO3+	Total three or more person auto home-other person trips.	Integer
WO1	Total drive alone work-other person trips.	Integer
WO2	Total two person auto work-other person trips.	Integer
WO3+	Total three or more person auto work-other person trips.	Integer
OO1	Total drive alone other-other person trips.	Integer
OO2	Total two person auto other-other person trips.	Integer
OO3+	Total three or more person auto other-other person trips.	Integer

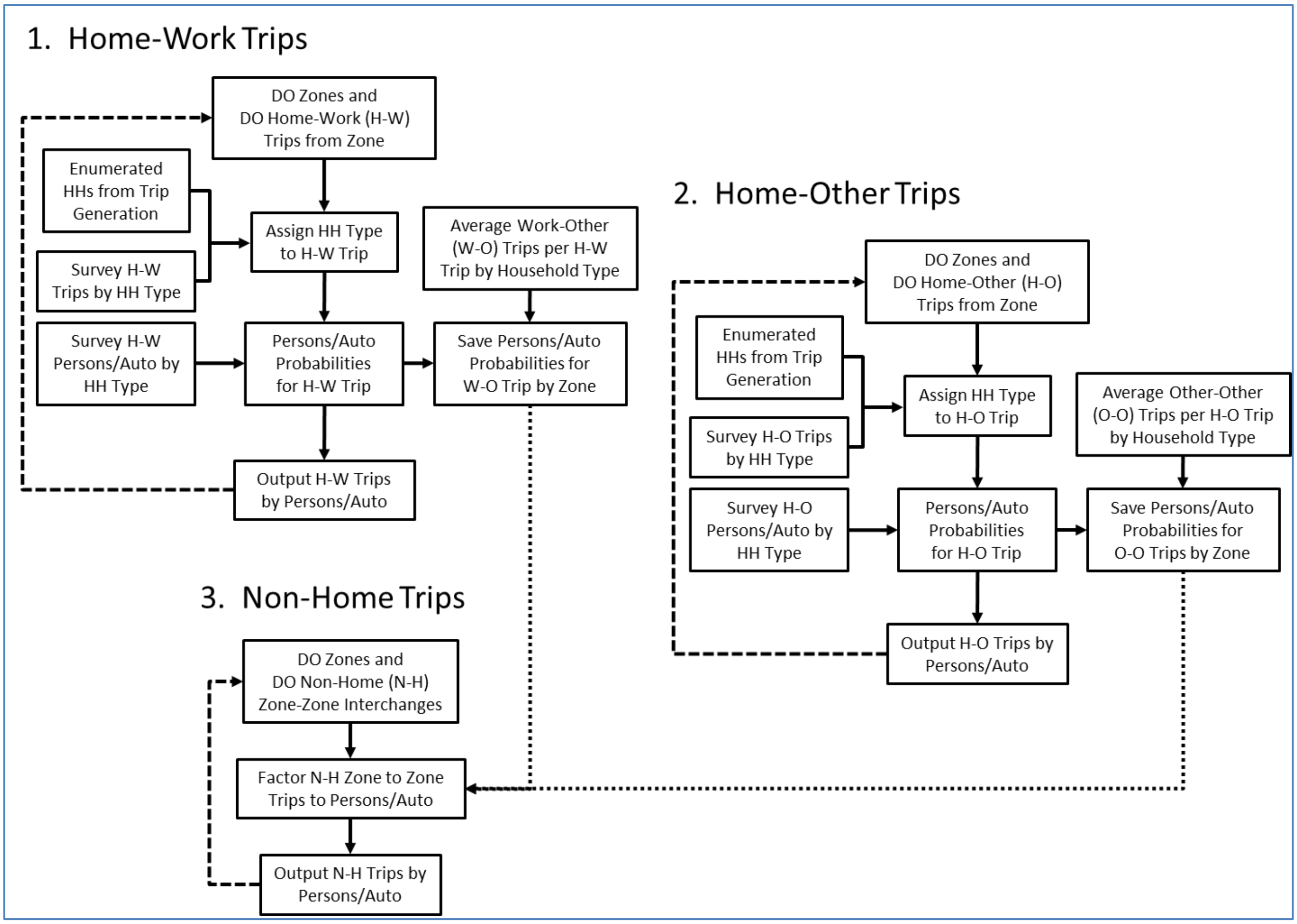
The following figure schematically shows the model logic. The approach is sequential moving from home-work to home-other, and finally, non-home trips. This ordering is because a household type cannot directly be matched to a non-home trip, and the non-home auto occupancies must be estimated after all home-work and home-other trips are processed.

Home Production-Work Attraction Trips

The process works trip-by-trip for home-work trips from a home zone. The first step is to assign a household type to each trip; the household type used is HHVTYPE which includes the number of vehicles available. The household type is randomly assigned given the types of households in the zone from the trip generation household enumeration file and the average number of home-work trips by household type from the CMAP survey. After the household type is linked to the trip, the household type survey file is again referenced to obtain average household type auto occupancy probabilities for the trip. These are summed to obtain the home-work trip auto occupancies by home zone.

The input file developed from the CMAP survey has, by household type, the number of work-other trips that take place at the work attraction end of the home-work trip. If it is assumed that the work-other auto occupancy probabilities are similar to the preceding home-work auto occupancy probabilities then the work-other trips can also be summed at the work end by auto occupancy. These are retained by the software for the subsequent non-home auto occupancy estimation.

Figure 11. Non-Work Vehicle Occupancy Processing Steps



As the default mode of running the Mode Choice model already estimates work trips by income level and vehicle occupancy, this part of the software reads the trip tables from mode choice and substitutes them for the household type based auto occupancy estimation.

Home Production-Other Attraction Trips

Following completion of the home-work trips, the software then moves on to process home-other trips. The logic for processing the home-other trips is the same as that used for home-work trips. For a given household type, each home-other trip has, on average, a fractional other-other trip associated with it. These fractional trips are accumulated at the other end of home-other trips by auto occupancy level.

Non-Home Trips

The final step uses the results of the home-work and home-other trip processing to estimate non-home auto occupancies. Zone-to-zone non-home trips are read and factored into auto occupancy trips using the average of the resulting non-home auto occupancies at both trip ends.

Data Processing

The software reads and writes trip tables directly from and to Emme matrices. The software requires several sets of input data: general parameters, data input matrices and data output matrices. These are listed in the following three tables.

Table 60. Non-Work Vehicle Occupancy Submodel Parameters

Variable	Description	Model Run Values
ZONES	Number of regional model zones in study area.	1944
RNSEED	Random number seed. When RNSEED is blank, a different sequence of random numbers is selected each time the program Is executed.	233
HOV	Drive alone, two person auto, and three or more person auto trip tables are to be read (True/False).	TRUE
WORKER$	Low and high income worker home-work trip tables are to be read (True/False).	TRUE

Table 61. Non-Work Vehicle Occupancy Submodel Input Matrices

Variable	Description	Model Run Values
INTABLE_HW_LOW_1	Matrix containing low income worker drive alone home-work auto trips.	50
INTABLE_HW_LOW_2	Matrix containing low income worker two person auto home-work trips.	51
INTABLE_HW_LOW_3	Matrix containing low Income worker three or more person auto home-work trips.	52
INTABLE_HW_HIGH_1	Matrix containing high income worker drive alone home-work auto trips.	53
INTABLE_HW_HIGH_2	Matrix containing high income worker two person auto home-work trips.	54
INTABLE_HW_HIGH_3	Matrix containing high Income worker three or more person auto home-work trips.	55
INTABLE_HO	Matrix containing all home-other auto person trips.	2
INTABLE_NH	Matrix containing all non-home auto person trips.	3

Table 62. Non-Work Vehicle Occupancy Submodel Output Matrices

Variable	Description	Model Run Values
OUTTABLE_HW_1	Matrix containing low income worker drive alone home-work auto trips.	101
OUTTABLE_HW_2	Matrix containing low income worker two person auto home-work trips.	102
OUTTABLE_HW_3	Matrix containing low Income worker three or more person auto home-work trips.	103
OUTTABLE_HO_1	Matrix containing drive alone home-other auto trips.	104
OUTTABLE_HO_2	Matrix containing two person auto home-other trips.	105
OUTTABLE_HO_3	Matrix containing three or more person auto home-other trip.	106
OUTTABLE_NH_1	Matrix containing drive alone non-home auto trips.	107
OUTTABLE_NH_2	Matrix containing two person auto non-home trips.	108
OUTTABLE_NH_3	Matrix containing three or more person auto non-home trips.	109

6.4 Tolling in Mode Choice

The effects of tolling are included in the CMAP trip-based model. Tolling increases the costs of using particular routes, so it must be accounted for within the traffic assignment procedures. The increased travel costs due to tolling also affect the choice of mode; however these calculations depend on the availability and travel costs of alternate routes to the tolled option in order to make an informed decision. This means the results of a traffic assignment must be available to the mode choice model. This is handled in practice by not implementing these procedures until the second global iteration of the model -- when traffic assignment results from the first global iteration are available.

The tolling procedures within the mode choice model are implemented as an extension to the FORTRAN code. In order to increase the transparency of the procedures, they are written as an Emme macro rather than as FORTRAN code. These procedures also take advantage of the modeling software's ability to track the paths used during traffic assignment. Within the context of the binary logit model, tolled facility users face the additional decision of switching to public transportation; this is addressed through a series of matrix calculations that estimate the diversion of person trips from autos to transit.

A set of full matrices are used to conduct the analysis within the travel demand modeling software. Table 63 lists the person demand tables used to conduct the diversion analysis.

Table 63. Toll Mode Choice Input Matrices

Matrix Number	Description
2	Auto home-other person trips
3	Auto non-home person trips
40	Transit low income worker home-work trips
41	Transit high income worker home-work trips
42	Transit home-other person trips
43	Transit non-home person trips
48	Auto low income worker home-work trips
49	Auto high income worker home-work trips
50	Auto low income worker drive alone home-work trips
51	Auto low income worker two person auto home-work trips
52	Auto low income worker three or more person home-work trips
53	Auto high income worker drive alone home-work trips
54	Auto high income worker two person auto home-work trips
55	Auto high income worker three or more person home-work trips

The mode choice toll diversion analysis proceeds in the following steps:

1. First the average tolls (in dollars) are collected along the tolled paths. These values are stored in the matrices listed in Table 64. The average tolls for home-work trips (*TollDA*, *Toll2*, and *Toll3* in the equations below) rely on path analyses using the AM peak period, while the midday period is used to collect the information for non-work trips.

Table 64. Toll Dollars

Matrix Number	Description
111	Low income worker drive alone home-work tolls
112	Low income worker two person auto home-work tolls
113	Low income worker three or more person auto home-work tolls
114	High income worker drive alone home-work tolls
115	High income worker two person auto home-work tolls
116	High income worker three or more person auto home-work tolls
117	Drive alone home-other tolls
118	Two person auto home-other tolls
119	Three or more person home-other tolls
120	Drive alone non-home tolls
121	Two person auto non-home tolls
122	Three or more person non-home tolls

2. Next the auto person trips along the tolled paths are collected. These are shown in Table 65.

Table 65. Tolled Auto Person Trips

Matrix Number	Description
131	Low income worker drive alone home-work trips
132	Low income worker two person auto home-work trips
133	Low income worker three or more person auto home-work trips
134	High income worker drive alone home-work trips
135	High income worker two person auto home-work trips
136	High income worker three or more person auto home-work trips
137	Drive alone home-other trips
138	Two person auto home-other tolls
139	Three or more person home-other tolls
140	Drive alone non-home tolls
141	Two person auto non-home tolls
142	Three or more person non-home tolls

3. Then the change in utility (generalized cost) due to tolling is calculated. Table 66 shows these matrices. The following example illustrates the calculations for low income worker home-work trips; cost coefficients are from the auto sub-mode choice model:
   a. Shared ride three or more persons

$$\Delta U_3 = Cost\ Coef * \frac{Toll_3}{3.0}$$

   b. Shared ride two persons

$$\Delta U_2 = Cost\ Coef * \frac{Toll_2}{2.0}$$

   c. Composite shared ride utility

$$\Delta U_{SR} = \ Cost\ Coef * \ln\left(e^{\Delta U_2}\frac{mf51}{mf51 + mf52} + e^{\Delta U_3}\frac{mf52}{mf51 + mf52}\right)$$

   d. Drive alone utility

$$\Delta U_{DA} = Cost\ Coef * Toll_{DA}$$

   e. Composite auto utility

$$\Delta U_{Auto} = \ Cost\ Coef * \ln\left(e^{\Delta U_{DA}}\frac{mf50}{mf50 + mf51 + mf52} + e^{\Delta U_{SR}}\frac{mf51 + mf52}{mf50 + mf51 + mf52}\right)$$

   f. Similar calculations are performed for the other auto purposes.

Table 66. Changes in Auto Utility Due to Tolls

Matrix Number	Description
Low income worker home-work trips	
151	Auto utility in auto versus transit
152	Drive alone utility in single occupant vehicle versus ridesharing
153	Rideshare utility in single occupant vehicle versus ridesharing
154	Two person auto utility in two person versus three or more person vehicles
155	Three or more person auto utility in two person versus three or more person vehicles
High income worker home-work trips	
156	Auto utility in auto versus transit
157	Drive alone utility in single occupant vehicle versus ridesharing
158	Rideshare utility in single occupant vehicle versus ridesharing
159	Two person auto utility in two person versus three or more person vehicles
160	Three or more person auto utility in two person versus three or more person vehicles
Person home-other trips	
167	Auto utility in auto versus transit
161	Drive alone utility in single occupant vehicle versus ridesharing
201	Rideshare utility in single occupant vehicle versus ridesharing
162	Two person auto utility in two person versus three or more person vehicles
163	Three or more person auto utility in two person versus three or more person vehicles
Person non-home trips	
168	Auto utility in auto versus transit
164	Drive alone utility in single occupant vehicle versus ridesharing
202	Rideshare utility in single occupant vehicle versus ridesharing
165	Two person auto utility in two person versus three or more person vehicles
166	Three or more person auto utility in two person versus three or more person vehicles

4. Then the change in mode choice probabilities are calculated. These storage matrices are listed in Table 67. Again illustrating the calculations for low income worker home-work trips, the steps are:
    a. Auto-transit mode choice

$$P_{Auto} = \frac{e^{\Delta U_{Auto}} * mf48}{e^{\Delta U_{Auto}} * mf48 + mf40}$$

    b. Drive alone-rideshare mode choice

$$P_{DA} = \frac{e^{\Delta U_{DA}} * mf50}{e^{\Delta U_{DA}} * mf50 + e^{\Delta U_{SR}} * (mf51 + mf52)}$$

$$P_{RS} = 1 - P_{DA}$$

c. Two person-three or more person mode choice

$$P_2 = \frac{e^{\Delta U_2} * mf51}{e^{\Delta U_2} * mf51 + e^{\Delta U_3} * (mf52)}$$

$$P_3 = 1 - P_2$$

Table 67. Changes in Mode Choice Probability

Matrix Number	Description
Low income worker home-work trips	
171	Auto probability in auto versus transit
172	Drive alone probability in single occupant vehicle versus ridesharing
173	Rideshare probability in single occupant vehicle versus ridesharing
174	Two person auto probability in two person versus three or more person vehicles
175	Three or more person auto probability in two person versus three or more person vehicles
High income worker home-work trips	
176	Auto probability in auto versus transit
177	Drive alone probability in single occupant vehicle versus ridesharing
178	Rideshare probability in single occupant vehicle versus ridesharing
179	Two person auto probability in two person versus three or more person vehicles
180	Three or more person auto probability in two person versus three or more person vehicles
Person home-other trips	
181	Auto utility in auto versus transit
182	Drive alone probability in single occupant vehicle versus ridesharing
183	Rideshare probability in single occupant vehicle versus ridesharing
184	Two person auto probability in two person versus three or more person vehicles
185	Three or more person auto probability in two person versus three or more person vehicles
Person non-home trips	
186	Auto utility in auto versus transit
187	Drive alone probability in single occupant vehicle versus ridesharing
188	Rideshare probability in single occupant vehicle versus ridesharing
189	Two person auto probability in two person versus three or more person vehicles
190	Three or more person auto probability in two person versus three or more person vehicles

5. Next the changes in auto person trips are calculated for each trip purpose. These matrices are listed in Table 68 and the calculations for low income worker home-work trips follow:
   a. Auto worker trips (note that matrices 131, 132 and 133 are the auto person trips assigned onto the toll paths).

$$\Delta T_{Auto} = P_{Auto} * \frac{mf40 + mf48}{mf48} * (mf131 + mf132 + mf133)$$

   b. Drive alone auto worker trips.

$$\Delta T_{DA} = P_{DA} * \Delta T_{Auto}$$

   c. Two person auto worker trips.

$$\Delta T_2 = P_2 * P_{RS} * \Delta T_{Auto}$$

   d. Three or more person auto worker trips.

$$\Delta T_2 = P_3 * P_{RS} * \Delta T_{Auto}$$

Table 68. Changes in Auto Person Trips

Matrix Number	Description
191	Low income worker auto person home-work trips
192	Low income worker drive alone home-work trips
193	Low income worker two person auto home-work trips
194	Low income worker three or more person auto home-work trips
195	High income worker auto person home-work trips
196	High income worker drive alone home-work trips
197	High income worker two person auto home-work trips
198	High income worker three or more person auto home-work trips
199	Auto person home-other trips
200	Drive alone home-other trips
203	Two person auto home-other trips
204	Three or more person auto home-other trips
205	Auto person non-home trips
206	Drive alone non-home trips
207	Two person auto non-home trips
208	Three or more person auto non-home trips

6. In the final step, the changes in auto person trips by purpose are subtracted from the appropriate auto demand matrices and added to the corresponding transit demand matrices.

Additional discussion of how tolling is addressed within the trip-based model is provided in the Traffic Assignment section.

6.5 Monte Carlo Simulation

A major source of the inaccuracy of mode choice models is the use of average values such as the average cost of parking in a traffic analysis zone or the average income of the traveler. The CMAP/CATS travel demand analysts recognized this potential source for inaccuracy very early, perhaps before anyone else was aware of the problems that could be generated by the use of average values. The solution devised was to identify the major areas which are affected by average values and to use a method which would "convert" the average values into individual values. This methodology is called a Monte Carlo simulation technique and, after the Chicago application, the technique was also used in the Dallas-Fort Worth region and the Cleveland region.

A Monte Carlo simulation focuses on selecting a representative value for a measure with this value being selected at random from a distribution of values for the measure. For example, say there are six parking garages in an area with each lot having the following characteristics:

Parking Lot A: 150 spaces with a cost of $3.50 a day
Parking Lot B: 175 spaces with a cost of $3.75 day
Parking Lot C: 275 spaces with a cost of $3.25 a day
Parking Lot D: 75 spaces with a cost of $1.25 day
Parking Lot E: 150 spaces with a cost of $3.50 a day
Parking Lot F: 175 spaces with a cost of $3.25 day

In this case the average parking cost, for the 1,000 spaces, is $3.26. But a few "lucky" people (7.5 percent) could park for $1.25 and some "unfortunate" people (17.5 percent) have to pay $3.75. The difference between the average cost and the low cost is $2.00 while the difference between the average cost and the high cost is 50 cents. These differences are substantial given that a major determinant of mode usage is the cost of using the mode. In a Monte Carlo simulation a specific parking lot would be "picked" at random. The probability of being "picked" would be a function of a relative parameter, in this case the number of spaces. Therefore in approximately 7 percent of the "picks" the inexpensive lot would be selected, while the most expensive lot would be selected about 18 percent of the time.

In the Chicago Mode Choice model the Monte Carlo simulation technique is used to estimate:

1. The access attributes of the main transit network.
2. The egress attributes from the main transit network.
3. The traveler's annual income.
4. The parking costs and the walk from the parking lot to the person's final destination.
5. The final selection of the mode used by the traveler.

The access and egress attributes are estimated when the trip is made on a subway, elevated or commuter rail mode. These attributes include the mode access used, such as walking, feeder bus, drive or be driven to the station. The attributes also include the time spent walking, driving, riding in the bus and waiting for the bus (if the access/egress mode is feeder bus) and the cost of using the access mode including the cost of parking at the stations. The access/egress attributes are estimated given the number of bus miles in the analysis area (traffic analysis zone), the size of the analysis area, the distance to the rail station, the cost of parking at the rail station, and the type of area.

The income of the traveler is estimated using the average income of the traveler's home area. The parking cost and walk time is estimated given a range of parking costs and spaces for each analysis area in the central business district. This is the information stored in the CBD parking file.

Since the Monte Carlo simulation is applied using random probabilities to obtain specific values of time and cost rather than average values, the procedure is applied 100 times per zonal interchange in order to minimize variability. The Monte Carlo technique is also used to make the final mode choice estimate. The mode choice model estimates the probability that a trip would be a transit trip. This probability is then used with a Monte Carlo technique to estimate if the trip is a transit trip. For example if the mode choice model estimates that the probability of a trip being a transit trip is 0.25 then when the random number, generated by the Monte Carlo technique was less than 0.26 the trip would be considered a transit trip, otherwise the trip would be considered a highway trip. Since there were more than 21 million person trips in 2010, this results in a very large set of multiple applications.

7 Traffic Assignment

The final step in the four-step model is Traffic Assignment. This is the step that takes the demand matrices (auto person trips) developed by the mode choice model and routes them over the highway network. Prior to actually being assigned over the network, the daily demand matrices are converted from person trips to vehicle trips and are factored into time-of-day demand.

7.1 Special Trip Handling

In addition to auto vehicle trips, several other classes of vehicle trips are included in traffic assignment. These require special data-handling procedures to create the demand matrices.

Commercial Vehicle Trips

CMAP models truck trips for four truck classes: B-plate, light trucks, medium trucks and heavy trucks. B-plate trucks are vans and pickup trucks with performance characteristics similar to passenger cars and carrying “B” license plates. Light trucks are “step vans” and smaller delivery vans which carry weight plates D-J and MD-MJ. Medium trucks are defined as heavy fixed-wheelbase trucks such as concrete mixers, scavenger trucks, double rear axle refrigerator units, etc., and some other lighter weight articulated vehicles carrying weight plates K-T and MK-MT. Finally, heavy trucks comprise the 73,280 and 80,000 pound maximum load vehicles which are tractor-trailer combinations. These carry weight plates of V-Z.

In the past, CMAP used vehicle registration files from the Illinois Secretary of State to develop “base year” trip totals for each of the truck classes. The relationship between registered vehicles and actual trips was always somewhat tenuous but it provided the best available information at the time. CMAP currently uses more robust data to develop the base year trip totals that inform the trip-based model:

- B-Plate trucks: An analysis of b-plate vehicle registrations was conducted for the seven CMAP counties and Grundy County using 2015 data from the Secretary of State. Using the registrations and the total population in these counties, an average rate of b-plate vehicles per person was developed. This rate was applied to the remaining counties in the CMAP modeling area to determine total b-plate vehicles registered within the modeling area, and was factored by ten percent to reflect external b-plates that operate on the roadway network within the modeling area. Finally, an analysis of b-plate vehicles included in the Travel Tracker survey provided the average number of trips made daily. This value multiplied by the number of b-plate vehicles provides an estimate of daily trips for this vehicle class.
- Heavy trucks: Data on heavy truck trips within the CMAP modeling area was purchased from the American Transportation Research Institute (ATRI). This dataset

was analyzed to determine the number of trips heavy vehicles make within the CMAP modeling area and to identify the specific locations they visit.

- Light and Medium trucks: The data purchased from ATRI does not include these truck classes; instead the number of trips for these trucks is derived from vehicle registration data and established relationships in the number of trips for these truck classes relative to heavy trucks. As an extra level of data verification, the reasonableness of these trip values was confirmed by reviewing the results of a truck demand model developed for IDOT to support the Illiana Expressway analysis.

Once the truck trips were developed, they were converted to a year 2000 "base value" to provide a set of trip values consistent across all truck classes. These base values were developed assuming a growth rate of 10 percent per decade, the same growth used to forecast future truck trips. Table 69 presents the base trip totals by vehicle class.

Table 69. Truck Trip Totals by Vehicle Class

Truck Type	Base Year 2000 Total
B-Plate Trucks	2,085,000
Light Trucks	246,500
Medium Trucks	229,500
Heavy Trucks	395,000

Once the total number of trucks per class is determined, the non-heavy truck trips are allocated to production and attraction zones based on development patterns. The measure of development is represented by non-home based trip productions, used because they are most closely related to total development with an emphasis on employment density. The process is a simple allocation of trips to zones based on the zonal share of the total regional development. The distribution of trips is then created based on a trip length distribution of distances ranging from 10 to 13 miles rather than by using congested travel time. This method was validated by applying the regional model and comparing the assigned truck volumes to observed truck counts on the road.

For b-plate trucks the trip length distribution was enhanced using odometer readings collected by the Illinois Environmental Protection Agency as part of the vehicle inspection and maintenance program. These readings were obtained for the seven CMAP counties and Grundy County and specific vehicles were matched to the Secretary of State registration data to isolate b-plate trucks. From the resulting dataset, and distribution of average daily VMT was calculated for b-plates.

In place of non-home based trip productions, the distribution of heavy trucks uses a seed matrix of zonal weights developed from the detail trip data supplied in the ATRI file. Special consideration is given to zones that include facilities likely to be frequented by heavy trucks, including warehouses, distribution centers, intermodal terminals, etc. The ATRI file was also used to develop a trip length distribution for heavy trucks.

- The size and operating characteristics of commercial vehicles require them to be treated differently than automobiles during traffic assignment. Prior to the traffic assignment process, truck vehicle trips are converted to trips measured in vehicle equivalents. The truck vehicle trips are converted using the following factors: B-plate and light trucks equal one vehicle equivalent.
- Medium trucks equal two vehicle equivalents.
- Heavy trucks equal three vehicle equivalents.

Point-of-Entry Trips

Point-of-entry (POE) trips represent four categories of travel: auto travel entering the modeled region on major expressways, heavy truck travel entering the region on major expressways, travel to and from the region's airports, and work trips between Kenosha/ Racine/Walworth counties to greater Milwaukee (discussed under Trip Distribution). POE locations are external zones (numbered 1945 through 1961) and are not modeled in the same way as the rest of the region's travel because there is little knowledge about the traveler, the trip purpose, or the destination. These trips are created based on observed traffic counts at the locations in question and some assumptions about the travel behavior of the trip maker, including an assumption that external travelers are indifferent about the actual length of the trip within the region (i.e., their destination is fixed).

Highway POE base year trip production totals are derived from expressway traffic counts at locations around the region. Airport base year POE trips are based on an analysis of observed enplanements. To create future productions and attractions, the base year number of total trips is factored using the same growth rates as commercial vehicles: 10 percent per decade. The year 2015 POE productions are presented in Table 70.

Table 70. Point-of-Entry Base Year Productions

Truck Type	Base Year 2015 Total
Auto External	255,600
Truck External	109,500
Air Traveler	69,500
Work trips to Milwaukee	31,200

All POE trips (except work trips destined for Milwaukee) are handled at the same time using a gravity model. To begin, an impedance file based on a gamma function was created. To accomplish this, a destination vector of non-work trip attractions plus a weighted number of

POE trips was calculated. Again, this information is used as a measure of development density with an emphasis on employment density. The impedance matrix is proportional to the productions multiplied by the attractions and inversely proportional to the square of the midday travel distance (capped at 60 miles):

$$Impedance = \frac{(.0001 * (POE\ Productions * Destination\ Development))}{(60.max.travel\ distance)^2}$$

The impedance matrix is balanced using the original productions at the origin, and trip attractions apportioned to destinations based on zonal shares of non-work attractions and zonal POE totals as the attractions.

At this point, the balanced trip matrix must be separated into its component pieces to be used within the traffic assignment procedures. Trips with origins at the expressway points-of-entry (zones 1945 – 1961) are extracted to a matrix which is summed with its transpose matrix. This represents the total external expressway daily trip table. Thirty percent of the trips in this daily trip table are apportioned as external truck trips. The remaining 70 percent are allocated to external auto trips. To determine air traveler trips, all trips with origins in the region are extracted to another matrix, which is also summed with its transpose matrix. External truck trips are assumed to be heavy commercial vehicles, thus this demand matrix is factored by three vehicle equivalents prior to the traffic assignment.

7.2 Tolling

Within the traffic assignment procedures, tolling is reflected in the generalized cost of a roadway segment. While all of the user classes perceive the same travel time on a link, they may perceive differing generalized costs. This scheme allows different vehicle classes to be assessed different toll amounts. It also allows for differing toll amounts to be charged to the user classes based on the time of day.

The generalized cost on toll links reflects travel time and a fixed link cost. The fixed link cost is the value of time (for a vehicle, not an individual) multiplied by a perception factor. Table 71 lists the hourly values of time used for each user class. These values were synthesized from two sources: the analysis used to develop comparable values during the development of CMAP's activity-based model and a consultant study conducted for IDOT for the proposed Illiana Expressway.[6]

The generalized cost process converts the value of time into a minutes per dollar value that is multiplied by the toll amount. This straight-forward calculation fails to take into account all of

[6] Parsons Brinckerhoff, "Illiana Corridor Tier II Final Environmental Impact Statement: Appendix C: Toll Sensitivity Analysis" (2013, November), http://nepa.illianacorridor.org/tier_2/tier2_feis.aspx.

the other elements that individuals consider when determining whether the cost of a tolled route is "worth it." User classes may not perceive the cost of paying a toll as 100 percent of the actual amount. Transponder users, for instance, are not paying cash out-of-pocket for each toll and may only "see" the cost when they view a monthly credit card statement (at which point the cost has already been incurred). Additionally, the expected travel time savings from using the tollway may more than offset the perceived cost of the toll. Similarly, commercial vehicle drivers may be reimbursed for toll expenses or their Just-in-Time delivery responsibilities may play a much larger role in routing decisions than tolls. The perception factors in Table 71 are an attempt to quantify these individual decisions and effectively increase the user classes' value of time, thus lowering their minutes per dollar and the effective impedance of tolling. The perception factors were calibrated using vehicle class volumes on tollway facilities. During the traffic assignment process, the auto trip purposes are combined into demand tables and the values of time and perception factors used in the generalized cost calculation reflect the weighted average values based on the number of trips in each user class.

Table 71. Vehicle Value of Time and Perception Factor by User Class

User Class	Hourly Value of Time	Perception Factor
HBW low income (SOV)	$12	9
HBW high income (SOV)	$20	9
HBW low income (HOV2)	$18	9
HBW high income (HOV2)	$30	9
HBW low income (HOV3+)	$27	9
HBW high income (HOV3+)	$45	9
HBO (SOV)	$12	8
HBO (HOV2)	$18	8
HBO (HOV3+)	$27	8
NHB (SOV)	$12	8
NHB (HOV2)	$18	8
NHB (HOV3+)	$27	8
B-Plate truck	$20	2
Light truck	$25	2
Medium truck	$25	2
Heavy truck	$40	2
External auto	$18	3
Air traveler	$30	3

Implementation of this scheme ensures that route choice decisions are sensitive to changes in toll amounts.

7.3 Assignment Time Periods

The principal objective behind multiple time period highway assignments is to develop more accurate estimates of vehicle-miles by different speed ranges and vehicle classes for air quality conformity analyses. Separate assignments estimate highway vehicle-miles and travel speeds for eight time periods during the day:

1. The ten hour late evening-early morning off-peak period (8:00 p.m. to 6:00 a.m.);
2. The shoulder hour preceding the AM peak hour (6:00 to 7:00 a.m.);
3. The AM peak two hours (7:00 to 9:00 a.m.);
4. The shoulder hour following the AM peak period (9:00 to 10:00 a.m);
5. A five hour midday period (10:00 a.m. to 2:00 p.m.);
6. The two hour shoulder period preceding the PM peak period (2:00 to 4:00 p.m.);
7. The PM peak two hours (4:00 to 6:00 p.m.), and;
8. The two hour shoulder period following the PM peak period (6:00 to 8:00 p.m.).

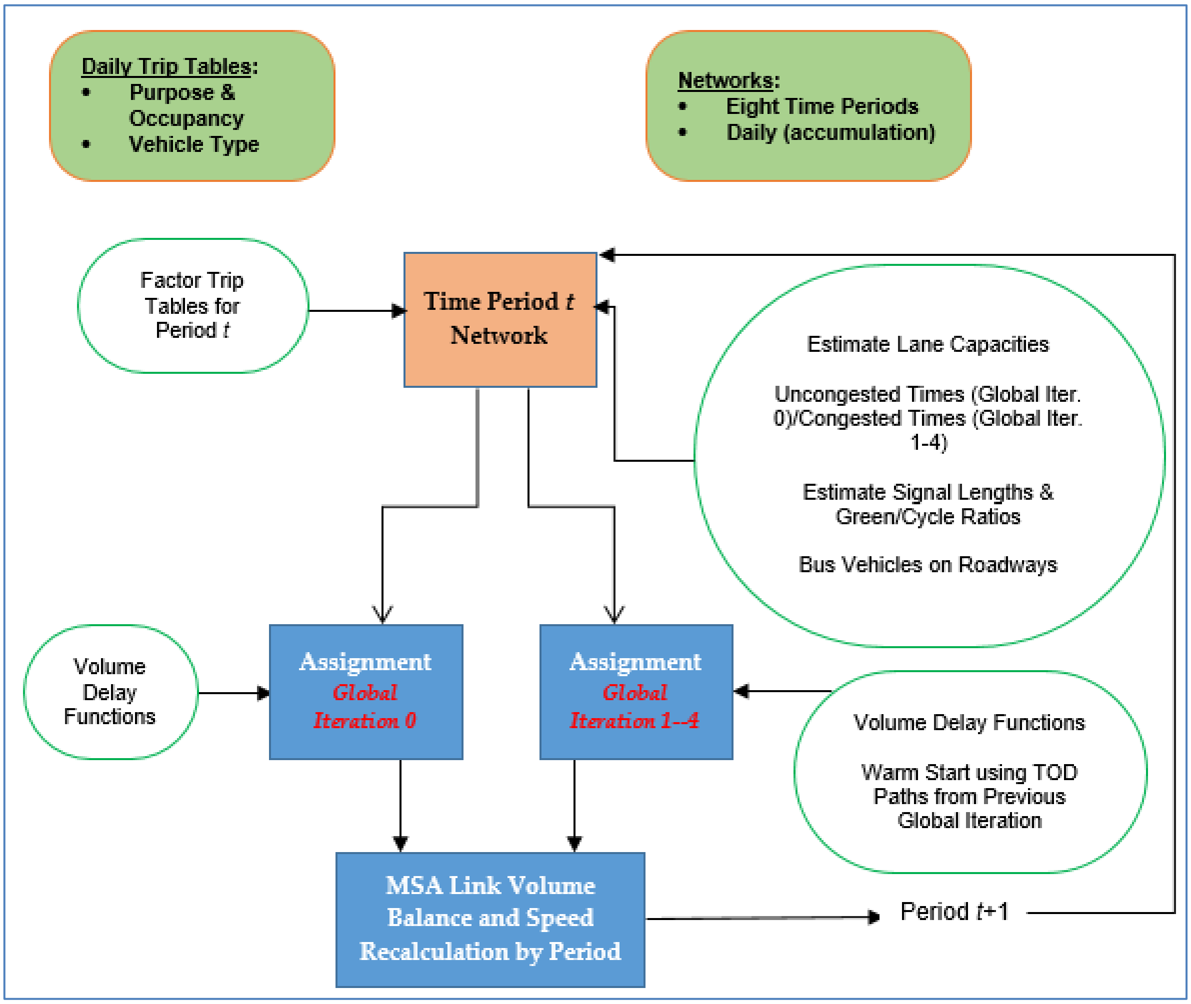
Error! Reference source not found. is a schematic diagram that shows the sequence of steps in the multiple time period assignment. Nine highway network scenarios are first assembled (eight time-of-day specific networks and a ninth all-inclusive network to hold the sum of daily information). The presence of time-of-day restrictions on highway network links allows for variation between the TOD networks. At present, these restrictions are modeled on the Kennedy Expressway reversible lanes and an on-ramp from eastbound IL 38 to eastbound I-290, as well as on arterials with peak period parking restrictions. In practice the eight TOD periods use a total of four unique highway networks:

- An AM peak network used in the morning peak and its shoulders.
- A midday network used during time period 5.
- A PM peak network used in the evening peak and its shoulders.
- An overnight network used in time period 1.

The travel model proceeds through five global iterations. During each iteration the time period assignments are executed and the assignment results are averaged with the results of the TOD assignment for the same time period from the previous global iteration using MSA. This results in a final link volume for each time period; these are used to estimate the AM peak and midday travel times, which are fed back into the rest of the modeling process. The effects of bus operations on other traffic are also accounted for in the assignment process, as buses operating on shared-use facilities are included in the volume-delay function calculations.

After five passes through the time of day modeling process, the results of the separate MSA period assignments are accumulated into daily volumes, and also tabulated into the vehicle-mile by vehicle type by speed range tables needed for the vehicle emission calculations. The completion and summarizing of the eight time period assignments is highly simplified through the use of Emme® macros for repetitive sequences of control statements.

Figure 12. Multiple Time Period Highway Assignment Process



The current assignment macros account for nineteen TOD trip tables: 12 auto driver/passenger tables by trip purpose (HW, HO and NHtrips categorized by three occupancy levels [1, 2, 3+], with HW trips further subdivided by income level), four truck trip tables by vehicle type, two external trip tables for autos and trucks, and a trip table of auto air passenger trips. The assignment macros can be modified to accommodate different trip tables, either additional trip purposes if the trip distribution and mode choice models are revised or to include special trip tables for major developments. The current CMAP practice is to assign the TOD demand as seven different vehicle classes: three auto classes representing the occupancy levels and the four truck classes.

The actual traffic assignment is accomplished using a path-based algorithm in Emme®. This procedure uses the projected gradient method to reach network equilibrium, in place of the commonly-used linear approximation method (Frank-Wolfe algorithm). The path-based assignment is able to reach finer levels of convergence in a shorter amount of time than the standard assignment. Another benefit of the path-based assignment is that the paths generated during the assignment are saved (one for each assigned vehicle class) in files that can be used to conduct detailed analyses after the assignment is finished and are, in fact, a critical component of the toll mode choice procedures.

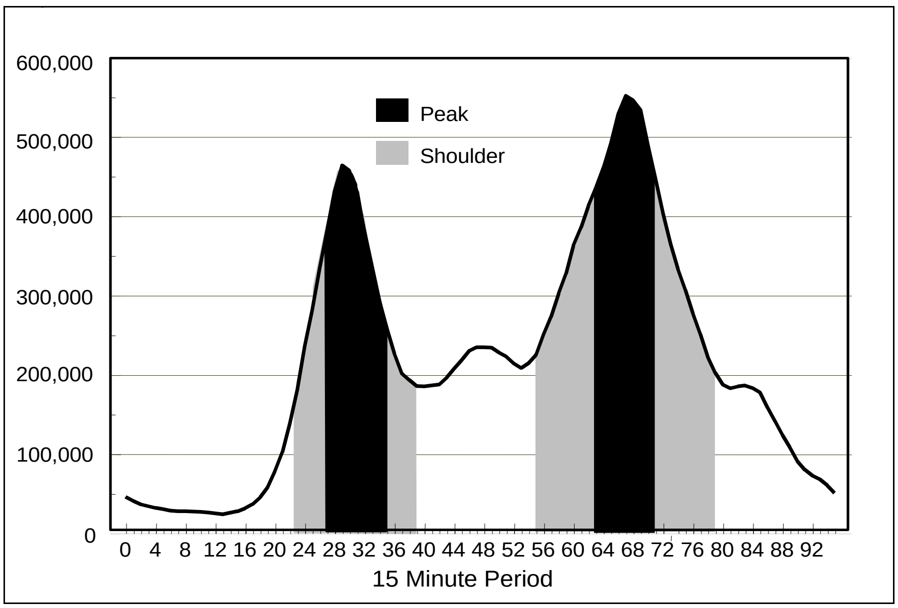
The process begins by calling the macro for the first time period assignment (the overnight period). The appropriate network scenario is selected and the matrices used to store the overnight period trip tables are initialized. The matrices are then filled with the trip tables factored from the daily trip tables. All period trip tables used for assignment are calculated on-the-fly. The slots used for the time period trip tables are reused, being overwritten by the trip tables from a subsequent period.

For the first time period, the standard set of volume-delay functions (discussed in section 7.5) are loaded, the scenario is prepared for assignment, and a full equilibrium assignment is completed. The procedure repeats through the remaining time periods. When the eight time periods are completed, the link volumes and travel times are successively averaged with the same time periods from previous global iterations. This occurs for iterations 1-4, since iteration 0 has no previous iteration to be averaged with. The result is a set of eight modeled scenarios representing each time period and containing the final MSA volumes and speeds. From this information, other macros generate the tables needed as input to the emission calculations. (discussed in Chapter 8).

The logic of the equilibrium assignment process is slightly altered in global iterations 1- 4 of the model. The TOD path files from the previous global iteration are loaded and are used as the starting point for the traffic assignment. This allows the traffic assignment to get a "warm start." The assignment is then readied for additional iterations and the remaining equilibrium assignment iterations are completed.

The travel data that led to selecting the eight time periods is illustrated in Figure 13. This is a plot of the auto driver and auto passenger trips in motion reported in CATS' 1990 household travel survey. Trips were accumulated at the end of 96 fifteen minute periods throughout the day. The plot shows a moving average of these accumulated trips calculated over four consecutive fifteen minute periods. The moving average smooths out the irregularities in the plot that are caused by the tendency of surveyed travelers to report trip start and completion times to the nearest quarter-hour or half-hour. An analysis of the Travel Tracker data confirmed that the eight time periods are still relevant.

Figure 13. Time Distribution of Auto Driver and Passenger Trips



The plot shows the distinct peaking of auto travel during the morning and evening peak periods. The large number of trips in motion during peak travel periods is due not only to increased trip making during these time periods. Peak period auto trips also stay in motion longer because they are more likely to be lengthy work trips subjected to slower congested peak period travel speeds.

The plot in Figure 13 is not symmetric because the evening peak period is longer and slightly worse than the morning peak. The two peak periods are separated by a midday period that has a fairly uniform number of trips in motion, except for a bulge in trip making around the noon lunch period. Trips in motion plateau between 8:00 and 9:00 p.m. after the evening peak period, and then quickly decline during the late-night period.

The two assignment peak periods are defined differently because of these auto travel characteristics. The shading under the Figure 13 curve shows the peak and shoulder periods used in the multiple time period assignments. A two hour AM peak (7:00 to 9:00 a.m.) and two one hour AM peak shoulder periods (6:00 to 7:00 a.m. and 9:00 to 10:00 a.m.) effectively cover the morning peak period. Six hours are needed to capture the evening peak period: a two hour PM peak (4:00 to 6:00 p.m.) plus two hour PM peak shoulder periods on either side of the PM peak (2:00 to 4:00 p.m. and 6:00 to 8:00 p.m.). This leaves a nearly uniform four hour midday period between the two peaks (10:00 a.m. to 2:00 p.m.), and an off-peak period (8:00 p.m. to 6:00 a.m.) covering the late evening and early morning hours.

The time period assignments provide a more detailed and accurate picture of congestion effects in the highway network, which is advantageous for several reasons. While daily estimated traffic volumes may just be marginally improved compared to volumes produced by average daily assignments, estimates of network speeds are substantially improved and regional vehicle-miles of travel agree more closely with state estimates of daily vehicle-miles. Since congestion is more correctly modeled, impacts from proposed highway improvements that reduce congestion are also more accurately reproduced by the time period assignments.

Table 72 provides an illustration of the number of vehicle equivalents assigned during each of the TOD periods. It offers a comparison of the 2015 base year scenario and the 2050 horizon year of the region’s long-range comprehensive plan.

Table 72. Total Vehicle Equivalents Assigned by Time Period, ON TO 2050 Local Area Allocation Analysis

Time Period	2015	2050
1: 8:00 p.m.– 6:00 a.m.	3,414,760	4,351,076
2: 6:00 – 7:00 a.m.	1,069,328	1,354,689
3: 7:00 – 9:00 a.m.	3,129,478	3,963,505
4: 9:00 – 10:00 a.m.	1,221,535	1,560,197
5: 10:00 a.m. – 2:00 p.m.	5,270,487	6,751,992
6: 2:00 – 4:00 p.m.	3,128,825	3,993,464
7: 4:00 – 6:00 p.m.	3,560,882	4,520,592
8: 6:00 – 8:00 p.m.	2,672,644	3,400,906
Total	**23,467,939**	**29,896,421**

7.4 Time-of-Day Factors

The person trip tables prepared by the Mode Choice model require some factoring before they can be assigned to the highway network. After Mode Choice, the home-work and home-other trips are still productions and attractions and not origins and destinations. A set of directional factors (shown in **Error! Reference source not found.**) convert these trip types into origin-destination movements. Time-of-day factors are next applied to convert daily trips into time periods for assignment.

Table 73. Directional Factors

Origin-Destination	Proportion of Productions-Attractions
HBW to CBD (SOV)	0.520
HBW to CBD (HOV)	0.532
HBW from CBD (SOV)	0.480
HBW from CBD (HOV)	0.468
HBW to nonCBD (SOV)	0.529
HBW to nonCBD (HOV)	0.532
HBW from nonCBD (SOV)	0.471
HBW from nonCBD (HOV)	0.468
HBW to airports (SOV)	0.488
HBW to airports (HOV)	0.532
HBW from airports (SOV)	0.512
HBW from airports (HOV)	0.468
HBO to home (SOV)	0.520
HBO to home (HOV)	0.507
HBO from home (SOV)	0.480
HBO from home (HOV)	0.493

Factors to allocate daily auto person trip tables into the eight time period trip tables were derived from the Travel Tracker survey -- the survey is the only source of data that provides information on the time-of-day distribution of auto trips by purpose. Expanded survey auto driver and auto passenger trips were allocated to time periods by their start and completion times. Trips spanning two or more periods are apportioned to the separate periods according to time spent traveling in each period. For example, a survey trip with an expansion factor of 100 that spends 30 percent of its time in one time period and 70 percent of its time in a second period would have 30 trips allocated to the first period and 70 to the second period.

As the Travel Tracker data are a decade old, the auto TOD factors were revised to take advantage of more recent data. As part of recent trip-based model validation analyses, an examination of roadway traffic volumes by time-of-day was conducted relying on observed data from IDOT time-of-day traffic counts and transaction data from the Illinois Tollway. The results showed that the TOD factors derived from Travel Tracker were not entirely consistent with current recorded traffic volumes during the day. As a result the auto TOD factors represent an average of the Travel Tracker TOD factors and the factors developed from the observed data.

TOD factors for the other trips were developed using the following methods:

- Heavy trucks: Time-of-day factors for these vehicles were derived directly from the ATRI truck trip dataset. These same factors are applied to external truck trips.
- Light and Medium trucks: Factors for these vehicles were developed using transaction data from the Illinois Tollway; specifically focusing on Tier 2 and Tier 3 transactions (which correspond to CMAP's light and medium truck categories, respectively). These data were combined with hourly count data of single unit trucks on Cook County arterials provided by IDOT. The final factors represent an averaging of these two data sources.
- All other vehicles: The TOD factors for all other vehicles were developed from the model validation time-of-day traffic analysis.

Error! Reference source not found. lists the factors that create the eight time period trip tables from the daily trip tables. As can be seen, separate factors are applied to work trips with destinations in the Central Area, at the airports and in the remainder of the region.

Table 74. Auto Person Trip Time-of-Day Factors

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
HBW to CBD (SOV)	0.122	0.096	0.318	0.072	0.154	0.081	0.088	0.069
HBW to CBD (HOV)	0.130	0.085	0.310	0.067	0.147	0.081	0.103	0.077
HBW from CBD (SOV)	0.168	0.028	0.069	0.026	0.130	0.119	0.271	0.189
HBW from CBD (HOV)	0.169	0.032	0.067	0.026	0.145	0.177	0.256	0.128
HBW to nonCBD (SOV)	0.124	0.102	0.296	0.064	0.166	0.089	0.094	0.065
HBW to nonCBD (HOV)	0.130	0.085	0.310	0.067	0.147	0.081	0.103	0.077
HBW from nonCBD (SOV)	0.146	0.029	0.073	0.029	0.157	0.168	0.267	0.131
HBW from nonCBD (HOV)	0.169	0.032	0.067	0.026	0.145	0.177	0.256	0.128
HBW to airports (SOV)	0.207	0.086	0.150	0.056	0.193	0.156	0.093	0.059
HBW to airports (HOV)	0.130	0.085	0.310	0.067	0.147	0.081	0.103	0.077
HBW from airports (SOV)	0.248	0.043	0.093	0.035	0.136	0.136	0.189	0.120
HBW from airports (HOV)	0.169	0.032	0.067	0.026	0.145	0.177	0.256	0.128
HBO to home (SOV)	0.169	0.032	0.104	0.044	0.223	0.145	0.156	0.127
HBO to home (HOV)	0.235	0.029	0.070	0.033	0.187	0.139	0.154	0.153

HBO from home (SOV)	0.110	0.041	0.152	0.071	0.240	0.126	0.139	0.121
HBO from home (HOV)	0.115	0.036	0.128	0.057	0.214	0.119	0.169	0.162
NHB (SOV)	0.104	0.031	0.093	0.054	0.322	0.153	0.147	0.096
NHB (HOV)	0.133	0.028	0.080	0.044	0.270	0.151	0.159	0.135
external auto	0.161	0.054	0.129	0.050	0.214	0.132	0.150	0.110
AirPass to airports	0.161	0.054	0.129	0.050	0.214	0.132	0.150	0.110
AirPass from airports	0.161	0.054	0.129	0.050	0.214	0.132	0.150	0.110
B trucks	0.161	0.054	0.129	0.050	0.214	0.132	0.150	0.110
L truck	0.143	0.052	0.142	0.066	0.264	0.147	0.112	0.074
M trucks	0.174	0.049	0.129	0.061	0.251	0.139	0.113	0.084
H trucks	0.216	0.039	0.102	0.059	0.249	0.118	0.092	0.125
external trucks	0.216	0.039	0.102	0.059	0.249	0.118	0.092	0.125

Daily auto driver and auto passenger trip tables (that include auto access to transit trips) are multiplied by the TOD factors in **Error! Reference source not found.** and the directional factors in **Error! Reference source not found.** to obtain auto person trip matrices (driver or passenger) for the eight time periods. They are then divided by the auto occupancies in **Error! Reference source not found.** for rideshares with more than two people to produce the auto vehicle trip tables that are assigned, or by dividing by one or two for drive-alone trips and two-person rideshares, respectively. The occupancy rates were calculated from Travel Tracker by adding auto drivers, auto passengers, and taxi passengers and then dividing the total by auto drivers. As some time periods contained a relatively small number of observations of HOV3+ trips by purpose, and there was not significant variation in occupancy rates throughout the day, a single set of occupancy rates was developed for each trip purpose to apply during all time periods.

Table 75. HOV3+ Auto Occupancy Rates

	All Periods
HBW	3.37
HBO	3.35

NHB	3.45

7.5 Volume-Delay Functions

The volume-delay functions are used to represent the congestion that occurs on links as traffic volumes increase. The volume-delay functions include estimated signal characteristics for links that end at signalized intersections. This means that assignments are sensitive to signal characteristics and can reflect major signal modernization programs. In addition to more accurately representing the characteristics of the network, these signal sensitive volume-delay functions allow the emission reductions from signal improvements to be evaluated.

CMAP's volume-delay functions have also been revised from their initial versions because of the previous functions' limitations when they were used for time period assignments. Their most severe limitation was that freeways and expressways tended to be over-assigned in the congested peak time periods. Several factors contributed to this peak period over-assignment including: (1) an unrealistic initial peak period assignment since paths were built using uncongested travel times; (2) the inability to model bottlenecks in the freeway network that occur during peak periods, and; (3) not restricting freeway on-ramps whose peak period capacities were controlled by metering. The approach taken was to alter the volume-delay functions for freeways, expressway and metered freeway entrance ramps so that travel times increase far more quickly after capacity is reached. The capacities of metered on-ramps are also set to maximum metered flow rates. Note that the link volume included in the volume-delay function calculations includes all assigned auto and truck traffic (in VEQs), as well as buses operating on the roadway links, represented as three vehicle equivalents.

Volume-Delay Functions for Links Ending at Signalized Intersections (vdf1 and vdf3)

Intersection delays in the volume-delay functions are based upon the Webster equation.[7] In this equation, intersection delay has uniform and incremental components, and both are fairly complicated to calculate. For the volume-delay functions, simpler regression equations were fit to calculated uniform and incremental delays for a range of signal cycle lengths and green time to cycle length ratios.

The regression equations for uniform and incremental signal delays are combined with link travel time estimates in the first (arterial) and third (freeway exit ramp to arterial) volume-delay functions as follows:

1. Link travel time between intersections is:

[7] F. V. Webster and B. M. Cobbe. *Traffic Signals*. Road Research Laboratory, Ministry of Transport Road Research, Technical Paper No. 56, 1966.

$$T_{link} = T_0 * \left(1 + 0.15 * \left(\frac{volau}{capacity}\right)^4\right).$$

This is the widely used BPR (Bureau of Public Roads) function where T_{link} equals the link's travel time without any intersection delay and T_0 is the uncongested link travel time without intersection delay. The uncongested link travel time is computed using the maximum speed permitted on the link. Quantity *volau* is the link's traffic volume for the time period in auto equivalents. Capacity represented within the link travel time function is approximately the service volume at level of service C. It is calculated as 75 percent of the level of service E time period link capacity. Note that link capacity is calculated by multiplying the hourly lane capacity by the number of lanes and the number of hours in the assignment time period.

2. Uniform intersection delay equals:

$$D_u = 6.0 * \left(\frac{volau}{capacity}\right) - 0.39 * green + 0.35 * cycle - 4.5.$$

Where D_u is the average uniform intersection delay at the link's j-node in seconds. *Green* is the green time allowed the link at the j-node intersection and *cycle* is the cycle length at the intersection. Both quantities are in seconds. The uniform delay is restricted to positive values in the volume-delay functions.

3. Incremental delay at intersections equals:

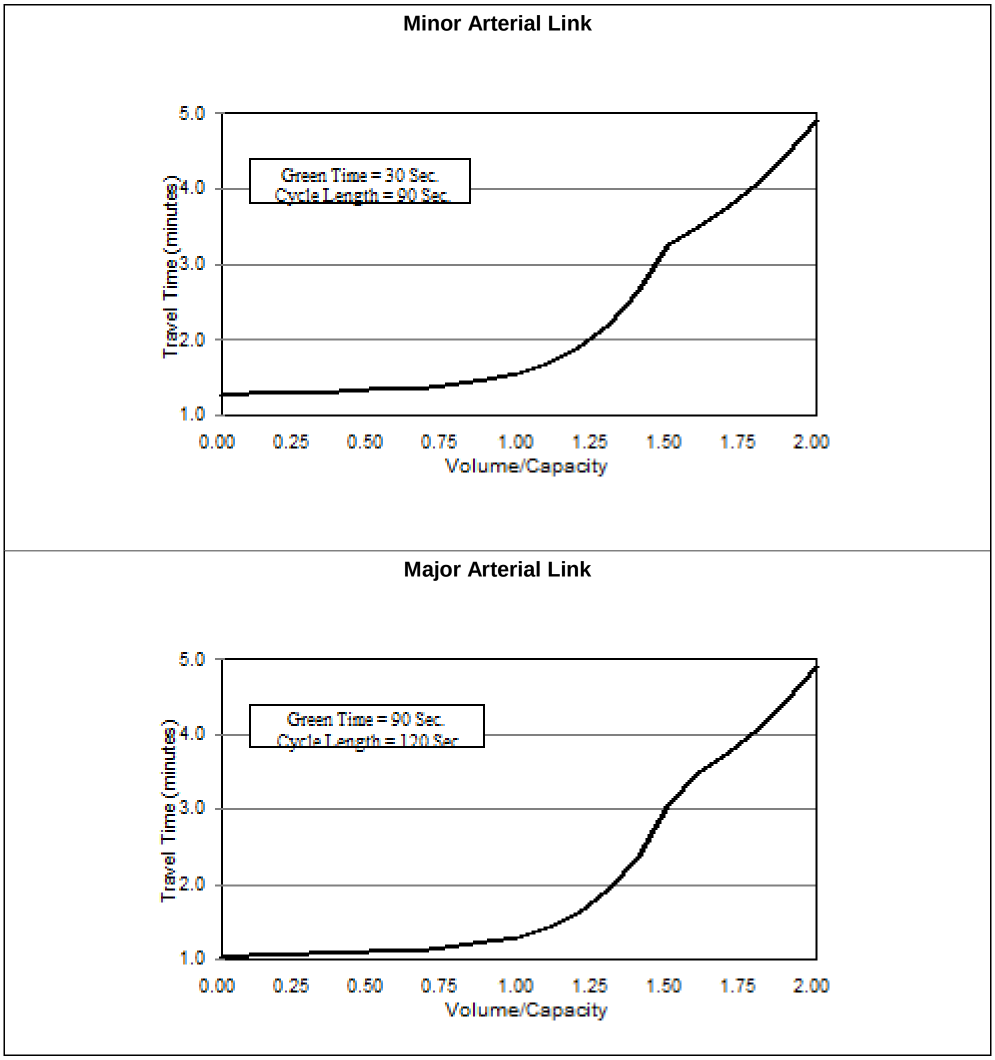
$$D_i = 2.7 * \left(\frac{volau}{capacity}\right)^8 - 7.3 * \left(\frac{green}{cycle}\right) + 3.4.$$

Where D_i is the average incremental intersection delay at the link's j-node in seconds. Incremental delay is also restricted to positive values in the volume-delay functions.

Figure 14 shows the volume-delay functions with intersection delay for two links. The top graph is for a minor arterial street with an uncongested travel time of one minute between intersections. The cycle length at the j-node is ninety seconds, and the link receives thirty seconds of green time in the cycle.

The bottom graph is for a major arterial street link, which also has an uncongested travel time of one minute between intersections. Cycle length at the downstream node is 120 seconds and the link is allowed ninety seconds of green time. The major arterial link is allowed more green time at the j-node than the minor link and intersection delays on the major link are less than on the minor link at the same link volume to capacity ratios. Both volume-delay relationships have a kink in them because the maximum combined uniform and incremental intersection delay is limited to one cycle length.

Figure 14. Example Volume-Delay Functions for Two Arterial Links



Volume-Delay Functions for Freeways and Expressways (vdf2, vdf4 and vdf5)

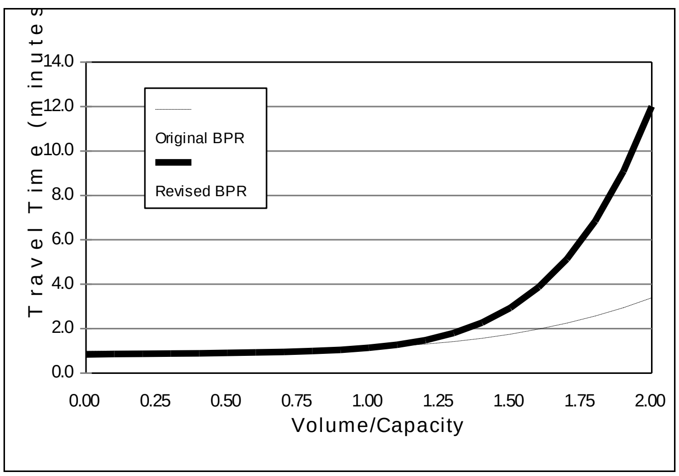
The second (freeway), fourth (expressway) and fifth (freeway-freeway ramps) volume-delay functions were adjusted to increase the travel times for volume to capacity ratios greater than one. At the same time, uncongested link travel times on freeway and expressway links were reduced 15 percent to reflect drivers' tendency to exceed speed limits on high type facilities at low traffic volumes. The quantity T_0 is again determined by the maximum legal speed. These adjustments were made to the basic BPR volume-delay relationship, as follows:

$$T_{link} = \frac{T_0}{1.15} * \left(1 + 0.15*\left(\frac{volau}{capacity}\right)\right) * \left(1 \;+\; 0.15*\left(\frac{volau}{capacity}\right)^8\right), \text{ for } \left(\frac{volau}{capacity}\right) \leq 1.$$

$$T_{link} = T_0 * \left(1 \;+\; 0.15*\left(\frac{volau}{capacity}\right)^8\right), \text{ for } \left(\frac{volau}{capacity}\right) > 1.$$

Figure 15 compares the revised BPR volume-delay function with the original BPR function for a one mile link with a maximum speed of 60 miles per hour. At a volume to capacity ratio of one, both functions predict the same link travel times. At lower volume to capacity ratios, the revised function's travel time is slightly less than the original function due to the lower initial uncongested travel time. For volume to capacity ratios greater than one, the travel time predicted by the revised function is higher and rapidly increases because the volume to capacity ratio is exponentiated to a higher power.

Figure 15. Revised BPR Volume-Delay Function for Freeway/Expressway Links



Volume-Delay Function for Metered Freeway Entrance Ramps (vdf8)

For metered freeway entrance ramps, the original BPR function is revised so that travel time greatly increases when the link volume exceeds the maximum metered flow rate. This effectively restricts the ramp's volume to the metered flow rate. The adjusted BPR function is:

$$T_{link} = T_0 * \left(1 + 0.15*\left(\frac{volau}{metered\ flow}\right)^{10}\right).$$

The maximum metered flow rate is taken as 720 vehicles per hour per lane, or an average vehicle delay at the ramp metering signal of five seconds.

Volume-Delay Function for Links with Tolls (vdf7)

The original toll collection link volume-delay function implemented in the trip-based model decades ago attempted to measure delay at the toll collection facility itself through the generalized cost (time and money) of using the facility. This particular method of reflecting the impact of tolls on individuals' route choice makes little sense today given the state of toll collection technology. The entire system operated by the Illinois Tollway utilizes electronic toll collection technology: mainline plazas require no reduction in operating speed and no-stop tolling is available at ramp tollbooths. Further, the vast majority of toll transactions in the CMAP region use transponders, thus only a small share of tollway drivers even stop at plazas.

The current toll collection link volume-delay function merely reflects the travel time on the link (generally coded as 200 feet long) based on the average speed of the incoming link. These links are of negligible length within the larger overall network, thus no attempt is made to constrain their capacity. The true impact of tolling on route choice is measured through the generalized cost procedures described earlier.

Link Speeds

Traffic volume on every link for each time period of the day is one product of the time-of-day network assignment. The speed of travel for each link is calculated by an equation that uses the volume-capacity ratio for the link as the independent variable. The following equations are used to produce the final link speed.

Freeways:

$$S=S_0 \frac{1}{1+.15\,(V/C)} \times \frac{1}{1+.15\,(V/C)^8} \quad \text{for } V/C \le 1$$

$$S=S_0 \frac{1}{1+.15\,(V/C)^8} \quad \text{for } V/C > 1$$

Arterials:

$$S=S_0 \frac{1}{(1n(S_0) * .249) + .153\,(V/(C * .75))^{3.98}}$$

Where:

S = Speed on link used for emission calculation
S_0 = Initial Speed on link
V/C = Volume-Capacity ratio for the link

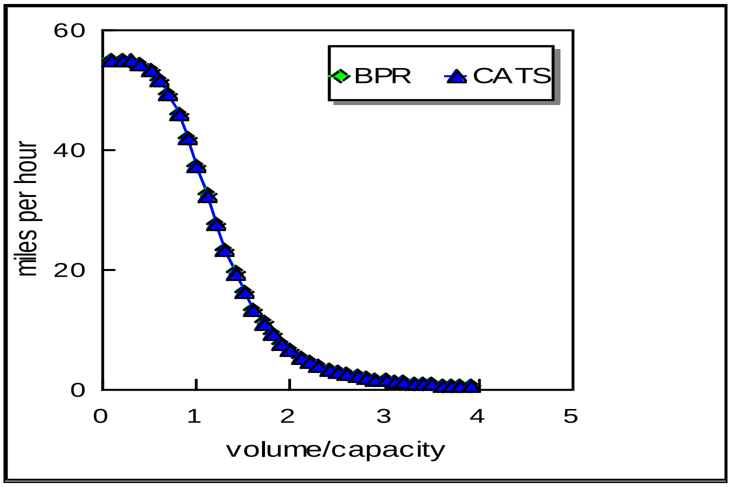
These curves represent modifications to the BPR curves that have been used at CMAP and other agencies for many years. Consistent with a national trend for agencies to use modified curves based on local data, these curves are based on the information gathered from local empirical data. The freeway curve is the same as used in the volume delay functions in the time of day assignment iterations. The arterial curve is slightly modified to better correlate with the empirical data. The data used to develop the modification is from IDOT's traffic sensor system for the expressway system as well as CATS-conducted speed runs for the arterial system. This data base is documented in CATS Working Paper 95-09: Travel Time Database and Structure Chicago Area Expressway System (September 1995), and CATS Working Paper 97-09: 1994, 1995 and 1996 Combined Travel Time Database Documentation: Arterial Highway System (July 1997)[8]. The methodology for the curve development is presented in CATS Working Paper 97-12: Method for Adjusting Modeled Speeds Based on Empirical Speed Data (August 1997).

Figure 16 presents a comparison of the CMAP arterial V/C speed curve and the BPR curve for two initial speeds. As can be seen, the curves are similar for an initial speed of 55 miles per hour. For the initial speed of 30 miles per hour, the curves are similar for V/C ratios above one. For lower V/C ratios, the CMAP curve has higher speeds than the BPR curve consistent with observed data.

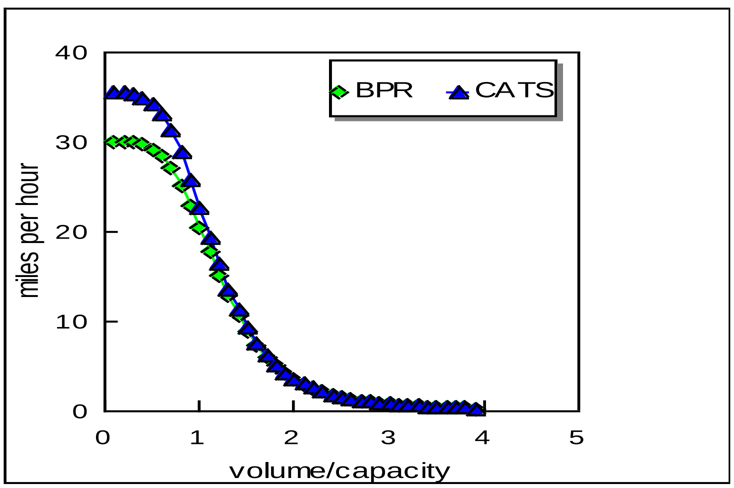
Current traffic assignment validation results can be found in the CMAP Travel Demand Model Validation Report.

[8] Note: All CATS Working papers are available on the CMAP Data Hub.

Figure 16. Comparison of CMAP/CATS Curve to BPR Curve



Initial speed=55 mph



Initial speed=30 mph

8 Emissions Calculation

The conformity analysis consists of a calculation of total emissions for each analysis year required. The current analysis years are given in the main conformity document. The total emissions must be lower than the corresponding approved emission budgets for ozone precursors or for fine particulate matter ($PM_{2.5}$) and its precursor, nitrogen oxides (NO_x). The geographic distribution of emissions within the region is not considered in conformity calculations.

When the travel simulation process is complete, several additional steps need to be taken to calculate scenario emissions. The regional model results must be transformed to be compatible with the MOVES 2014a model's emission rate structure. The MOVES 2014a model must then be run to produce emission rates that match the transportation data available and reflect the region's environmental and vehicular conditions. This chapter explains how the mobile source emission rates are developed and how the total emissions are calculated from the assignment results. The steps completed to compute the scenario network-based mobile source emissions are given below.

8.1 Model Data Processing

Highway networks are built with zone connectors coded to lengths proportional to zone size so connector link volumes represent the amount of "local" travel needed to reach the regional highway system. Thus, this conformity analysis does not have a separate off-network mobile emission component. Mobile source emission estimates based upon the network traffic assignment reflect both specifically coded non-local roadways and local non-coded roadways.

The highway assignment process produces two basic pieces of information essential to calculating emissions: link loads and link speeds. While essential, the information on link loading is not a perfect match for use with the MOVES emission rates. While the assignment model defines vehicles in terms of how much of a roadway's available capacity to carry traffic is used for a given loading, the MOVES model defines vehicles in terms of engine type and size. For assignment, it makes no difference if a vehicle is diesel or gasoline powered, but it does impact the calculation of emission rates. Highway assignment accounts for the different operating characteristics of various vehicle types using the concept of vehicle equivalents[9] (VEQ). In the simplest case a standard passenger auto is one VEQ, while a semi-trailer truck is three VEQs. The truck occupies approximately the same physical space on the roadway as several standard passenger cars and interacts with other traffic in ways akin to multiple standard vehicles. For example, the truck takes more time to reach cruising speed from a stop than an individual standard passenger auto; the amount of time is similar to that needed by

[9] Comparable terms also used are passenger car equivalents (pce) and passenger car units (pcu).

several standard passenger cars to reach cruising speed when driver reaction delay and vehicle spacing are considered. However, the emissions from a large truck and several standard autos are not the same (especially if the truck is diesel powered). During the data processing, the travel model vehicle classes must be converted to the MOVES vehicle classes.

The time-of-day highway assignment process makes use of the modeling software's ability to keep track of multiple vehicle classes (as described in the Traffic Assignment chapter). The travel information of fixed route public transportation buses is also included. Table 76shows the correspondence between the MOVES vehicle types and the travel demand model vehicle classes. It also includes the correspondence with the HPMS (Highway Performance Monitoring System) vehicle types.

Table 76. Correspondence between MOVES and HPMS Vehicle Types

MOVES Vehicle Type & Description	HPMS Vehicle Type & Description	VHT Distribution Source from Travel Model
11: Motorcycle	10: Motorcycles	(use auto distribution)
21: Passenger Car	25: Passenger Cars	autos
31: Passenger Truck	25: Other 2 axle-4 tire vehicles	b-plate trucks
32: Light Commercial Truck	25: Other 2 axle-4 tire vehicles	light duty trucks
41: Intercity Bus	40: Buses	(use transit bus distribution)
42: Transit Bus	40: Buses	transit bus
43: School Bus	40: Buses	(use transit bus distribution)
51: Refuse Truck	50: Single Unit Trucks	(use medium duty trucks under 200 miles distribution)
52: Single Unit Short-haul Truck	50: Single Unit Trucks	medium duty trucks under 200 miles
53: Single Unit Long-haul Truck	50: Single Unit Trucks	medium duty trucks 200+ miles
54: Motor Home	50: Single Unit Trucks	(use medium duty trucks 200+ miles distribution)
61: Combination Short-haul Truck	60: Combination Trucks	heavy duty trucks under 200 miles
62: Combination Long-haul Truck	60: Combination Trucks	heavy duty trucks 200+ miles

Following the completion of a region travel demand model run for an Air Quality Conformity Analysis, the results must be processed and formatted for input into MOVES for emissions calculation. Two scripts are used to first export the relevant information from Emme® and then to process it into the data inputs MOVES requires. In addition to basic network link data (e.g., length and number of lanes), the first script also captures the following information for every link in a scenario network by the TOD highway assignment:

- final loaded speed
- number of autos
- number of b-plate trucks
- number of light trucks
- number of medium truck VEQ
- number of heavy truck VEQ
- number of fixed route public transit buses
- number of long-distance (i.e., traveling at least 200 miles) medium and heavy trucks

After the appropriate data have been extracted from the travel demand model, a second script processes the data for input into MOVES. This script performs a number of functions. First, vehicle equivalents are converted to the actual number of vehicles so that VMT and vehicle hours of travel can be computed for each link in all of the TOD networks. The modeled vehicles are converted into MOVES vehicle categories, as shown in Table 76.

Next, the model network links are converted into the MOVES road types; this correspondence is shown in Table 77. The links are identified based on the volume-delay function they reference. The urban/rural designation is determined by the *areatype* (Capacity zone) value attached to the from-node of each link: a value less than nine is considered urban and a value greater than or equal to nine is rural. Note that "Off-network" in the MOVES model refers to processes that generate emissions but are not associated with being on a road. These include starts, emissions from a parked vehicle, and extended idling by heavy-duty trucks.

Table 77. Correspondence between MOVES Road Types and Model Links

MOVES Road Type & Description	Model Volume-Delay Function
1: Off-Network	N/A
2: Rural Restricted Access	rural 2,3,4,5,7,8
3: Rural Unrestricted Access	rural 1,6
4: Urban Restricted Access	urban 2,3,4,5,7,8
5: Urban Unrestricted Access	urban 1,6

A set of link speed bins is created to store the link data. The lowest bin reflects link speeds under 2.5 miles per hour (MPH). The bins then proceed in 5- mile per hour increments beginning with 2.5<=MPH<7.5 MPH and ending with 67.5<=MPH<72.5. A final bin captures links with speeds of at least 72.5 MPH.

Finally, the vehicle-specific VMT and VHT values are disaggregated from the time period totals into hourly values for each link. The script then produces the following files for use by MOVES:

1. **Average Speed Distribution** – This file contains the share of daily VHT summarized for each vehicle type within each unique combination of [road type – hour of the day – speed bin] category. Within each group of [road type – vehicle type – hour of the day], the values must sum to one. MOVES requires a VHT distribution for all of these categories. If the results of a model run do not provide a distribution for a given category, the following substitutions are made:
    - Bus – when no distribution is available for rural restricted access facilities, the distribution from urban restricted access facilities is used. This applies to vehicle types 41, 42, and 43.
    - Single Unit Long-haul truck – when no distribution is available, the distribution from Single Unit Short-haul truck is used. This applies to vehicle types 53 and 54.
    - Combination Long-haul truck – when no distribution is available, the distribution from Combination Short-haul truck is used. This applies to vehicle type 62.
2. **Road Type Distribution –** This file contains the daily share of VMT for each [vehicle type – road type] combination. Within each vehicle type, the VMT shares must sum to one. The same substitution method described above is implemented if necessary.
3. **Ramp Fraction –** This file reports the share of total freeway VHT that occurs on ramps. This value is reported separately for urban and rural restricted access facilities.
4. **Hourly VMT Fraction –** This file contains the hourly share of daily VMT for each [vehicle type – road type – hour of the day] combination for weekdays. The shares within each [vehicle type – road type] category must sum to one. The Average Speed Distribution substitution method is used if necessary.
5. **HPMS Daily VMT –** This file contains total VMT by road type summarized by HPMS vehicle type.

8.2 MOVES Model Emissions Calculation

This conformity analysis used MOVES 2014a, the current version of the approved US EPA emissions model. The default database is the October 30, 2012 release. Files used to supply the input to calculate the emissions inventory for each of the emissions types (VOC and NOx for ozone, direct $PM_{2.5}$ and NOx for $PM_{2.5}$) are included on the following pages. Descriptions of the input commands and changes for other scenario years are also given.

For ease of execution, one MOVES run was created for each scenario year. The runs developed inventories for both VOC and NOx ozone precursors, for direct PM emissions, and for the NOx precursor for the annual $PM_{2.5}$ standard.

MOVES allows the user to calculate emissions rates, which can be applied to VMT, or to calculate emissions inventories, which can be compared directly to SIP budgets. Since a limited number of "small" MOVES runs are required for conformity, and the calculation of inventories from emissions rates requires detailed VMT, trip and fleet size breakdowns, CMAP has chosen to run MOVES in inventory mode.

MOVES Model Settings Used in Conformity Analysis

This section describes the various inputs used to obtain emission inventories from MOVES for conformity analysis:

- Navigation Panel input
- County Data Manager input

Navigation Panel Input

Each MOVES run requires completion of the Parameters in the Navigation Panel. CMAP has chosen to make a separate run for each analysis year, mainly to keep down the run time required. In addition, separating the years is seen as a way to more readily distinguish the input for each year. The Parameters in the navigation panels and their inputs are listed below. Unless otherwise indicated the parameters are the same for each year.

Description – a narrative description to identify the run; this varies slightly between analysis years to help distinguish them. It has no effect on emissions.

Scale – The county domain is selected, as recommended for conformity analyses. The inventory calculation type is selected.

Time Spans – The Time Aggregation Level is set to hour, as recommended in the guidance. The year is set to the appropriate analysis year. Both weekdays and weekends are selected, as are all months and all hours. These are required for the annual $PM_{2.5}$ emissions inventory; for ozone precursors, only July weekday data are used from the output database.

Geographic Bounds – The Custom Domain region is selected. Although the choice has no effect on emissions calculations, the County ID is set to 1, and the description is "northeastern Illinois nonattainment area." The GPA fraction is zero, in line with the guidance, and the barometric pressure is set to 29.25, which is the average of the barometric pressures in the MOVES database for the six whole Illinois counties in the nonattainment area (Cook, DuPage, Kane, Lake, McHenry, and Will). Both vapor adjust and spill adjust are set to zero. The Domain Input Database is set to the database created in the County Data Manager.

Vehicles/Equipment – All fuel types are selected and all available vehicle types are selected for each fuel type. (Only motorcycles are not available for diesel fuel; only inter-city buses and combination long-haul trucks are not available for gasoline.)

Road Type – all five road types (Off-Network, Rural Restricted Access, Rural Unrestricted Access, Urban Restricted Access, Urban Unrestricted Access) are selected.

Pollutants and Processes – The following pollutants are selected. In most cases subsidiary pollutants are required; they are listed following each pollutant. In all cases, all applicable processes are selected (achieved by selecting the pollutant check box to the left of the pollutant name in the window):

a. Volatile Organic Compounds – Total Gaseous Hydrocarbons and Non-Methane Hydrocarbons
b. Oxides of Nitrogen (NOx) – no subsidiary pollutants are required
c. Primary Exhaust $PM_{2.5}$ – Total – Primary $PM_{2.5}$ – Organic Carbon, Primary $PM_{2.5}$ – Elemental Carbon, Primary $PM_{2.5}$ – Sulfate Particulate (Sulfate Particulate requires Total Energy Consumption)
d. Primary $PM_{2.5}$ – Brakewear Particulate (combined with Primary Exhaust $PM_{2.5}$ and Tirewear to produce total $PM_{2.5}$)
e. Primary $PM_{2.5}$ – Tirewear Particulate (combined with Primary Exhaust $PM_{2.5}$ and Brakewear to produce total $PM_{2.5}$)
f. CO_2 Equivalent – Total Energy Consumption, Atmospheric CO_2, Nitrous Oxide, Methane, Total Gaseous Hydrocarbons

Manage Input Data Sets – No databases are used for input other than the default MOVES database, and the run-specific inputs entered through the County Data Manager.

Strategies

a. On-Road Retrofit – This input is not used
b. Rate of Progress – This setting is not used

Output

a. General Output – Each run's output is sent to a separate database. As noted previously, the emissions for ozone and fine particulates are estimated in one run; thus a conformity analysis consists of four MOVES runs and hence there are four output databases. Mass units are specified as grams, energy as millions of BTU, and distance as miles. The activity output selected is distance traveled and population.
b. Output Emissions Detail – Time is set to hour, and the location is set to county. No vehicle/equipment categories are selected. Among the On Road/Off Road selections, Road Type and Source Use Type are selected.
c. Database – The names follow the convention of tipamendment_yyyymmdd_all_YYYY_out, where yyyymmdd is the date of the Policy Committee consideration, "all" refers to all pollutants, YYYY is the analysis year and "out" means that this is the output file. If other types of analysis are conducted, the "tipamendment" portion of the name is changed appropriately. If only selected pollutants are estimated, then the "all" is changed appropriately.

Advanced Performance Features – These parameters to improve program performance in complex run situations are not used in the conformity analysis.

County Data Manager Inputs

The County Data Manager allows the analyst to include specific data for the geography under consideration and the analysis year in the MOVES dataset. Much of the data comes from the travel demand model.

Database – the input database unique to this MOVES run is created here. CMAP currently creates a separate database for each run. The names follow the convention of tipamendment_yyyymmdd_all_YYYY_in, where yyyymmdd is the date of the Policy Committee consideration, "all" refers to all pollutants, YYYY is the analysis year and "in" means that this is the input file. If other types of analysis are conducted, the "tipamendment" portion of the name is changed appropriately. If only selected pollutants are estimated, then the "all" is changed appropriately. Once the County Data Manager is complete, this database name is selected in the Geographic Bounds section of the Navigation Panel. (The user has to refresh the list of input databases in order to get the newly-created database to appear.)

Ramp Fraction – The fraction of total VMT attributable to expressway ramps is calculated from the results of the travel demand model. Since ramps are represented as links in the network, the total VMT assigned to ramps can be calculated. This computation is done separately for each analysis year.

Road Type Distribution – The fraction of VMT for each vehicle type by road type is calculated from the travel demand model results, based on the classification of each link in the network.

Source Type Population – Data from the Secretary of State's office was examined for suitability in this input. The data yielded inconsistent results, so the default procedure suggested in the Technical Guidance was used. The procedure uses national default values relating vehicles to VMT which are applied to VMT from the travel demand model to estimate populations. The default procedure yielded a motorcycle population that was clearly inconsistent with the region's actual population. Therefore, motorcycle registration data from the Illinois Secretary of State's office was used to create a more realistic estimate.

Vehicle Type VMT

a. Annual VMT by vehicle type is calculated by expanding average weekday VMT resulting from the travel demand model. This takes place in two steps. First, model VMT is summarized by MOVES category vehicle type and facility type. Using vehicle count data from IDOT's monitoring program, average weekday VMT is factored into average daily VMT for all days, including weekends. Again using IDOT monitoring data, daily VMT for each month is adjusted to be a percentage of annual average daily VMT. The annual average daily VMT (based on the travel demand model) is then adjusted to the monthly daily averages and multiplied by the number of days in the month to obtain monthly VMT. The monthly VMT values are summed to yield annual VMT

b. Monthly – Each month's fraction of annual VMT, by vehicle type, is computed using the same data and factors as the annual VMT described previously. However, the monthly VMT values are converted to fractions of the annual total rather than simply being summed.

c. Daily – Since the travel demand model results are for average weekdays only, IDOT traffic monitoring data were used to estimate the weekday vs. weekend VMT fractions. These observed data are limited because they do not include information by vehicle type. Therefore, the weekday and weekend fractions used to create the MOVES inputs are the same for all vehicle types. Finally, off-network (road type 1) data are not part of the IDOT monitoring system, so the Cook County default values were used.

d. Hourly – The travel demand model results support the calculation of VMT by time of day, road type and vehicle type. A post-processing routine was used to generate this input directly from the model results. The same values were used for both weekday and weekend days.

Zone – This input allows a user to define multiple zones within a larger custom domain region. CMAP does not use this feature, and so a single dummy zone is used with all activity allocated to that zone.

a. Zone Data – As noted above, a single dummy zone is used with all activity allocated to that zone.

b. Zone Road Type – As noted above, a single dummy zone is used with all activity allocated to that zone.

I/M Programs – The inspection and maintenance program description was created by staff at the Illinois Environmental Protection Agency, which administers the program. The same basic file is used for each analysis year. They differ in that the last model year of vehicle inspected depends on the analysis year; this parameter thus varies from year to year (increasing with later years).

Age Distribution – The vehicle age distribution is based on data compiled by the Illinois Environmental Protection Agency. The same distribution is used for all scenario years; the input file has a year field, which is set to the applicable analysis year.

Average Speed Distribution – The average speed distribution is developed by post-processing the travel demand model results. The travel demand model produces annual average weekday results, but there are no other sources for weekend speed distributions. Thus, the weekday values from the model were also used for the weekend.

Fuel Type and Technologies – MOVES defaults were used for most vehicles types. However, MOVES has a default percentage of CNG transit buses. Since there are none of these in the CTA and Pace fleets, the values for diesel buses were set to 100 percent.

Fuel

a. Fuel Supply – The types of fuel supplied to the region were supplied by the Illinois Environmental Protection Agency, as used in SIP development. The input is the same for all analysis years, except that the input file has a year in it, which is set to the analysis year.

b. Fuel Formulation – the formulation of the fuels in the region is also supplied by the Illinois Environmental Protection Agency, as used in SIP development. The input is the same for all analysis years.

Meteorology Data – These data are from climate records at O'Hare Airport, as compiled in the MOVES input format by the Illinois Environmental Protection Agency, as used in SIP development. The input is the same for all analysis years.

At the conclusion of a MOVES run, a summary report is generated using the MOVES interface. This summary report produces daily emissions inventories by month and day type (weekday versus weekend). These inventories are then multiplied by the number of weekdays and weekend days in each month to produce the annual $PM_{2.5}$ emissions inventories. For ozone inventories, the summary results for the July weekday are used directly.

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