CMAP

GO TO 2040
UPDATE APPENDIX

Travel Model
Documentation
DRAFT

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1. Overview

The northeastern Illinois region does not attain national ambient air quality standards for certain pollutants. It is classified as a marginal non-attainment area for the 8-hour ozone standard under the Clean Air Act Amendments of 1990, and a non-attainment area for the annual fine particulate matter (PM2.5) standard. Provisions of this act require regional transportation plans and programs to conform to the State Implementation Plan (SIP) for air quality, which sets out how the region will meet emission reduction targets specified by the act.

As part of the transportation planning and programming process, staff at the Chicago Metropolitan Agency for Planning (CMAP) evaluates the impact of proposed transportation activities on the region's air quality. This evaluation, called a conformity analysis, is submitted to the Illinois Environmental Protection Agency and the U.S. Environmental Protection Agency for their review before a long-range Regional Transportation Plan or Transportation Improvement Program (TIP) is approved. The conformity analysis must demonstrate that the emissions resulting from the plan or TIP meet the requirements of (i.e., "conform with") the regulations governing air quality.

The travel demand models, and emission calculations that depend on the models' travel forecasts, are the technical core of the conformity evaluations of the region's TIP and Regional Transportation Plan. The purpose of this report is to document the travel demand modeling process used in the conformity analysis.

CMAP is the official regional planning organization for the northeastern Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will. CMAP developed and now guides the implementation of metropolitan Chicago's first comprehensive regional plan in more than 100 years, GO TO 2040, which was adopted unanimously by leaders from across the seven counties in fall 2010. To address anticipated population growth of more than 2 million new residents, GO TO 2040 is an innovative, policy-based plan that establishes coordinated strategies that help the region's 284 communities address transportation, housing, economic development, open space, the environment, and other quality-of-life issues.

CMAP was created in 2006 by the merger of two long-standing agencies: the Chicago Area Transportation Study (CATS) and the Northeastern Illinois Planning Commission (NIPC). For fifty years, CATS was responsible for regional transportation planning in northeastern Illinois and served as the federally-designated Metropolitan Planning Organization, responsibilities that were transferred to CMAP upon its creation. Concurrently, NIPC was the regional land use planning agency for northeastern Illinois.

Since the early 1990s, CMAP/CATS has been working to enhance the travel demand modeling process used in the air quality conformity analysis of transportation improvement programs and regional transportation plans. Travel demand modeling was first employed to assist in the development of regional transportation plans. The four-step process (trip generation,

distribution, mode split and 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. In the 1970s, in response to concerns about improving public transit, CMAP/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, CMAP/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, 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 document describes the regional travel demand model used by CMAP to generate the inputs required to calculate regional motor vehicle emissions. The regional model is a classical four-step or trip-based travel demand model. CMAP is also aggressively implementing a ten year strategic plan for developing a set of advanced models to address the policy needs of the region, as documented in the CMAP Strategic Plan for Advanced Model Development.

This report documents the current status of CMAP's regional travel demand model. Much of the text in this document is drawn from a predecessor report (Chicago Metropolitan Agency for Planning, 2010) developed for the adoption of the GO TO 2040 plan. Since that time a number of procedural and model coefficient updates have been implemented within the CMAP model. Most of these improvements were developed by a consulting firm under contract with either CMAP or the Illinois Department of Transportation. Where appropriate, the work of the consulting firm is cited within this document.

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, Lake, McHenry, Will, Kendall, 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/land use data to estimate the trip ends for each trip type. 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.

The CMAP procedure to estimate productions consists of several sub-models. One of these models estimates the number of households stratified by adults, workers and children in the household. Another model adds vehicle ownership to the stratification. Vehicle ownership rates are dependent on the composition and income of the household as well as the transportation characteristics of the area in which the household is located. Area characteristics include a measure of the pedestrian friendliness and the availability of transit. Transit availability is based on a modeled mode split estimate for the zone. Consequently trip generation is network dependent. In general, higher transit mode shares decrease vehicle ownership rates, which in turn decrease trip rates. The attraction model uses employment, categorized as retail and total, and the number of total households to estimate the attractions, by purpose, for each analysis zone. The model has a trip rate associated with each type of employment and household, used with the total number of employees and households.

Figure 1. Modeling Process Overview

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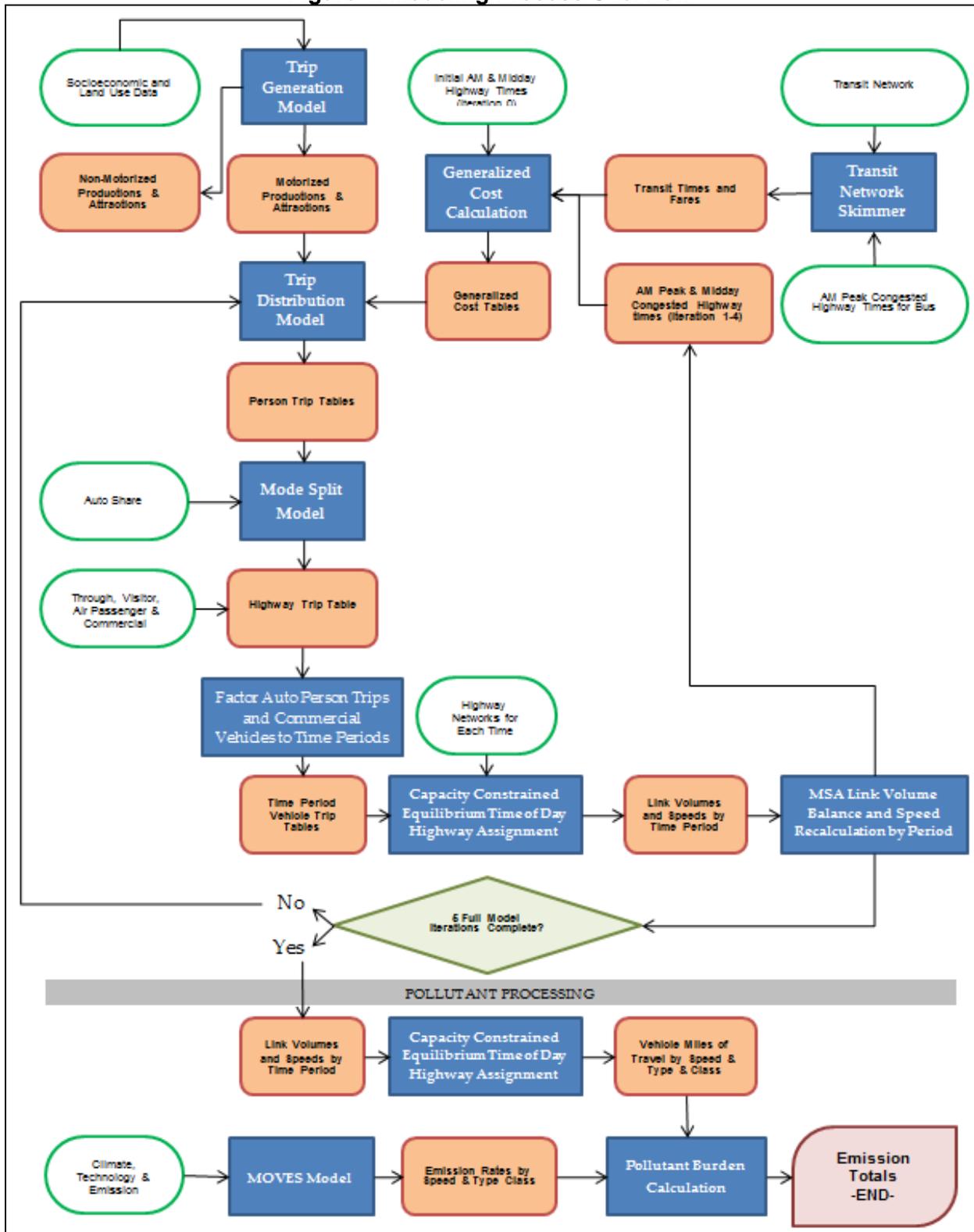
The trip generation model estimates total trips, including both motorized trips such as those made by auto and public transit, and non-motorized trips such as those made by pedestrian and bicycle modes. A model calculates the estimated number of non-motorized trips in an area. Non-motorized trips are subtracted out from the total number of trips generated from an area, and only the motorized trips are carried through the remaining model steps. The regional motorized trip total is therefore sensitive to the allocation of development between areas that differ in their measure of pedestrian and bicycle friendliness.

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 mode choice model is applied once for each person trip resulting from the distribution model. 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 fourth step of the travel demand procedure is the assignment model. The 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 of travel (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.

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 4). AM 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.

The time-of-day 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 also incorporates features such as multiclass traffic assignment. This enables the conformity emissions analysis to reflect link volumes by specific vehicle type, rather than using regional or statewide averages. 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: (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 MOVES (the MOtor Vehicle Emissions Simulator) 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 needs of the regional model.

2.1 Travel Survey Data

CMAP (and before it the Chicago Area Transportation Study) is 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. 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. The original CATS home interview survey was taken in 1956 and consisted of almost 40,000 household interviews.

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.

Most recently, starting in January 2007 and lasting one year, CMAP completed a comprehensive travel and activity survey for northeastern Illinois called the "Travel Tracker Survey." 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)[1]. As a test of available technology, four-hundred and sixty Travel Tracker participants also volunteered to wear global positioning devices (GPS) or to use auto-based devices to track their travel.

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

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[1] 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.

2.2 Socioeconomic Data

Base Year (2010) Data

Socioeconomic data used for trip generation estimates are derived primarily from three sources: 2010 Census Summary File 1 (SF-1), 2008 – 2012 American Community Survey (ACS), and ES-202 data from the Illinois Department of Employment Security. Block-level SF-1 data were summarized to subzones (described in section 2.5) using a block-to-subzone assignment procedure; ACS data were obtained at the split-tract (incorporated vs. unincorporated) level and allocated to subzone.

All data are reported at the subzone level for the entire modeling area. Along with the necessary geographic identifiers, the Socioeconomic file contains the following variables:

- **Number of Households (HH)**
  This is a straight count of Households (*Occupied Housing Units, Table H3*) from 2010 block-level Census counts, summarized to subzones.

- **Average Number of Adults (aged 16 & over) per Household (AHH)**
  Average Number of Children (aged 15 & under) per Household (CHH)
  Census SF-1 data report the number of people per block per age-year up to age 20 (*Table P14*) broken out by sex; however, this table does not distinguish between Household and Group Quarters (GQ) populations. For blocks without a reported GQ population, all age columns between "Under 1 Year" and "15 years" are summed for a total count of children (15 & under); the adult count for these blocks then is the total population minus children.

  For blocks that include a Group Quarters population, the Population in Households (*Table P16*) data were used to get a count of household population aged 18 and up as well as the below-18 population. Assuming adjacent blocks had similar age distribution characteristics, a GIS-based "near" function was used to get the average percentage of the under-18 population in the 12-15 and 16-17 age groups for the five non-GQ census blocks closest to each GQ census block. Those percentages were then applied to the "Under 18 Population in Households" total for GQ blocks to estimate the number of people in households aged 12-15 (needed for **P1215**, below) and 16-17 in those blocks.

  Once age 0-15 and 16+ totals were calculated for each block, they were summarized at the subzone level using block assignment procedures, and applied against subzone Household counts to determine Adults per Household and Children per Household rates.

- **Average Number of Workers per Household (WHH)**
  Developed using the Census' American Community Survey (ACS) split-tract (Summary Level 080) data (*Workers 16 Years and over in Households, B08137.001*), pushing the worker

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count estimate down to each split-tract's component blocks by using the ratio of aforementioned workers to the total population in households aged 16 & over. This ratio was applied to the total count/estimate of persons in households over age 16 at the block level. Workers-per-block estimates were then summarized to subzone using the block assignment procedures.

- **Household Income Index (HHII)**
  This is defined as the *mean income of the subzone* divided by the *regional median income*.
    - o Subzone Mean Income**:** Used tract-level ACS table *Aggregate Household Income in the Past 12 Months* (*Table B19025*), along with ACS household estimate for each tract[2]. Using a tract-to-subzone allocation table, each tract's aggregate income and ACS household total was apportioned to all subzones that the tract participates in (this apportionment is based on 2010 block-level household counts, with the portions going to the corresponding subzone that each block is assigned to). A new, subzone-level aggregate income is created by summing all of the tract-portions assigned to each subzone; this total is divided by the number of apportioned ACS housing units summed to the subzone.

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

    - o Regional Median Income: Since the CMAP modeling area does not conform to a reported Census geography, a regional median was estimated using the sum of split-tract income data presented as a grouped frequency distribution in *Table B19001, Household Income in the Past 12 Months (in 2010 inflation-adjusted dollars)*. 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 & 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).

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[2] Note that two missing tract-level values were replaced by subtracting the known tract values from the parent Township values.

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 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.

- **Percent of Children (aged 15 & under) Between the Ages of 12 and 15 (P1215)**
Generated with the **HH**, **AHH** and **CHH** variables; population aged 12-15 is summed (in non-GQ blocks) or estimated (in GQ blocks) and divided by total population in households aged 0 - 15.

- **Workers Living in Non-Institutionalized Group Quarters (WNIGQ)**
Non-Workers Living in Non-Institutionalized Group Quarters (NWNIGQ)
The WNIGQ/NWNIGQ figures were based on the 2008-12 ACS estimate for Civilian Population Living in Households *(B27015.001)* at the split-tract level. The Civilian Workers in GQ and Civilians in NIGQ were generated by comparing a series of different population totals from the ACS [Armed Forces (*B23001*), Civilians in Households (*B27015*), Civilian Non-Institutionalized Population (*B27001*), Total Population in Households (*B09019*), Total Workers in Households (*B08137*), and Total Workers (*B08101*)]. A ratio between Civilian Workers in GQ and Civilian Workers in NIGQ was then applied to the college/other categories at the block level to develop a civilian employed NIGQ population. Totals were then summarized to subzone.

- **Number of Retail Trade Jobs in Subzone (RETAIL)**
Total Number of Jobs in Subzone (TOTEMP)
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 by

the Bureau of Labor Statistics' (BLS) *Current Employment Statistics* and the Census Bureau's *County Business Patterns* reports.

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/Census control procedures as the Illinois data.

Retail totals are based each businesses' NAICS code. Companies with a two-digit NAICS code of 44 or 45 (Retail Trade) were counted as Retail, with the exception of those businesses with a three-digit NAICS of 454 (Non-Store Retailers).

Forecast Year Data

Most socioeconomic variables for the 2040 horizon originate with the revised Forecast of Population, Households and Employment (see *GO TO 2040 Update Appendix: Socioeconomic Forecast Update Overview*). Households, Population in Households, and Total and Retail Employment were all direct outputs from the forecast model. Household composition was based on existing rates of adults per household, workers were derived from the existing worker-to-adult ratio, and children were based on subtracting adults in households from the total household population. Household Income, Pedestrian Environment Factor, and Private Vehicle Mode Share were based on current (2010) figures.

Horizon-year data for the extra-regional portion of the modeling area were derived from figures provided by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) and Northwestern Indiana Regional Planning Commission (NIRPC). These data were supplemented by the original CMAP 2040 forecast for these areas, as well as household and employment projection data from Woods and Poole.

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).

- *Wisconsin*: three full counties (Kenosha, Racine and Walworth) plus additional minimal roadway network extends into two other counties (Milwaukee and Rock).

The current CMAP Planning Area only includes the Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry and Will, along with Aux Sable Township in Grundy County. In March 2013 the CMAP Board and MPO Policy Committee approved expanding the Planning Area to include the townships of Sandwich and Somonauk in DeKalb County; final approval by the Governor is anticipated by June 1, 2014. The three Indiana counties covered by the MHN represent the planning area for the Northwestern Indiana Regional Planning Commission. Most of the Wisconsin terrain covered by the MHN is within the planning area of the Southeastern Wisconsin Region Planning Commission.

The MHN is a collection of links and nodes that represents roadway segments and intersections throughout the region. It contains information on more than 45,000 directional roadway segments and includes more than 17,500 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 2010, 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
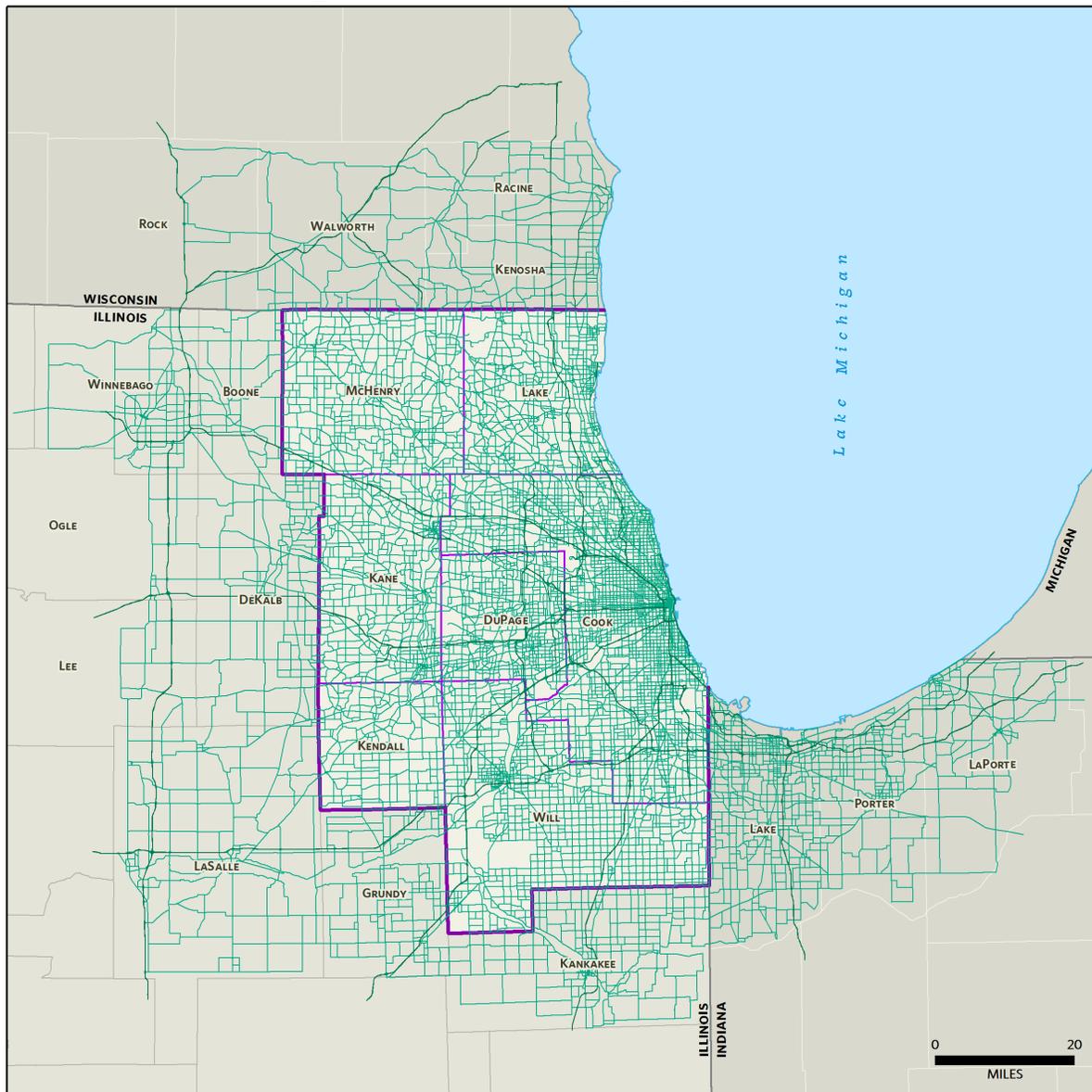
Network Arc-Node Topology

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 in order 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. The exception to this *baselink*=0 rule is if *modes*=4 (transit only): then *thrulanes1* and *type1* are also coded. All other link attributes are fairly straightforward in their definition. Each link in the coverage is identified by a unique anode-bnode-baselink combination (variable *ABB*).

Table 1. Master Highway Network Link Attributes

Variable	Description
ANODE	CMAP "From" node of link.
BNODE	CMAP "To" node of link.
MILES	Link length in miles.
TYPE1 & 2	Facility Type: 1=Arterial 5=Freeway/Freeway Ramp 2=Freeway 6=Centroid Connector 3=Freeway/Arterial Ramp 7=Toll Collection link 4=Expressway 8=Metered Ramp
TOLLDOLLARS	Toll amount in dollars. [This is the I-PASS rate for autos.]
AMPM1 & 2	Time period restrictions: 1=open all time periods 2=open periods 2-5 (Kennedy reversible lanes inbound) 3=open periods 1, 6-8 (Kennedy reversible lanes outbound) 4=open off-peak periods only
SIGIC	Signal interconnect flag: 0=no, 1=yes
POSTEDSPEED1 & 2	Posted speed limit.
THRULANES1 & 2	Number of driving lanes. [This represents the most-restrictive capacity on the link, i.e., the fewest number of lanes present.]
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.
BASELINK	Link description flag: 0=future project link ("skeleton" link); attributes added with project coding 1=existing network link ("base" link); all attributes present,
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=autos only 3=trucks only 4=transit only (only called for transit networks, currently only used for Grant Park busway links)
ABB	Text concatenation of Anode "-" Bnode."-" Baselink.
TRUCKRES	Truck restriction code: 0=no known restriction. 2=no trucks greater than 5 tons. 1=no trucks. 3=no trucks except B plates.

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).
ZONE09	Zone number 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

Standard trip-based modeling software only requires that networks be schematic representations of the roadway system, explicitly defining the length of roadway segments, selected attributes and providing general network connectivity. Advanced modeling techniques such as microsimulation require a more robust network, as roadway geometry enters into the calculus of operational performance. Additionally, the ubiquitous use of GIS software has increased the possibility that the MHN may be viewed as a general data resource for purposes other than travel demand modeling. These factors led CMAP staff to undertake a systemic process of improving the spatial accuracy of intersection locations and incorporating roadway geometry into the MHN, guided by the model network improvement needs identified in the **CMAP Strategic Plan for Advanced Model Development**.

The legacy of travel demand modeling at CMAP (and one of its predecessor agencies, CATS) predates the advent of GIS software. While CMAP has been maintaining the MHN in GIS since the mid-1990s and the network has been greatly expanded and modified over the years, staff resources did not allow for a wholesale update of the network to make it appear more realistic. From mid-2010 through the end of 2012 CMAP staff undertook an effort to update the network. A set of scripts and procedures was developed to automate the network update as much as possible, and to automate quality control review to target specific areas requiring manual review and adjustment. Among the network improvements made were:

- Moving intersection locations to spatially accurate positions.
- Applying vertex coordinates to links in order to replicate roadway geometry.
- Converting expressway interchanges from schematic representations to fully-expanded interchanges including ramps representing all possible traffic movements.

Figure 3 illustrates one interchange in the MHN, both before and after the spatial and geometric updates were applied to the network.

Figure 3. Master Highway Network Geometric Improvement Example

BEFORE   AFTER

I-57 at US-6

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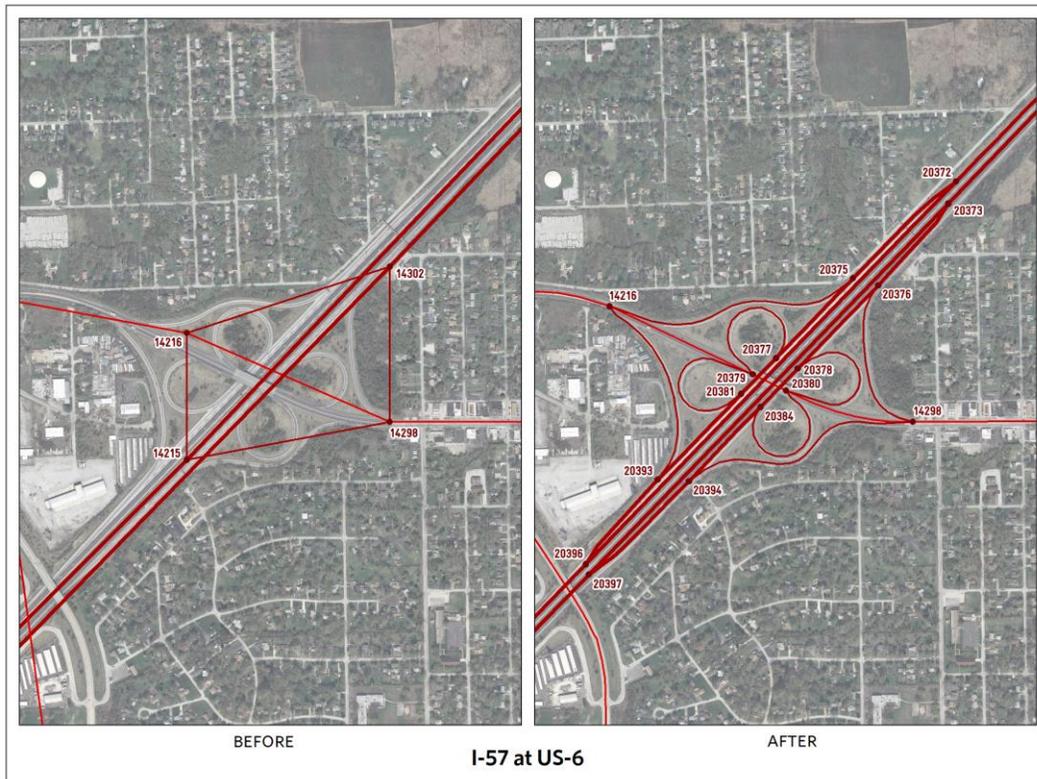
Highway Project Coding

As mentioned, the MHN includes links serving as placeholders for future planned facilities, identified by *baselink*=0. The TIP database is the official and only correct repository of all project information. While only projects which can be modeled are analyzed within the travel demand models, relying solely on the TIP database for project information provides a single direct link for reconciling network coding with the planned improvement.

Highway project coding is stored within a route system in the MHN database. A group of network links is selected to define an individual route (i.e., a specific highway project) within a route system. The route attribute table contains summary information for each project, shown in Table 3. Routes are understood within the database topology through the individual sections which comprise them; sections correspond to the arcs which are referenced by the individual highway project. 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 section attribute table contains one record for every arc referenced by every highway project.

Table 3. Master Highway Network Highway Project Route Attributes

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

The section 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 link attributes in the arc table. As with the arc attribute table, variables ending in "1" apply to the "from-to" direction of the link. During network processing data from the arc attribute table are updated (overwritten) with section table entries to represent conditions after the project is implemented. Only those attributes changing due to project implementation are coded in the section table.

Section table 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

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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 Section Attributes

Variable	Description
TIPID	TIP project identification number.
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 driving lane width.
NEW_THRULANES1 & 2	New number of driving lanes.
NEW_POSTEDSPEED1 & 2	New speed limit.
REP_ANODE REP_BNODE	CMAP nodes of link providing attributes, ONLY for action_code=2.
NEW_TOLLDOLLARS	New toll amount.
NEW_DIRECTIONS	New directions flag.
ADD_PARKLANES1 & 2	Add/remove parking lanes, coded number will be added to number in AAT 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 5=10 AM – 2 PM 2=6 AM – 7 AM 6=2 PM – 4 PM 3=7 AM – 9 AM 7=4 PM – 6 PM 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).

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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 route table. As complete project coding information exists in the section and route tables, a simple mathematical expression is 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.

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 autonomous 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 older suburbs. Pace operates nearly exclusively in the suburbs, with selective 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, but does not include vanpools, paratransit or subscription service.

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	Emme Network – Base Year Scenario
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.	**Step 4.** A future scenario modeling network includes the roadway extension and the new intersection.

Bus route coding is maintained as a separate route system within the MHN. This 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 GTFS-Based Bus Coding
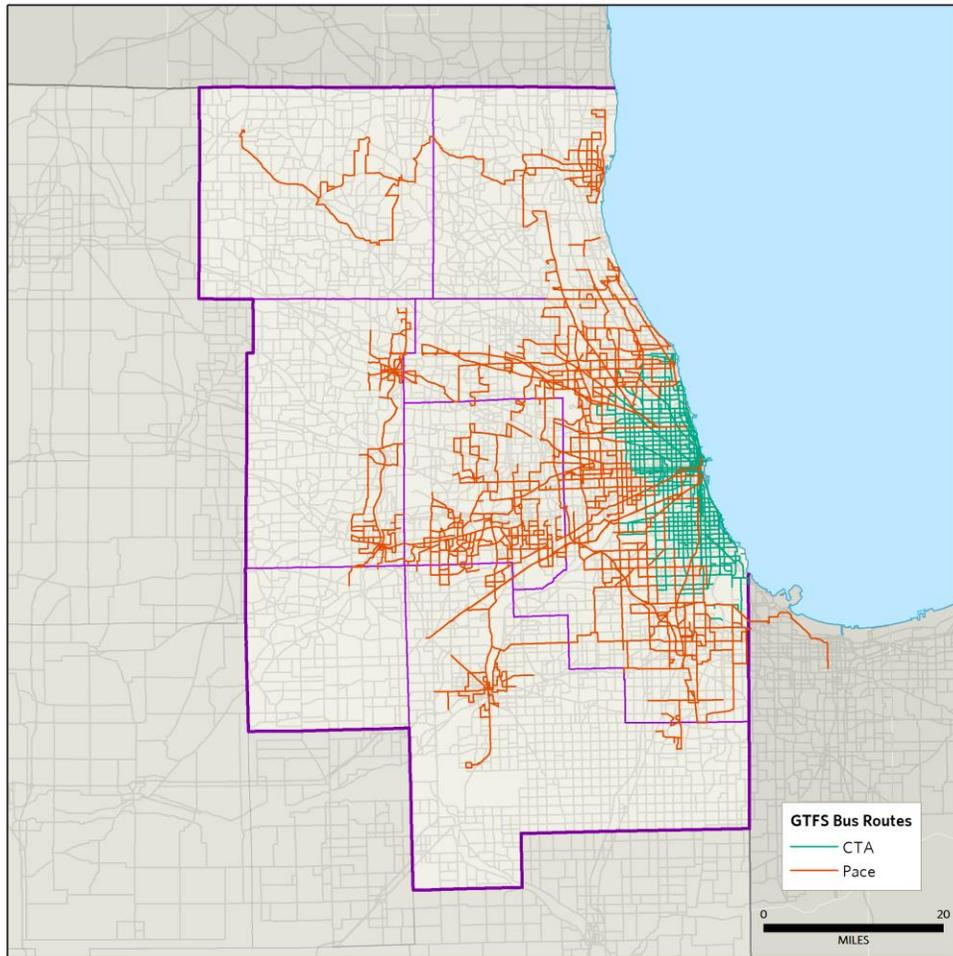
Bus coding in the MHN includes the complete itinerary (or node-by-node path) of the bus route and attributes associated with each itinerary segment. Bus routes are coded as single-direction runs. CMAP bus coding is derived from General Transit Feed Specification (GTFS) data files created by the transit 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.

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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 database.

As with the highway project coding, bus route data are stored in a set of related data tables; these tables relate to the arc table in the same manner as the highway project coding tables. The bus coding route and section 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.

Table 5. Master Highway Network Bus Route Attributes

Variable	Description
TRANSIT_LINE	Unique CMAP bus route identifier (6 characters).
DESCRIPTION	Real-world description of bus route (20 characters maximum – limit imposed by Emme).
MODE	Bus mode code: B=CTA regular service Q=Pace express service E=CTA express service L=Pace local service P=Pace regular service
VEHICLE_TYPE	Bus vehicle type code (based on mode code): 1=mode B 4=mode Q 2=mode E 5=mode L 3=mode P
HEADWAY	Length of the time-of-day period (in minutes) within which the bus run falls.
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 section 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 2010 (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 nearly 26,000 bus runs comprised of more than 700,000 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 Bus Itinerary Attributes

Variable	Description
TRANSIT_LINE	Unique CMAP bus route identifier (6 characters).
ITIN_A	CMAP node number of first node of link bus travels on.
ITIN_B	CMAP node number of second node of link bus travels on.
ABB	Unique ID of the segment's corresponding MHN link.
ITIN_ORDER	Order number of bus segment in itinerary.
LAYOVER	Layover time in minutes applied to itinerary_b. Default=3.

DWELL_CODE	Code for stops (corresponding Emme code), applied to itinerary_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	Departure time at beginning of segment from GTFS data (in seconds).
ARR_TIME	Arrival time at end of segment from GTFS data (in seconds).
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 bus network, the eight individual time-of-day bus networks are used in CMAP's activity-based model.

Table 7. Time-of-Day 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 current bus service, future bus route service is also coded in the MHN to represent future planned or programmed service. Consistent with GTFS bus runs, future bus routes are 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 route 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 (6 characters).
DESCRIPTION	Real-world description of bus route (20 characters maximum – limit imposed by Emme).
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 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 Emme. 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 for Emme:

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.

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. 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.

   c. 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.

d. 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.

e. Last chance headway: a final future headway value if all other options fail; set to 60 minutes for periods 2 and 4, and 90 minutes for all other periods.

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

- *Priority 1*: Use Coded headway for periods 3, 7 and AM if applicable and the value is greater than zero. If that does not apply, go to Priority 2.

- *Priority 2*: For non-peak periods or instances where the coded future headway=0, use Replaced headway. If that does not apply, go to Priority 3.

- *Priority 3*: The future headway is the maximum of [Mode headway, Factored 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.

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 older suburbs. Suburban commuters are served by Metra's radial rail services, which generally carry passengers from suburban areas to the central area. There are, however, 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
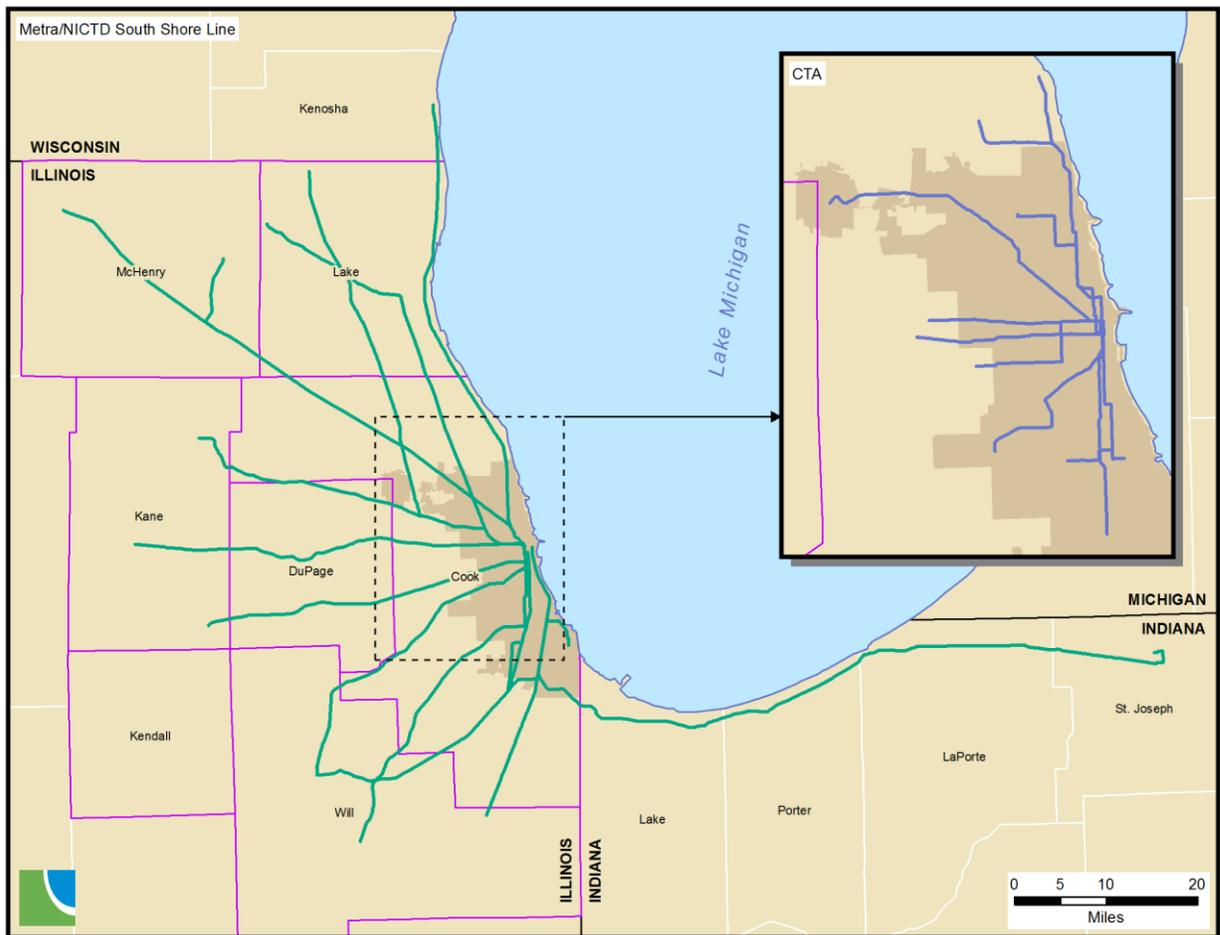
Topology rules within the MRN are enforced programmatically by rebuilding the routes each time the network is updated or new routes are imported using the arc geometry. In addition to being an extremely efficient way to process the data, this procedure also ensures that rail routes will always be coincident 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, which represent the variables required by Emme® in a network batchin file. 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 in Section 2.6.

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	Length of the time-of-day period (in minutes) within which the rail run falls.
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 in Emme®, 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 2010 (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 2,400 rail runs comprised of more than 63,000 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 Emme-required fields as the existing coding, as well as a few additional fields shown in Table 14 below. The *scenario* variable identifies all of the specific modeling scenarios that individual bus 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
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 for Emme®, 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. Each is a set of polygons representing different geographies. 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, IL. The entire CMAP modeling region is comprised of 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
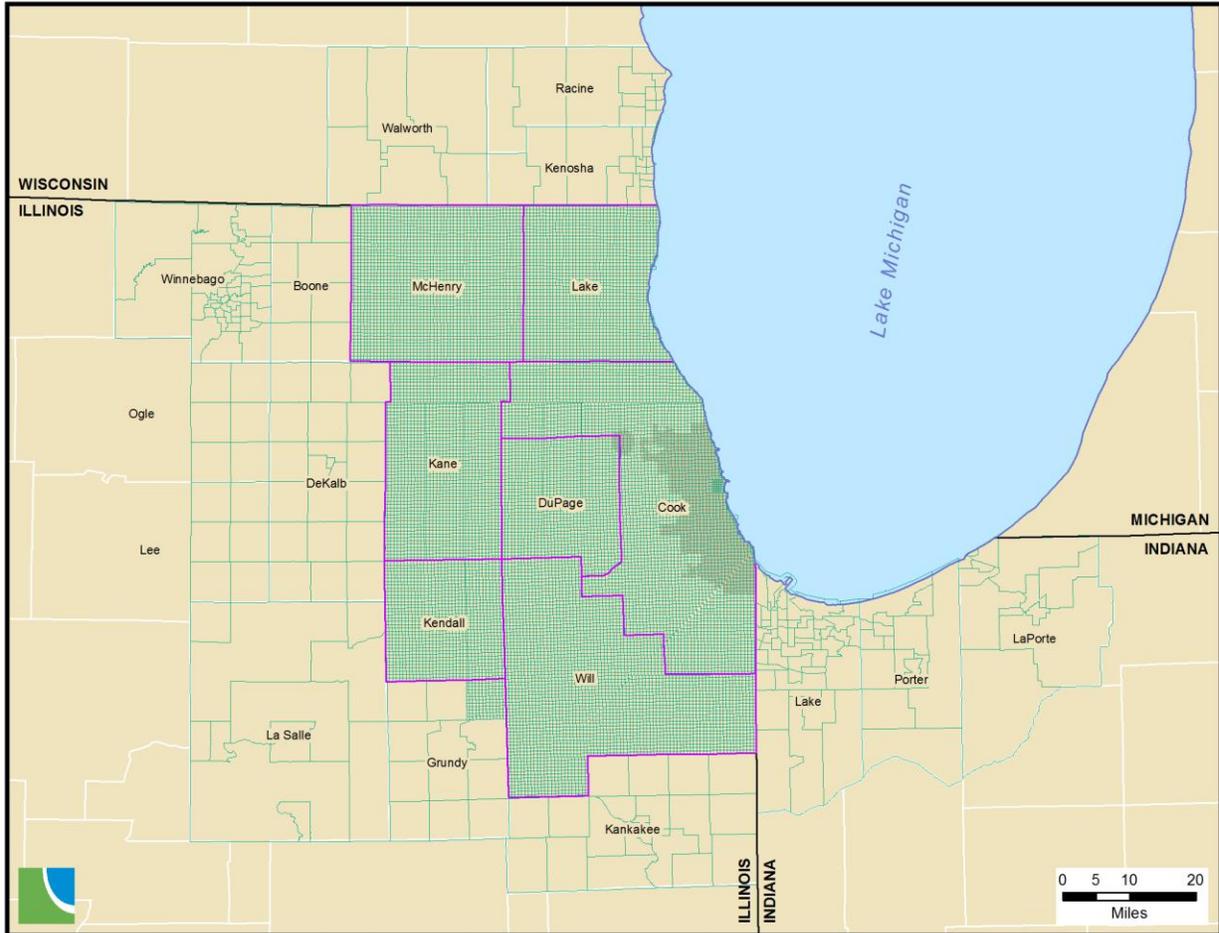
Modeling Zones

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 Highway Assignment).

Figure 8 shows the 1,944 modeling zones (commonly referred to as traffic analysis zones) for the CMAP modeled region. These zones generally follow the survey township geography.

Zones are either sections (approximately one square mile) or regular subdivisions of townships (four-square-mile ninths of townships, nine-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 seventeen 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
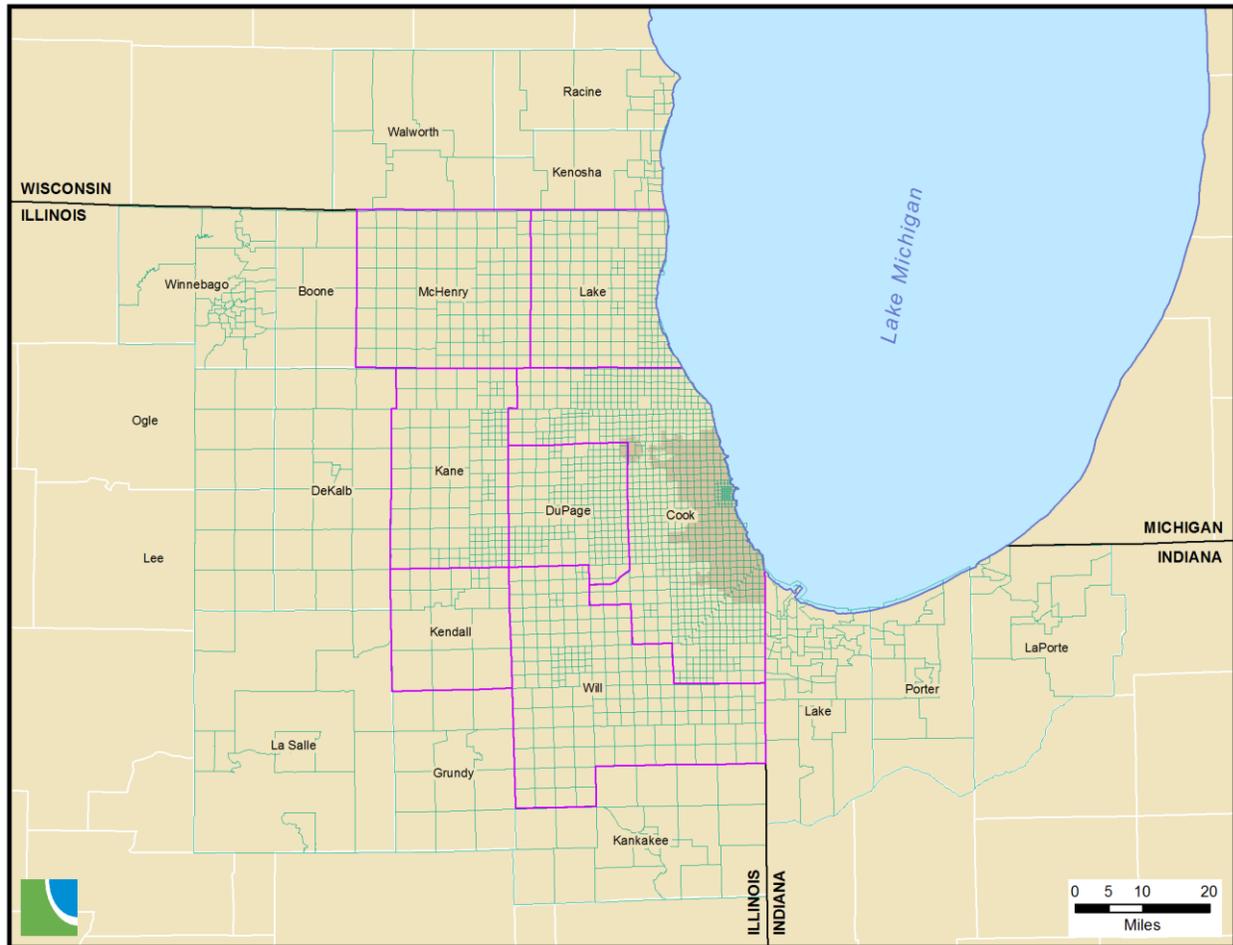
The density of the modeling zones (and by extension the subzones) increases within downtown Chicago. The Chicago Central Business District (CBD) is a pre-GIS convention established by CATS and NIPC based on section boundaries at: Chicago Avenue, Halsted Street and Roosevelt Road. This is represented by 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 section boundaries at: North Avenue, Ashland Avenue and Cermak Road. The Chicago Central Area is shown in Figure 9.

The Central Area is defined by modeling zones 1 through 77. Of the seventy-seven zones, thirty 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
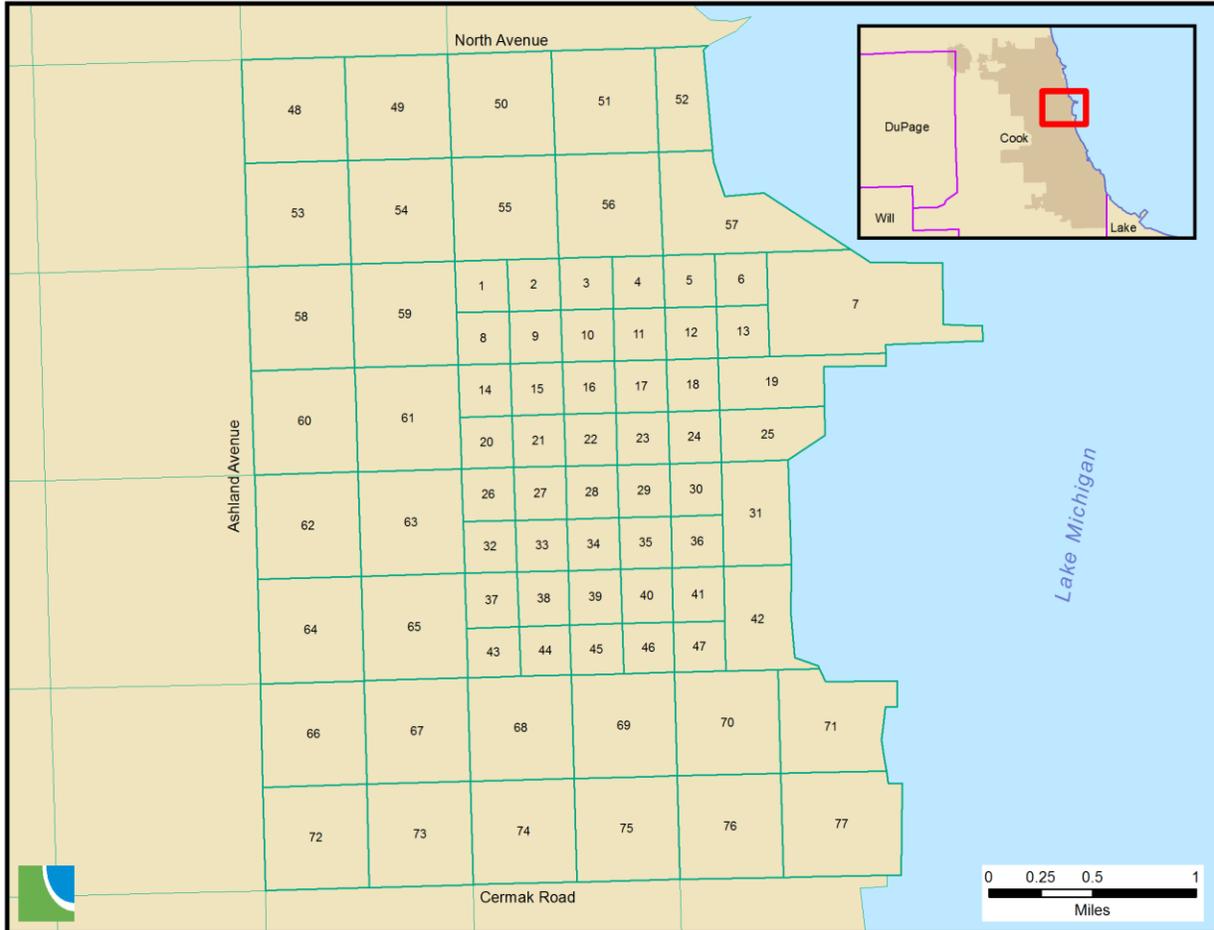
In order to simplify selecting discrete geographic areas, the modeling zones are numbered consecutively by County and Township. The City of Chicago is consecutively numbered starting with the CBD (1-47), the Central Area (48-77), the Transit Hub (78-88) which provides a one-mile buffer around the Central 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
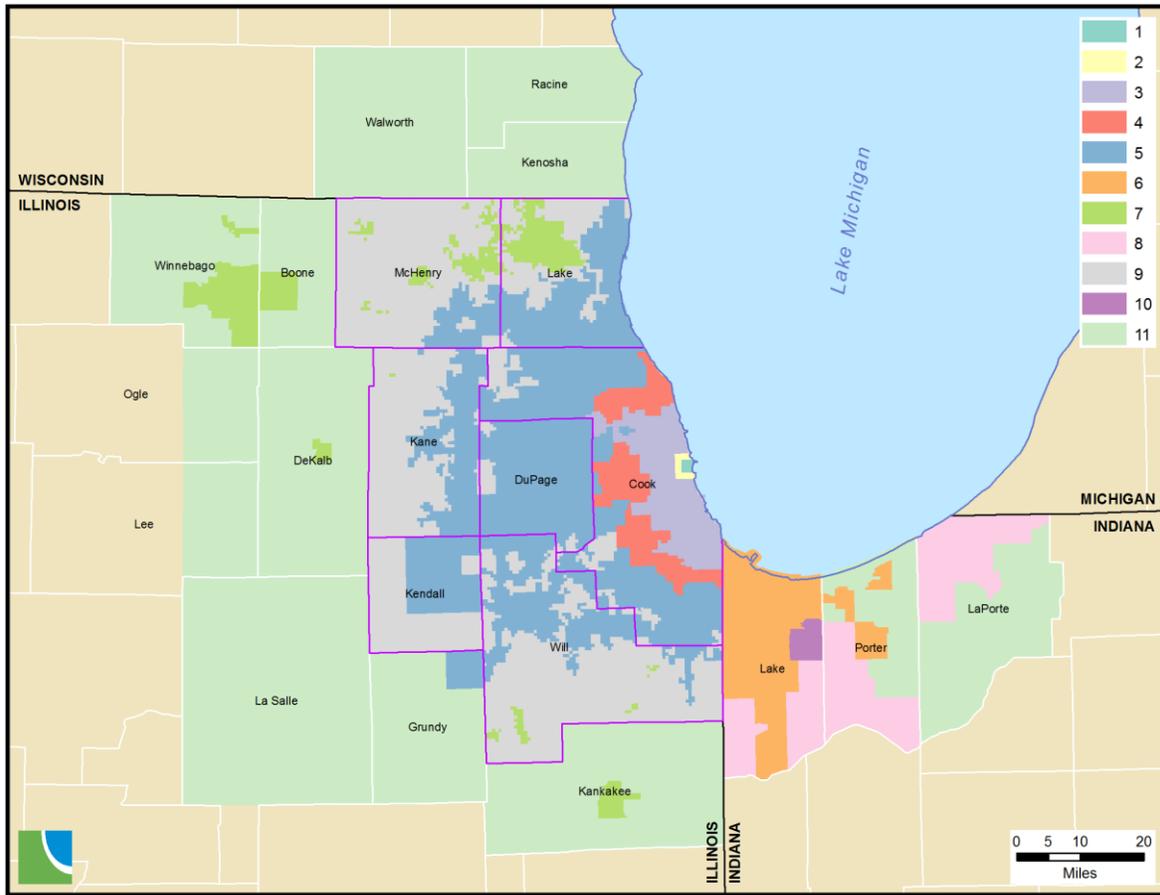
The values of the Capacity Zone system are listed in Table 17 below. Within the travel demand model structure, the Capacity Zone values are stored as a node attribute in the highway network database. Thus the values in the table below correspond to the values of the *areatype* variable in the highway 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 salient 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 Emme® (referred to as "batchin" files) is created which contain the data necessary to define the transportation network.

Highway Network

Separate batchin 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 (time-of-day restrictions, reversal of flow, etc.). Each TOD highway network has a set of four batchin files: two defining link attributes and two defining node attributes. The files contain the standard link and node attributes required by Emme®, as well as extra attributes (denoted by "@") used within the travel demand model. The batchin files are imported into the modeling software to create the TOD highway networks.

Emme® highway network link attributes are shown in Table 18; required attributes are highlighted in blue. Modes on links 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" and "H" allow high occupancy vehicle facilities to be coded in the network. For example, mode "S" would not be coded on HOV links. All links in the network allowing high occupancy vehicles (generally every network link, with the possible exception of truck-only facilities) would have mode "H" coded.

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.		
@tollv	Maximum volume on toll link without tolls.		macros
@ftime	Uncongested link travel time in minutes.		
@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 Emme®, 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 speed limit (or an estimate of the uncongested speed on the link without intersection delay), as well as the number of parking lanes and the average width of driving lanes on the link. For toll collection links, the amount of the toll is also included.

The variable *tollv* is an estimate of the maximum volume that would use a toll collection link if no toll was collected. This value is estimated using the assigned volume from an all-or-nothing assignment without tolls. This variable and the toll amount are used in the toll link volume-delay function. Note that since the introduction of regionwide open-road tolling, the delay associated with toll collection is not currently modeled by CMAP within the traffic assignment procedures. However, the variables associated with tolling are still included in the database for future refinement of the toll volume delay function.

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 generated in Emme®, two macros are submitted to prepare the additional link and node attributes needed for the time period assignments. The first macro (*Ftime.Capacity*) systematically calculates link lane capacities 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. More importantly, the capacities of arterial street links reflect the type of signalized intersection located at the link's j-node (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 a couple of 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, which is used within the volume-delay functions, is later obtained by multiplying this quantity times the number of driving lanes on the link and the length of 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 (@cycle stored as a node variable) 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 later used in the volume-delay functions.

Transit Network

The coded transit network reflects transit service in the morning peak period (7 AM -9 AM). The base year (2010) 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 is comprised of three separate components that must be integrated in order to create complete Emme® transit 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 Master Rail Network (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 also require a system of auxiliary links to provide needed connections. These 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.

Table 20 lists the twelve 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 (which connect transit lines to one another), access (which are at the beginning of a trip and connect a zone centroid to transit service) and egress (which are at the end of a trip and connect transit service to a zone centroid). The rules used to automatically generate these links are based on the discussion provided in Appendix B of the Conformity Analysis Documentation from Conformity 2000. Transfer links are bi-directional while access and egress links (by definition) only serve one direction of travel.

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. 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 that 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 Emme 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 zones 1-78 under the current Zone System (representing an area just slightly larger than Chicago's Central Area), are used as mode "b" links. These links are included in the 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. Only 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

There are three access modes (each connecting a zone centroid to a different type of transit service) and three complementary 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 link (mode "w") running from the centroid to the station, and one link (mode "z") running from the station to the centroid. Some walk access and egress links (modes "v", "w", "y", and "z") are hard-coded to ensure that they are present in scenario networks. The access and egress links are created as follows:

- Modes u and x – 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/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 – 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. A set of "forced" links is created to ensure each CTA rail station is connected to the centroid of the zone it resides in, and a distance of 0.55 miles is assigned to those links if they exceed the distance threshold. All of the "forced" links are put into the final transit network. The remaining access links are ranked by shortest distance and are assigned to centroids until the maximum allowable number (in addition to the forced links) 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 forced set. These auxiliary links are stored in access.network.

- Modes w and z - 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 forced to connect to the centroid of the zone they are contained in,

and a distance of 0.55 miles is given to the link if it exceeds the distance limit. However, 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 by Emme. The final step is importing these files into an Emme databank, where they are combined to create the final transit network.

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

In the conformity analyses, the primary role of transit networks is to generate transit level of service variables which are needed as input to the generalized cost procedure. For each conformity scenario, 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 and quantities are generated using Monte Carlo Simulation techniques (discussed later).

Zone-to-zone minimum impedance paths are built using the time and cost (i.e., fare) 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 that they can be combined with times to create an overall measure of the impedance of a particular path. The transit paths serve as input to the trip distribution and mode split models.

A multi-path transit assignment is run to provide transit impedances for zones that have walk access to a transit station. The current transit network scenario is used to generate zone groups 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 then constructed based

upon the transit services likely to be utilized when moving between these zone groups. For zones with no walk access to a transit station, highway impedances from a complementary highway assignment are used to index the highway centroid to a station zone that minimizes highway and transit impedance to the destination. In this application, a generalized parking cost is calculated to reflect on- and off-street parking availability and cost. Station zones are identified by flagging the walk access centroids within an origin matrix. All cost components are then indexed from the station zone to the highway centroid. The resulting impedances are applied only to zones with no walk access.

The effects of roadway congestion on bus travel times are included in the transit skimming procedures. In the past, the skimmed bus times resulted only from the coded schedule times. Now, the AM peak period congested highway times are included as an extra attribute to the transit scenario. The network is skimmed for the impedance values with the bus travel times calculated as the larger of either the scheduled or congested roadway time for each link traversed. An additional feature allows the schedule time to be retained by coding the 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 that contain information on transit service, park-and-ride availability, CBD parking, and auto operating costs. These files are briefly described in this section.

M01 file

The M01 file is comprised of several arrays of variables that provide the mode choice and distribution models with transit availability and park and ride characteristic parameters regarding a specific zone. 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.

Two formats of the M01 file are created: one for Home-Based Work (HBW) trips and one for the other trip purposes. The differences between the files are listed in the above table. The Pre Distribution and Mode Choice programs expect M01 files that are specific to the program and the trip type, thus the following pre-distribution (PD) and mode choice (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 (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.

Source: Parsons Brinckerhoff, 2011.

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

Source: Parsons Brinckerhoff, 2010

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 that are 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 (Chicago Card or Chicago Card Plus fare).
- Rail transit boarding fare is $2.25 (Chicago Card or Chicago Card Plus fare).

- First transfer is $0.25 (Chicago Card or Chicago Card Plus fare).
- 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 was the source for the per mile costs of auto maintenance and tires (AAA, 2009). Figures on the average gasoline consumption per mile were obtained from an Oak Ridge National Laboratory publication (West et al., 1999). 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.

Table 25. M023 File Auto Operating Costs

| Miles/Hour | Fuel Used Gallon/Mile | Cents per 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

Source: Parsons Brinckerhoff, 2011.

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). All of the M023 data is collapsed into six records, which are shown in Table 26. All of the 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 and substantially elaborated in an undated memo by Gordon Schultz on the subject "1990 Central Business District Parking Costs." 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

Source: Parsons Brinckerhoff, 2011, p. 22.

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 twenty 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.

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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

Income Quintile	Park Free	Transit	Auto Occupancy			
			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. 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.

Over the period 2008-2009, many enhancements to the CMAP Trip Generation models were made. This section outlines the revisions to the CMAP household trip generation model that were completed by Parsons Brinckerhoff during this period. A much more detailed discussion of CMAP's Trip Generation model is provided in the consultant documentation included as Appendix A of this report; part of this document is excerpted below.

3.1 Recent Model Revisions

The most critical change made to the model was to update the existing Trip Generation model to reflect current travel behavior. Both the CMAP and the Northwestern Indiana Regional Planning Commission versions of the Travel Tracker survey of more than 14,000 combined households in northeastern Illinois and northwestern Indiana were used to estimate revised trip generation rates. In addition to re-estimating trip generation rates, there are other parts of the model that were re-estimated and/or recalibrated as well. These include the submodels within trip generation that: (1) create small area estimates of households grouped by their composition and income levels; (2) estimate the vehicles available to a household; (3) forecast trip generation by persons in group quarters; (4) estimate trips with one trip end outside the study area, and; (5) separate person trips into trips by motorized and non-motorized modes.

Updating the submodels required the use of additional data beyond that which is available in Travel Tracker, either because the relevant variables were not collected in the survey or because the sample of households is too small for reasonable statistical reliability of estimated model coefficients. The American Community Survey (ACS) is a continuous survey that annually collects long-form data from a smaller annual sample of households (approximately one in forty households annually compared to one in six households in past decennial censuses) than was collected in the past. Since 2006, the ACS also includes a 2.5 percent sample of persons living in group quarters.

The continuous nature of the ACS means that some trip generation model inputs can be updated more frequently than in the past. This has implications for the trip generation model software code. Observed tables of households required by the procedure to disaggregate households inside small areas were normally hard-coded in the program, along with a handful of other parameters for one or more trip generation submodels. This was a sensible approach when the model was originally programmed because these data and parameters could only be redone at ten year intervals with decennial census data, or even more infrequently, when a

regional household travel survey was completed. This approach also reduced the burden on the user for assembling inputs to apply the model. Updating the Trip Generation model provided an opportunity to minimize this practice, facilitating updates based on more frequent ACS and other data sources.

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.

As stated, CMAP has a ten-year strategy for developing advanced modeling tools. These "state of the art" models focus on individual travel behavior in far more detail than that allowed by the four-step models' limited number of trip types and aggregate trip movements between zones. Updates to the current travel demand models should (whenever practical) complement development of "advanced practice" models at CMAP. With respect to future usefulness of the CMAP Trip Generation model or its submodels, a positive feature of the current model is the disaggregation of households within small areas, which is a component of many "advanced practice" models.

In summary, the update of the Trip Generation model resulted in:

- Revised trip generation rates, input files, parameters, and submodel coefficients based on the CMAP household travel survey and recent ACS person and household data.

- Revised trip generation software with changes included in the model code to improve its flexibility and ease of use.
    o Code revised so that the model can be readily updated as ACS or other new data become available.
    o Code now allows for expansion of the study area or changes in the study area zone system.
    o The code permits more user control over operation of the program to save intermediate datasets.
    o The model's transparency was enhanced by improving model reports and outputs.

- Support CMAP's general model development program. For this updating of the CMAP trip generation model, the model calculations are less aggregate – more trip purposes are considered - so that they more closely resemble the level of detail in "advanced practice" models.

3.2 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 programmed model's code. The main processing steps in the model are briefly summarized:

1. *Read and Load Model Inputs*: These inputs control the operation of the program, define the study area geography, and provide large geographic area tables of cross-classified households that are the basis for the procedure to disaggregate households within small area trip generation subzones.

2. *Disaggregate Households by Subzone*: This step creates a four-way cross-classification table of households for each trip generation subzone from large area household tables and average subzone household characteristics. Households are classified by their number of adults (four categories), their number of workers (five categories), their number of children age fifteen and younger (four categories) and by household income quartile (four categories). This cross-classification results in two hundred twenty-four household categories: note that this is less than the product of multiplying all potential combinations due to the fact that the number of workers cannot exceed the number of adults in a household.

3. *Household Vehicle Availability*: Household vehicle ownership submodels are applied to estimate the vehicle ownership levels for each cell in the four-way household table, effectively adding a fifth dimension (vehicles available in the household) to the table.

4. *Household Trip Generation*: Daily trips per person by trip purpose are generated for the appropriate household members (workers, nonworking adults, and children aged twelve to fifteen). This is done by multiplying each cell of the household table by the trip generation rates appropriate for that individual and household type.

5. *Group Quarters Trip Generation*: Trips for workers and nonworking adults in non-institutionalized group quarters are estimated based on a subzone-level input file that is read by the model.

6. *Allocation of Non-home Trip Ends*: The subzone locations of trip ends that take place away from the household or group quarters are unknown at this point. In this step, a subzone-level file containing employment is first read and then non-home trip ends are allocated to subzones based on households and employment values.

7. *Trip Ends Outside the Study Area*: Some trip ends generated by study area residents are linked to trip ends outside of the CMAP modeling area. These are factored from the total generated person trips, leaving only trips wholly within the modeled study area. A file containing external trip factors is input for this purpose.

8. *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. These pedestrian and cycling person trips are factored from the total generated person trips by submodels that estimate the fraction of non-motorized trips as a function of household and subzone characteristics, leaving only person trips using vehicles.

9. *Create Final Vehicle Trip Reports and Output Trip Files*: This final step of the Trip Generation model is discussed in the next section.

3.3 Model Output

The last step in the Trip Generation model code writes out the trip generation reports and creates an output file for use in the remaining CMAP modeling process. This is a lengthy file that includes a record for each trip generation zone for each trip purpose. The variables included in the output file are listed in Table 29.

Table 29. Trip Generation Model Output File Attributes

Variable	Type	Description
SUBZONE	Integer (I6)	Trip generation subzone (1-25000)
ZONE	Integer (I6)	Modeling zone number (1-5000)
TRIP TYPE	Integer (2)	Trip type code, 1-11 when writing out 11 purposes, or 1-49 when writing out the expanded types
HH PRODS	Real Number (F9.1)	Household trip productions/origins for trips within the modeled study area.
HH ATTRS	Real Number (F9.1)	Household trip attractions/destinations for trips within the modeled study area.

As noted in the table above, there are two options available for the Trip Type code used in the Trip Generation model: the standard eleven trip types recognized by CMAP's travel demand models, or an expanded set of forty-nine trip purposes now available with the current version of the Trip Generation code. The following table (Table 30) shows the correspondence between the two options. The table also identifies the trip purposes that are in "Production-Attraction" format and those that are in "Origin-Destination" format.

CMAP currently writes out the forty-nine purposes and processes the results with a SAS® program to combine the trip purposes and aggregate the trip ends to the modeling zone system used in the remainder of the modeling process. Users of CMAP modeled data will note that the "current trip purpose" trip ends are further aggregated into four purposes for use in the Trip Distribution and Mode Choice models: home-based work low income, home-based work high income, home-based other and non-home based trips.

Table 30. Correspondence between Expanded and Current Trip Purposes

#	Expanded Trip Purposes			#	Current CMAP Trip Purposes	
1	**Worker**	Home (P)	Workplace-Low Income (A)	1	Home (P)	Work (A)
2			Workplace-High Income (A)			
3			Work-Related (A)			
4			School (A)			
5			Nonhome/Work at Residence (A)	3		Nonhome/Work (A)
6			Nonhome/Work Not at Residence (A)			
7			Shop (A)	2		Shop (A)
8		Work (P)	Nonhome/Work at Residence (A)	5	Work (P)	Nonhome/Work (A)
9			Nonhome/Work Not at Residence (A)			
10			Shop (A)	4		Shop (A)
11		Work (O)	Work (D)	6	Work (O)	Work (D)
12		Nonhome/Work at Residence (O)	Nonhome/Work at Residence (D)	7	Nonhome/Work (O)	Nonhome/Work (D)
13			Nonhome/Work Not at Residence (D)			
14			Shop (D)			
15		Nonhome/Work Not at Residence (O)	Nonhome/Work at Residence (D)			
16			Nonhome/Work Not at Residence (D)			
17			Shop (D)			
18		Shop (O)	Nonhome/Work at Residence (D)			
19			Nonhome/Work Not at Residence (D)			
20			Shop (D)			
21	**Nonworking Adult**	Home (P)	School (A)	1	Home (P)	Work (A)
22			Nonhome at Residence (A)	9		Nonhome (A)
23			Nonhome Not at Residence (A)	9		
24			Shop (A)	8		Shop (A)
25		Nonhome at Residence (O)	Nonhome at Residence (D)	10	Nonhome (O)	Nonhome (D)
26			Nonhome Not at Residence (D)			
27			Shop (D)			
28		Nonhome Not at Residence (O)	Nonhome at Residence (D)			
29			Nonhome Not at Residence (D)			
30			Shop (D)			
31		Shop (O)	Nonhome at Residence (D)			
32			Nonhome Not at Residence (D)			
33			Shop (D)			
34	**Child 12-15**	Home (P)	School (A)	11	Home (P)	Nonhome (A)
35			Nonhome at Residence (A)			
36			Nonhome Not at Residence (A)			
37			Shop (A)			
38		School (P)	Nonhome at Residence (A)			
39			Nonhome Not at Residence (A)			
40			Shop (A)			
41		Nonhome at Residence (O)	Nonhome at Residence (D)			
42			Nonhome Not at Residence (D)			
43			Shop (D)			
44		Nonhome Not at Residence (O)	Nonhome at Residence (D)			
45			Nonhome Not at Residence (D)			
46			Shop (D)			
47		Shop (O)	Nonhome at Residence (D)			
48			Nonhome Not at Residence (D)			
49			Shop (D)			

4. 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.

4.1 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 in the air quality conformity TIP and RTP network evaluations. 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 (Parsons Brinckerhoff, 2011, pps. 26-7). 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 MPO 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.

λ, γ = 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 1944 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.

4.2 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 (Parsons Brinckerhoff, 2011, p. 28):

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 31.

Table 31. Trip Distribution Calibration Coefficients

Trip Purpose	Median Cost	Fitted Parameters						
		λ	"t" Statistic	γ	"t" Statistic	$\mu*10^7$	"t" Statistic	R^2
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 , 2011, p29)

More on Trip Distribution model trip lengths can be found in the CMAP Travel Demand Model Validation Report.

4.3 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.

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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 one hundred 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 $5.55 in current dollars. The Pre-Distribution cost coefficients were, therefore, reduced to eighteen percent ($\frac{\$1.00}{\$5.55}$) of their previous levels.

Variables in the generalized cost calculation and their weights are listed in Table 32. 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. Transit bias (which is included in the Mode Choice model) is a constant that does not vary with the ease or difficulty of travel between zones. It is thought that this transit bias, while relevant for mode choice, should not enter into destination choice. 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.

Table 32. 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:

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- 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 2007 ACS median household income for the Chicago Consolidated Metropolitan Statistical Area.

- 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.

4.4 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 (Parsons Brinckerhoff, 2011); 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: $Dist_{Cent-Cor}$ = the x-y distance between the zone centroid and a zone corner.
   $Dist_{Zone-Zone}$ = the x-y distance between the sending and receiving zone centroids.
   $\$_{Auto-Transit}$ = 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. 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 most 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

Note that a "submode" model was recently added to the structure providing an estimate of high occupancy vehicle use for home-based work trips, enhancing CMAP's ability to respond to emerging policy questions.

5.1 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 33 presents the coefficients used in each of the Logit models. As noted in the Pre-Distribution discussion, all cost values have been revised from 1970 dollars to 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 reflect relative cost of transit versus highway mode.

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 33. 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 Emme® 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

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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 34 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 34. 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

5.2 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 35.

Table 35. 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)

Source: Parsons Brinckerhoff, 2011, p. 38

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 Emme® matrices that are used as the input and output tables needed to split auto trips by occupancy level. These are summarized in Table 36.

Some clarification of how the auto sub-mode bias constants are applied is warranted. The auto sub-mode model first splits auto occupants into drive alone and two or more person auto sub-modes. Two added bias constants are needed. HOV_CBDBIAS(2) and HOV_BIAS(2) are costs tacked onto the two or more person auto choice for this auto sub-mode choice. The two or more person auto occupants are then split into two person and three or more person auto sub-modes.

The HOV_CBDBIAS(1) and HOV_BIAS(1) bias constants increase the cost of the three or more person auto alternative at this choice level.

Table 36. 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	
TABLE_SOV_DIST	Highway distance traveled	Emme input matrix numbers
TABLE_HOV_TIME	Highway travel time	
TABLE_HOV_DIST	Highway distance traveled	
TABLE_SOV1	Drive alone auto person trips	
TABLE_HOV2	Two occupant auto person trips	Emme output matrix numbers
TABLE_HOV3	Three or more occupant auto person trips	

Source: Parsons Brinckerhoff 2011, p. 39.

Two CTPP Part 3 (worker flows) tables were used to estimate these auto sub-mode bias constants. The two or more occupant bias constant (drive alone versus two or more occupants) 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.

5.3 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 1000 spaces, is $3.26. But a few "lucky" people (seven and one-half percent) could park for $1.25 and some "unfortunate" people (seventeen and a half 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 seven percent of the "picks" the inexpensive lot would be selected, while the most expensive lot would be selected about eighteen 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 must be applied several times to obtain stable and accurate results. For example, mode choice procedures were applied for each estimated person trip. If the distribution model estimated that 50 trips would be made from zone A to zone B, the mode choice model would be applied 50 times for this interchange, one per trip, and the resulting probabilities would be applied to each of the 50 trips. The Monte Carlo technique was 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 are more than 21 million person trips in 2010, this results in a very large set of multiple applications.

6. 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.

6.1 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.

To create truck trip productions and attractions by modeling zone, base year trip totals were estimated by reviewing vehicle registration files for the appropriate classes of trucks. For future years, the base year figures are factored using a growth rate of 10% per decade to represent natural truck traffic growth. Table 37 presents the base trip totals by vehicle class. In order to more accurately represent heavy commercial vehicle traffic, heavy trips grow at the same 10-year rates as smaller vehicles but an additional factor to increase truck volumes within non-CBD Chicago is also applied.

Table 37. Truck Trip Totals by Vehicle Class

Truck Type	Base Year 2000 Total
B-Plate Trucks	1,530,000
Light Trucks	430,000
Medium Trucks	350,000
Heavy Trucks	109,000

Once the total number of trucks per class is determined, the 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.

The size and operating characteristics of commercial vehicles require them to be treated differently than automobiles. 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 three categories of travel: auto travel entering the modeled region on major expressways, heavy truck travel entering the region on major expressways, and travel to and from the region's airports. 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% per decade. The base year POE productions are presented in Table 38.

Table 38. Point-of-Entry Base Year Productions

Truck Type	Base Year 2010 Total
Auto External	329,000
Truck External	141,000
Air Traveler	67,000

All POE trips 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 seventy 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.

6.2 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 PM – 6 AM);
2. The shoulder hour preceding the AM peak hour (6 AM – 7 AM);
3. The AM peak two hours (7 AM – 9 AM);
4. The shoulder hour following the AM peak period (9 AM – 10 AM);
5. A five hour midday period (10 AM – 2 PM);
6. The two hour shoulder period preceding the PM peak period (2 PM – 4 PM);
7. The PM peak two hours (4 PM – 6 PM), and;
8. The two hour shoulder period following the PM peak period (6 PM – 8 PM).

Figure 11 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 the Method of Successive Averages (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.

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 11. Multiple Time Period Highway Assignment Process

The current assignment macros account for fifteen TOD trip tables: eight auto driver/passenger tables by trip purpose (one each for HO and NH trips, and HW trips categorized by income level and vehicle occupancy [1,2,3+]), 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 six different vehicle 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) and can be used to conduct detailed analyses after the assignment is finished.

The main macro starts the process by calling the macro for the first off-peak time period assignment. The appropriate network scenario is selected and the matrices used to store the off-peak period trip tables are initialized. The matrices are then filled with the off-peak 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 6.4) are loaded, the scenario is prepared for assignment, and a full equilibrium assignment is completed. The logic of the process is slightly altered in subsequent periods. 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 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 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 7).

The travel data that led to selecting the eight time periods is illustrated in Figure 12. 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 ninety-six 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 smoothes 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.

Figure 12. 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 12 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 PM and 9:00 PM 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 12 curve shows the peak and shoulder periods used in the multiple time period assignments. A two hour AM peak (7:00 AM to 9:00 AM) and two one hour AM peak shoulder periods (6:00 AM to 7:00 AM and 9:00 AM to 10:00 AM) effectively cover the morning peak period. Six hours are needed to capture the evening peak period: a two hour PM peak (4:00 PM to 6:00 PM) plus two hour PM peak shoulder periods on either side of the PM peak (2:00 PM to 4:00 PM and 6:00 PM to 8:00 PM). This leaves a nearly uniform four hour midday period between the two peaks (10:00 AM to 2:00 PM), and an off-peak period (8:00 PM to 6:00 AM) 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 39 shows the number of equilibrium assignment iterations by time period for the base year 2010 scenario of a representative Conformity analysis for global iterations zero and four. This table shows that the feedback incorporated into successive global iterations of the travel demand model results in a much more "stable" set of traffic demand assigned during the final global iteration. Note that the traffic assignment iterations of the path-based algorithm are not directly comparable to those used by the linear approximation method. Average path and link times are equal when network equilibrium is achieved.

Table 39. Assignment Iterations for Convergence, Conformity 2014 1st Quarter

	2010 Scenario	
Time Period	Iteration 0	Iteration 4
1: 8 PM – 6 AM	10	4
2: 6 AM – 7 AM	25	10
3: 7 AM – 9 AM	35	15
4: 9 AM – 10 AM	35	10
5: 10 AM – 2 PM	35	10
6: 2 PM – 4 PM	35	10
7: 4 PM – 6 PM	34	10
8: 6 PM – 8 PM	15	5
Total	**224**	**74**

Table 40 provides an illustration of the number of vehicle equivalents assigned during each of the TOD periods. It offers a comparison of the 2010 base year scenario and the 2040 horizon year of the region's long-range comprehensive plan.

Table 40. Total Vehicle Equivalents Assigned by Time Period, Conformity 2014 1st Quarter

Time Period	2010	2040
1: 8 PM – 6 AM	1,690,885	2,155,550
2: 6 AM – 7 AM	751,327	966,689
3: 7 AM – 9 AM	2,086,162	2,668,286
4: 9 AM – 10 AM	880,547	1,112,761
5: 10 AM – 2 PM	4,329,260	5,467,110
6: 2 PM – 4 PM	2,419,151	3,068,696
7: 4 PM – 6 PM	2,634,686	3,352,872
8: 6 PM – 8 PM	1,580,259	1,999,239
Total	**16,372,277**	**20,791,203**

6.3 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. An initial set of directional factors (shown in Table 41) 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 41. Directional Factors

Origin-Destination	Proportion of Productions-Attractions
Home to Work	
CBD Work Trip End	0.498
Non-CBD Work Trip End	0.528
Airport Work Trip End	0.528
Work to Home	
CBD Work Trip End	0.502
Non-CBD Work Trip End	0.472
Airport Work Trip End	0.472
Home to Other	0.489
Other to Home	0.511

Factors to allocate daily auto person trip tables into the eight time period trip tables were derived from the Travel Tracker survey. 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 thirty percent of its time in one time period and seventy percent of its time in a second period would have thirty trips allocated to the first period and seventy to the second period.

Table 42 lists the factors to create the eight time period trip tables from daily auto driver and auto passenger trip tables. Separate factors are applied to work trips with destinations in the Central Area, at the airports and in the remainder of the region. Adding together the home-work and home-other fractions does not total one because the trip tables are in home production and non-home attraction format. The factors sum to the proportion of trips from home and to home. Fractions for non-home/work trips do sum to one, since this trip table is by trip direction.

Table 42. 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	0.147	0.197	0.460	0.053	0.077	0.029	0.022	0.015
HBW from CBD	0.128	0.002	0.010	0.002	0.064	0.138	0.459	0.197
HBW to nonCBD	0.142	0.199	0.408	0.054	0.106	0.042	0.030	0.018
HBW from nonCBD	0.121	0.005	0.015	0.007	0.119	0.252	0.374	0.107
HBW to airports	0.245	0.134	0.258	0.043	0.144	0.139	0.023	0.016
HBW from airports	0.302	0.054	0.040	0.003	0.091	0.222	0.196	0.090
HBO to home	0.188	0.004	0.024	0.030	0.236	0.187	0.167	0.163
HBO from home	0.043	0.039	0.211	0.085	0.246	0.101	0.145	0.129
NHB	0.053	0.008	0.055	0.062	0.431	0.173	0.133	0.084

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Daily auto driver and auto passenger trip tables (that include auto access to transit trips) are multiplied by the factors in Table 42 to obtain auto person trip matrices (driver or passenger) for the eight time periods. They are then divided by the auto occupancies in Table 43 to produce the auto vehicle trip tables that are assigned. The occupancy rates are calculated by adding auto drivers, auto passengers, and taxi passengers and then dividing the total by auto drivers.

Table 43. Auto Occupancy Rates

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
HBW to CBD	1.05	1.17	1.20	1.48	1.27	1.21	1.14	1.12
HBW from CBD	1.24	1.00	1.00	1.00	1.27	1.14	1.18	1.09
HBW to nonCBD	1.08	1.06	1.06	1.06	1.07	1.08	1.14	1.20
HBW from nonCBD	1.15	1.13	1.03	1.01	1.04	1.07	1.06	1.07
HBO to home	1.70	1.23	1.17	1.33	1.49	1.88	1.76	1.74
HBO from home	1.38	1.94	2.33	1.49	1.49	1.52	1.77	1.68
NHB	1.40	1.10	1.13	1.14	1.17	1.18	1.21	1.34

When the mode split model is run to produce auto sub-modes that create auto HW trips by occupancy, more specific directional and time period factors can be specified by the number of persons per vehicle. Table 44 lists the directional factors to be used with these data. These rates were developed from the Travel Tracker survey.

Table 44. Directional Factors: HW Auto Person Trips by Occupancy

Origin-Destination	Proportion of Productions-Attractions
Single Occupant	
Home to Work	
CBD Work Trip End	0.497
Non-CBD Work Trip End	0.526
Work to Home	
CBD Work Trip End	0.503
Non-CBD Work Trip End	0.474
Two Persons Ridesharing	
Home to Work	
CBD Work Trip End	0.504
Non-CBD Work Trip End	0.545
Work to Home	
CBD Work Trip End	0.496
Non-CBD Work Trip End	0.455
Three or More Persons Carpooling	
Home to Work	
CBD Work Trip End	0.524
Non-CBD Work Trip End	0.559
Work to Home	
CBD Work Trip End	0.476

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Non-CBD Work Trip End	0.441

Source: Parsons Brinckerhoff 2011, p. 47

Table 45 contains the time-of-day factors for drive alone, two and three or more persons auto occupancy trips. Since the mode choice model for the auto sub-modes deals only with home-work trips, these factors are calculated for pre-peak, peak, and post-peak periods when most home-work trips take place. These factors are raw figures calculated directly from CMAP survey data, and the effect of the small sample size is evident in the empty cells in the table that have no survey observations. The final quantity needed to develop the three auto trip tables for assignment – single occupant autos, autos with two persons, and autos with three or more persons – is the average vehicle occupancy for three or more person vehicles. This was calculated from the Travel Tracker survey as 3.64 persons per auto.

Table 45. Time-of-Day Factors: HW Auto Person Trips by Occupancy

	Period 2	Period 3	Period 4	Period 6	Period 7	Period 8
Single Occupant						
HBW to CBD	0.204	0.434	0.047	0.030	0.024	0.016
HBW from CBD	0.002	0.012	0.002	0.143	0.448	0.196
HBW to nonCBD	0.201	0.407	0.054	0.042	0.028	0.015
HBW from nonCBD	0.005	0.016	0.008	0.248	0.378	0.109
Two Persons Ridesharing						
HBW to CBD	0.153	0.559	0.094	0.026	0.010	0.010
HBW from CBD				0.130	0.468	0.213
HBW to nonCBD	0.202	0.419	0.045	0.042	0.046	0.019
HBW from nonCBD	0.006	0.011		0.297	0.337	0.101
Three or More Persons Carpooling						
HBW to CBD	0.243	0.757				
HBW from CBD					0.908	0.092
HBW to nonCBD	0.147	0.412	0.096	0.031	0.049	0.126
HBW from nonCBD		0.003		0.232	0.344	0.074

Source: Parsons Brinckerhoff 2011, p. 48

6.4 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 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.

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.[3] 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:

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

   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

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

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 13 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 13. Example Volume-Delay Functions for Two Arterial Links

Minor Arterial Link

Green Time = 30 Sec.
Cycle Length = 90 Sec.

Travel Time (minute) vs Volume/Capacity

Major Arterial Link

Green Time = 90 Sec.
Cycle Length = 120 Sec.

Travel Time (minute) vs Volume/Capacity

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 fifteen 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 14 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 14. 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)

After the volume delay functions were originally developed, the Illinois State Toll Highway Authority implemented electronic tolling along its entire system (completed in 2006). Open road tolling is available at the mainline plazas, and no-stop tolling is available at ramp tollbooths. In 2009, the first all-electronic ramp plaza opened at Eola Road on the Reagan Memorial Tollway (I-88). At most locations, cash booths are available for those without toll transponders. Prices for trucks versus automobiles and for vehicles with transponders and without transponders differ.

The difficulty of representing this complicated scheme led to removing the impact of tolls from the volume delay functions altogether. While the effect of this volume-delay function is currently zeroed out within the trip-based modeling procedures, the volume-delay function itself remains in place as a placeholder for future updates. The impact of tolling and larger operational schemes such as congestion pricing is more suited to testing using CMAP's activity-based model.

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:

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

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

Arterials:

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

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). 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 15 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.

Figure 15. Comparison of CMAP/CATS Curve to BPR Curve
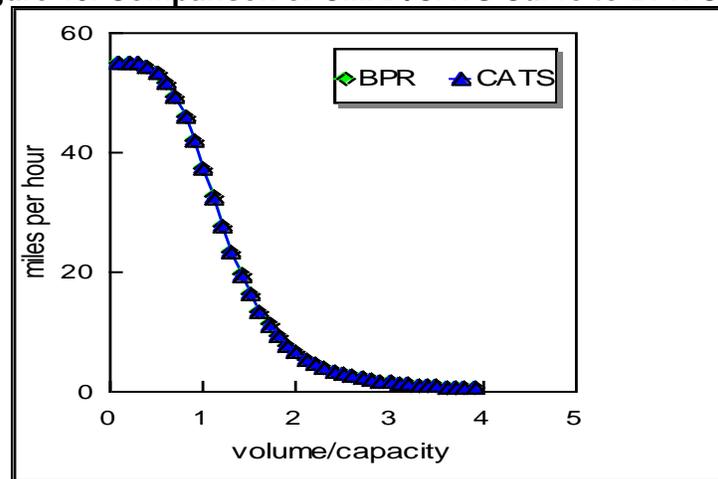
initial speed=55 mph
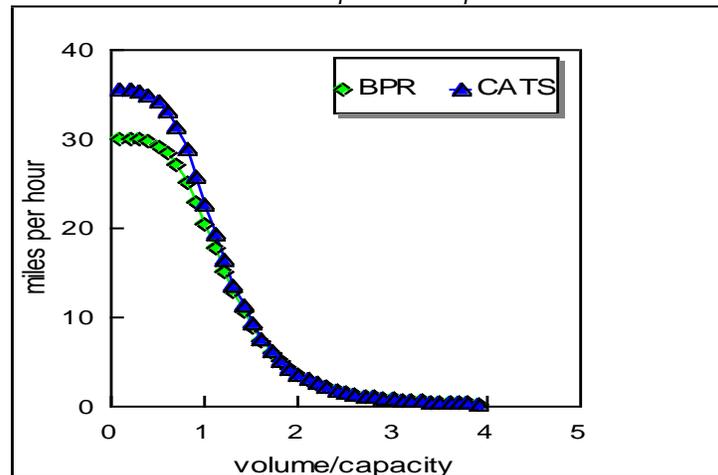
initial speed=30 mph

7. 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 (NOx). 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 model's emission rate structure. The MOVES 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.

7.1 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[4] (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 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

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

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 additional options assignment procedure 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 46 shows 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 46. 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	20: Passenger Cars	autos
31: Passenger Truck	30: Other 2 axle-4 tire vehicles	b-plate trucks
32: Light Commercial Truck	30: 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 vehicle miles of travel 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 46.

Next, the model network links are converted into the MOVES road types; this correspondence is shown in Table 47. 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 47. 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:

   o 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.

   o 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.

7.2 MOVES Model Emissions Calculation

This conformity analysis used MOVES2010b, 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 – Since there is no expectation that fuel types other than diesel and gasoline will constitute a significant fraction of the region's fleet over the years of the analysis, only those two fuel types are selected. 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 (give citation), 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 only activity output selected is distance traveled.

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 is 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 – 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.

c. SCC Road Type Distribution – 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 2013 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%.

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.

References

AAA. (2009). *Your Driving Costs: 2009 Edition*. Accessed at
http://www.aaaexchange.com/Assets/Files/200948913570.DrivingCosts2009.pdf, 2009.

Chicago Metropolitan Agency for Planning. (2010, October). *Travel Model Documentation Final Report.* Chicago: Chicago Metropolitan Agency for Planning.

Parsons Brinckerhoff. (2009, March 26). *Updates and Enhancements to the CMAP Household Trip Generation Model: April 2009*. Prepared for Chicago Metropolitan Agency for Planning. Unpublished Draft.

Parsons Brinckerhoff. (2010, July). *Technical Memorandum: I-290 Preliminary Engineering and Environmental (Phase 1) Study – West of Mannheim Road to East of Cicero Avenue: I-290 Travel Model Assumptions Methodology and Validation*. Prepared for Illinois Department of Transportation.

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

West, B.H., R.N. McGill, J.W. Hodgson, S.S. Sluder and D.E. Smith. (1999, March). *Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models*. Oak Ridge National Laboratory: Prepared for Federal Highway Administration, U.S. Department of Transportation.

APPENDIX A

Parsons Brinckerhoff Documentation of CMAP Trip Generation Model Update

UPDATES AND ENHANCEMENTS TO THE CMAP
HOUSEHOLD TRIP GENERATION MODEL: APRIL 2009

This report documents the revisions to the Chicago Metropolitan Agency for Planning (CMAP) household trip generation model that were completed by Parsons Brinckerhoff during the period October 2008 through March 2009. It is a narrative of the development process for the updates and enhancements that have been introduced into the CMAP model, and provides guidance for users of the model, both for running the model software and preparing the input files required to apply the model.

Background

Trip generation is the first model in a well-established set of sequential travel forecasting models employed by most Metropolitan Planning Organizations (MPOs). The first generation of these models was developed in the late 1950s and early 1960s for metropolitan transportation studies of that period. Trip generation models for personal travel convert socioeconomic data tabulated within analyses zones – households, employment, land use, floor space, and so forth – into travel demand measured by the person trip ends within the zone. Subsequent models link these trip ends into trip movements and allocate trips to different travel modes and routes.

Although some practitioners consider trip generation to be the most mundane of these travel models, its importance cannot be overstated since remaining models can never rectify a poor forecast of trip ends. How the trip generation model is structured affects what can be accomplished in the remaining models; in particular, only the trip types estimated in trip generation can be carried forward in the succeeding models.

The current CMAP household trip generation model was originally conceived and implemented during the mid-1990s by staff from the Chicago Area Transportation Study, CMAP's predecessor MPO for the northeastern Illinois region. Since that time, it has been maintained internally by CATS and CMAP staff with limited support from consultants. Versions of the model were routinely applied by CATS to prepare travel forecasts for a wide range of planning projects. CMAP primarily applies the model for long-range planning and air quality analyses.

The most critical parts of any person trip generation model are the trip generation rates that convert individual and household characteristics into person trip ends. In the CMAP model these trip generation rates are the daily trips per person. They depend upon the trip purpose, the type of individual (worker, nonworking adult, and child old enough to travel independently), and the characteristics of the household (composition and vehicle availability) where the individual resides. The only way to estimate these rates is to have access to observed data from a household survey that includes the number, purpose, and other attributes of trips made by household members plus individual and household characteristics. CMAP and the Northwestern Indiana Regional Planning Commission (NIRPC) recently completed a large

travel survey of more than 14,000 households in northeastern Illinois and northwestern Indiana that provides suitable local data for estimating trip generation rates ([1]).

Project Objectives

The principle objective for the project is to update the existing trip generation model to reflect current travel behavior based on this newly available data from the CMAP household travel survey. In addition to re-estimating trip generation rates, there are other parts of the model that need to be re-estimated and/or recalibrated as well. These include the submodels within trip generation that: (1) create small area estimates of households grouped by their composition and income levels; (2) estimate the vehicles available to a household; (3) forecast trip generation by persons in group quarters; (4) estimate trips with one trip end outside the study area, and; (5) separate person trips into trips by motorized and nonmotorized modes.

Updating these submodels requires additional data besides that available from the CMAP household survey, either because relevant variables were not collected in the CMAQ survey or because the sample of households is too small for reasonable statistical reliability of estimated model coefficients. The decennial census has historically been a source for much of the data required for updating these submodels. In addition to enumerating the population, the census collected detailed individual and household information from a sample of the nation's households that completed the long-form questionnaire. However, this long-form household sample is no longer part of the decennial census but has been replaced by the American Community Survey (ACS) [2]. The ACS is a continuous survey that annually collects long-form data from a smaller annual sample of households, approximately one in forty households annually compared to one in six households in past decennial census. Since 2006, the ACS also includes a 2.5 percent sample of persons living in group quarters.

The long-form has several questions regarding journey to work commuting. A special tabulation of the journey to work data, the Census Transportation Planning Package [3], is especially useful to MPOs. It includes residence and workplace based tables plus residence to workplace flow tables in transportation analyses zones (TAZs) defined by the MPO; and is the only source of observed travel data for many MPOs. A CTPP based on ACS data is funded and planned. Small area estimates (census tracts, block groups, and TAZs) will be tabulated from a five year accumulation of ACS data [4].

The continuous nature of the ACS means that some trip generation model inputs can be updated more frequently than in the past. This has implications for the trip generation model software code. Observed tables of households required by the procedure to disaggregate households inside small areas are presently hard-coded in the program, along with a handful of other parameters for one or more trip generation submodels. This was a sensible approach when the model was originally programmed because these data and parameters could only be redone at ten year intervals with decennial census data, or even more infrequently, when a regional household travel survey was completed. This approach also reduced the burden on the user for assembling inputs to apply the model. This practice now needs to be minimized to take advantage of more frequent ACS data.

The CMAP area for modeling travel has grown larger over the years and now covers twenty-one counties in northeastern Illinois, northwestern Indiana, and southeastern Wisconsin. The modeled region has even outgrown some of the arrays in the trip generation code that store data for geographic areas. While CMAP staff has been able to work around this problem, the situation is at best an inconvenience and at worst an opportunity to introduce mistakes into tabulations of trip generation results. The regional zone system for the CMAP models has also been altered over the years. Sections of the trip generation code should be rewritten to allow for expansion of the CMAP modeled area and changes in regional zones.

As the trip generation model software executes, it creates temporary files of households tabulated by composition, income, and vehicle ownership. These files might conceivably 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. Users of the model cannot save these files at present. Allowing more control over the operation of the model software, including retaining intermediate data sets could increase the model's usefulness.

As noted, the CMAP models are examples of the traditional four-step sequential travel forecasting models. While these models have become more complex over time and practitioners have increasingly pushed them toward more sophisticated applications, their limitations in dealing with evolving transportation issues are well documented ([5]). Several MPOs have introduced so-called "advanced practice" models and many larger MPOs are considering transitioning from the four-step sequential trip-based models to these new models. These "state of the art" models focus on individual travel behavior in far more detail than that allowed by the four-step models' limited number of trip types and aggregate trip movements between zones.

While it is difficult to foresee the long-term evolution of the CMAP transportation models, one can state with some certainty that the existing models with marginal enhancements will continue to be used for some years. However, updates to current models should - whenever practical - complement development of "advanced practice" models at CMAP. With respect to future usefulness of the CMAP trip generation model or its submodels, a positive feature of the current model is the disaggregation of households within small areas, which is a component of many "advanced practice" models.

The following objectives for the project can be formulated from these comments:

1. Update the model's trip generation rates, input files, parameters, and submodel coefficients based on the CMAP household travel survey and recent ACS person and household data.

2. Introduce these model revisions into the trip generation software and make marginal changes in the model code to improve its flexibility and ease of use.

a. Revise code so that the model can be readily updated as ACS or other new data become available.

b. Allow for expansion of the study area or changes in the study area zone system.

c. Permit more user control over operation of the program.

d. Increase the model's transparency by improving model reports and outputs.

3. Support CMAP's general model development program. For this updating of the CMAP trip generation model, the model calculations are less aggregate – more trip purposes are considered - so that they more closely resemble the level of detail in "advanced practice" models.

Overview of the CMAP Trip Generation Model

The following discussion refers to the updated CMAP trip generation model as of March 2009. The revised model has a linear logic identical to past versions of the model. This logic also corresponds to subroutines in the programmed model's code.

1. **Read and Load Model Inputs:** These inputs control the operation of the program, define study area geography, and provide large geographic area tables of cross-classified households that are the basis for the procedure to disaggregate households within small area trip generation subzones. The report file **TG_OUTPUT.TXT**, which generates reports as the program executes, is also opened.

2. **Disaggregate Households by Subzone:** This step creates a four-way – households by adults, workers, children, and income quartile – table of households for each trip generation subzone from large area household tables and average subzone household characteristics.

3. **Household Vehicle Availability:** Household vehicle ownership submodels are applied to estimate the vehicle ownership levels for each cell in the four-way household table, effectively adding a fifth dimension (vehicles available in the household) to the table.

4. **Household Trip Generation:** Household members - workers, nonworking adults, and children aged twelve to fifteen - in each cell of the household table are multiplied by trip generation rates – daily trips per person by trip purpose – appropriate for that individual and household type.

5. **Group Quarters Trip Generation:** A trip generation subzone level input file containing workers and nonworking adults in non-institutionalized group quarters is read and then trips by persons in group quarters are estimated.

6. **Allocation of Nonhome Trip Ends:** The subzone locations of trip ends that take place away from the household or group quarters are unknown at this point. In this step, a subzone level file containing employment is first read and then nonhome trip ends are allocated to subzones by households and employment.

7. **Trip Ends Outside the Study Area:** Some trip ends generated by study area residents are linked to trip ends outside the study area. These are factored from the total generated person trips leaving only trips wholly within the modeled study area. A file containing external trip factors is input for this purpose.

8. **Nonmotorized Trips:** The remaining CMAP models after trip generation only address person trips by vehicles (this may change when the agency's mode choice model is updated). Pedestrian and cycling person trips are factored from total generated person trips by submodels that estimate the fraction of nonmotorized trips as a function of household and subzone characteristics leaving person trips by vehicles.

9. **Create Final Vehicle Trip Reports and Output Trip Files**

Figure 1 is a detailed flowchart of the model's logic, beginning with the loading of program control variables and ending with the final trip generation files. The details required to fully understand this flowchart, including options for running the software and the formats of data files, are discussed in order of the above stepwise model logic.

Read and Load Model Inputs

Three inputs to the CMAP trip generation are read into memory before any calculations are carried out: program control variables, geographic area inputs, and large area cross-classified household tables.

Program Control File. Program control variables are entered in the text file named **TG_INPUT.TXT**. An example is shown in Figure 2.

Figure 2. Sample TG_INPUT.TXT File

```
&PARAM
  TITLE = 'TEST RUNS FOR CMAP TRIP GENERATION'
  SUBZONES=16819
  PUMA5 = 69
  PUMA1 = 20
  ZONES = 1944
  COUNTIES = 21
  PUMA_TG = .FALSE.
  SAVE_FILE = .TRUE.
  EXP_TTYPE = .TRUE.
  IN_EMPFACT = 1.000
  WI_EMPFACT = 1.000
&END
```

The **&PARAM** and **&END** statements identify the beginning and end of the NAMELIST input. The variables in the program control file have the following definitions (geographic areas in the model are discussed in the next section):

1. **TITLE**: An 80 character name identifying the model run enclosed in single quotes.

2. **SUBZONES:** Trip generation subzones in the study area.

3. **PUMA5:** Five percent sample Public Use Microdata Areas in the modeled study area.

4. **PUMA1:** One percent sample Public Use Microdata Areas in the modeled study area.

5. **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).

6. **COUNTIES:** Counties in the study area.

7. **PUMA_TG:** A true/false variable. When true the model's logic includes an optional subroutine that prepares an updated (future) four-way cross-tabulation of households within subzones. This new table is based upon (future) large area average household characteristics and the initial (base year) cross-tabulated household table.

Figure 1. Logic Flow in the CMAP Trip Generation Model
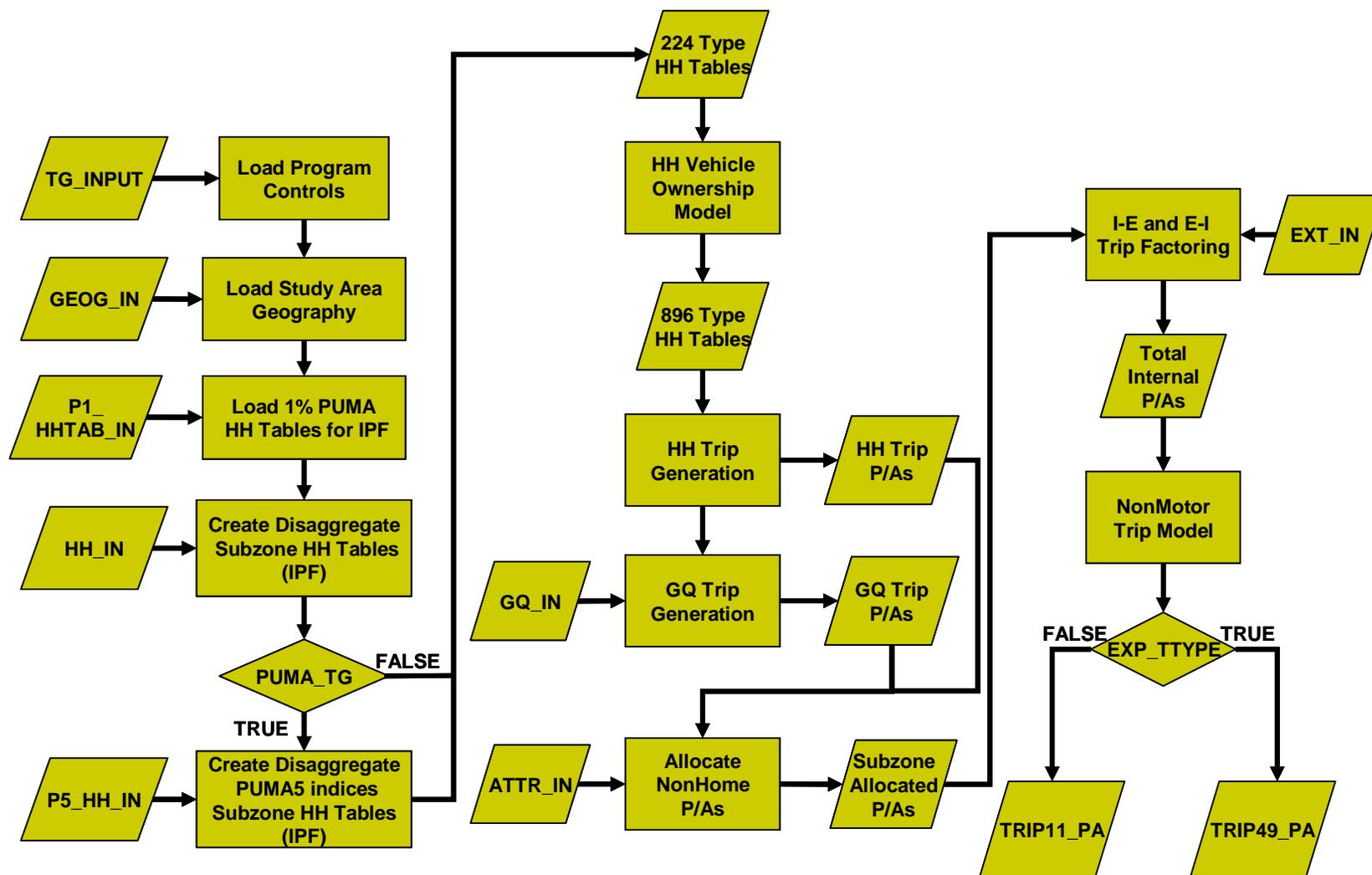
8. **SAVE_FILE:** A true/false variable that causes all intermediate program files to be retained after the model run is completed.

9. **EXP_TTYPE:** A true/false variable. When true, all files and reports include forty-nine trip types based upon trip purposes in the CMAP household travel survey. When false, files and reports have the eleven trip types in the current CMAP trip generation.

10. **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.

11. **WI_EMPFACT:** Employment in Wisconsin is factored by this value.

Geographic Areas and Trip Generation. The current subzones for trip generation (referred to as 2009 subzones) are shown in Figure 3. Within the majority of the study area subzones are roughly square areas one-half mile on a side, or a quarter of square mile sections. These are further subdivided into quarter-quarter section subzones in the Chicago CBD, while larger subzones are used in the outlying counties. Indiana and Wisconsin subzones are based on census geography and the zone systems developed by the two MPOs in these adjacent states, NIRPC and the Southeastern Wisconsin Regional Planning Commission. Note that hatched portions of the Illinois counties Lee, Ogle and LaSalle extend beyond the limits of the modeled area.

Although the trip generation model does not perform calculations specifically for the larger zones used by the remaining CMAP models, most output files include this geographic area. Final trip generation estimates are summed into these modeling zones. Current zones (referred to as 2009 zones) are shown in Figure 4. Zones are either combinations of trip generation subzones or the same as subzones.

Two principal census products are used in updating the CMAP trip generation model, pre-tabulated household and person tables of long-form data at various geographic levels and Public Use Microdata Sets (PUMS). The PUMS are not tables but two files of person and household data, and each record in a PUMS file contains data for a single household or person. Detailed tables and PUMS were prepared for the 2000 decennial census and are also available for individual years of the ACS, plus three year (currently) and five year (eventually) ACS averages. Due to census disclosure requirements, a single year ACS household sample limits data tables to geographic areas with a population of 65,000 or more. It is possible to obtain tables for areas with a population of 20,000 or more from three year accumulations of annual ACS data. Five annual ACS surveys must be completed before small area estimates comparable to those available from the 2000 census are available.

Person and household PUMS data sets are somewhat like the household and person data sets created from a household travel survey, but without any activity or travel information other than the journey to work. A household is also not located to any small area geography. PUMS

households are only coded to Public Use Microdata Areas (PUMAs), whose sizes are determined by the household sample rate and disclosure rules. One percent sample PUMAs are very large areas containing 400,000 or more persons. Smaller five percent sample PUMAs have 100,000 or more persons. Both are shown in Figure 5 overlying the trip generation subzones.

Figure 3. CMAP Regional 2009 Trip Generation Subzones
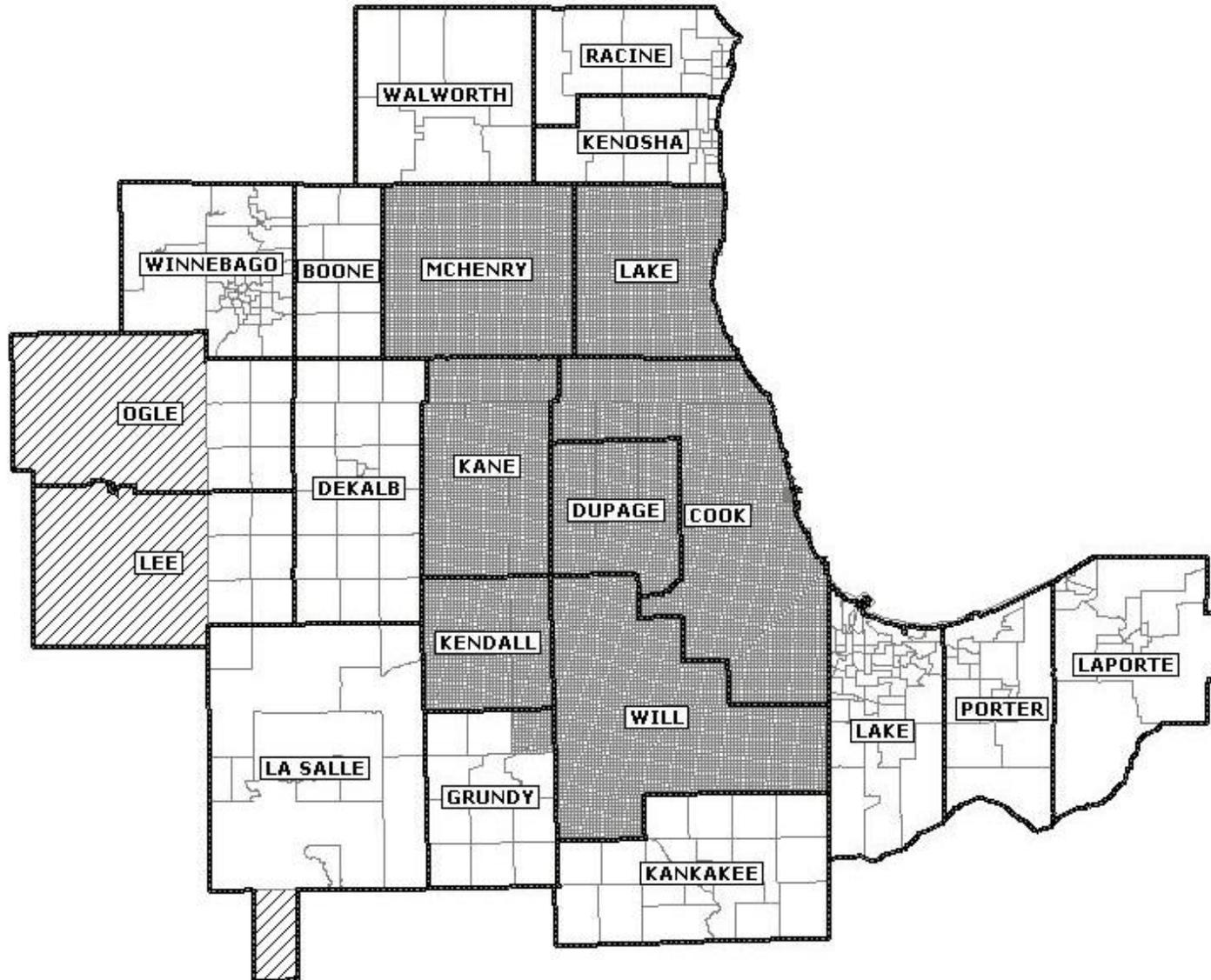
Figure 4. CMAP Regional 2009 Zones
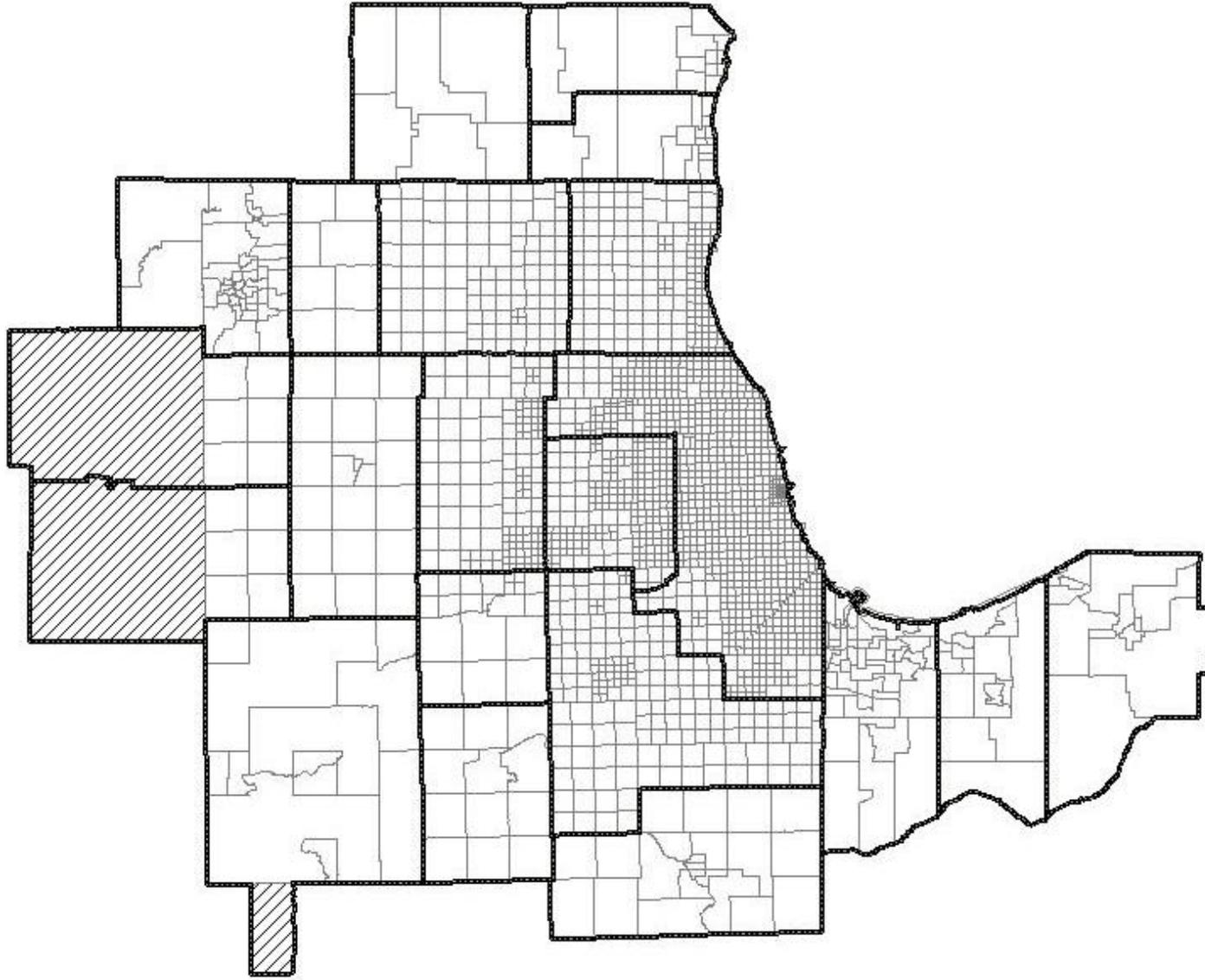
Figure 5a. Public Use Microdata Areas Defined in Census 2000: One Percent Household Sample PUMAs
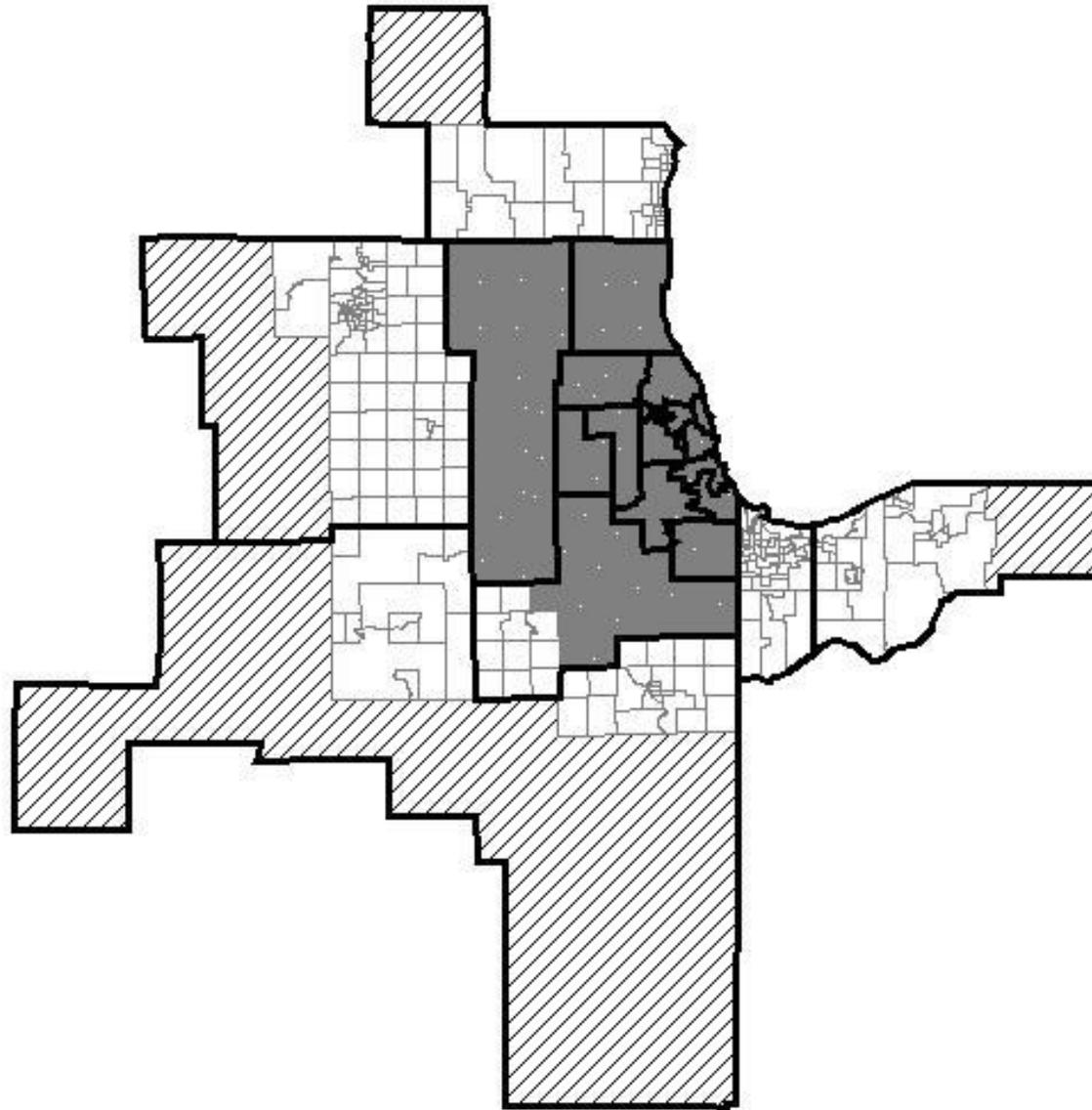
Figure 5b. Public Use Microdata Areas Defined in Census 2000: Five Percent Household Sample PUMAs
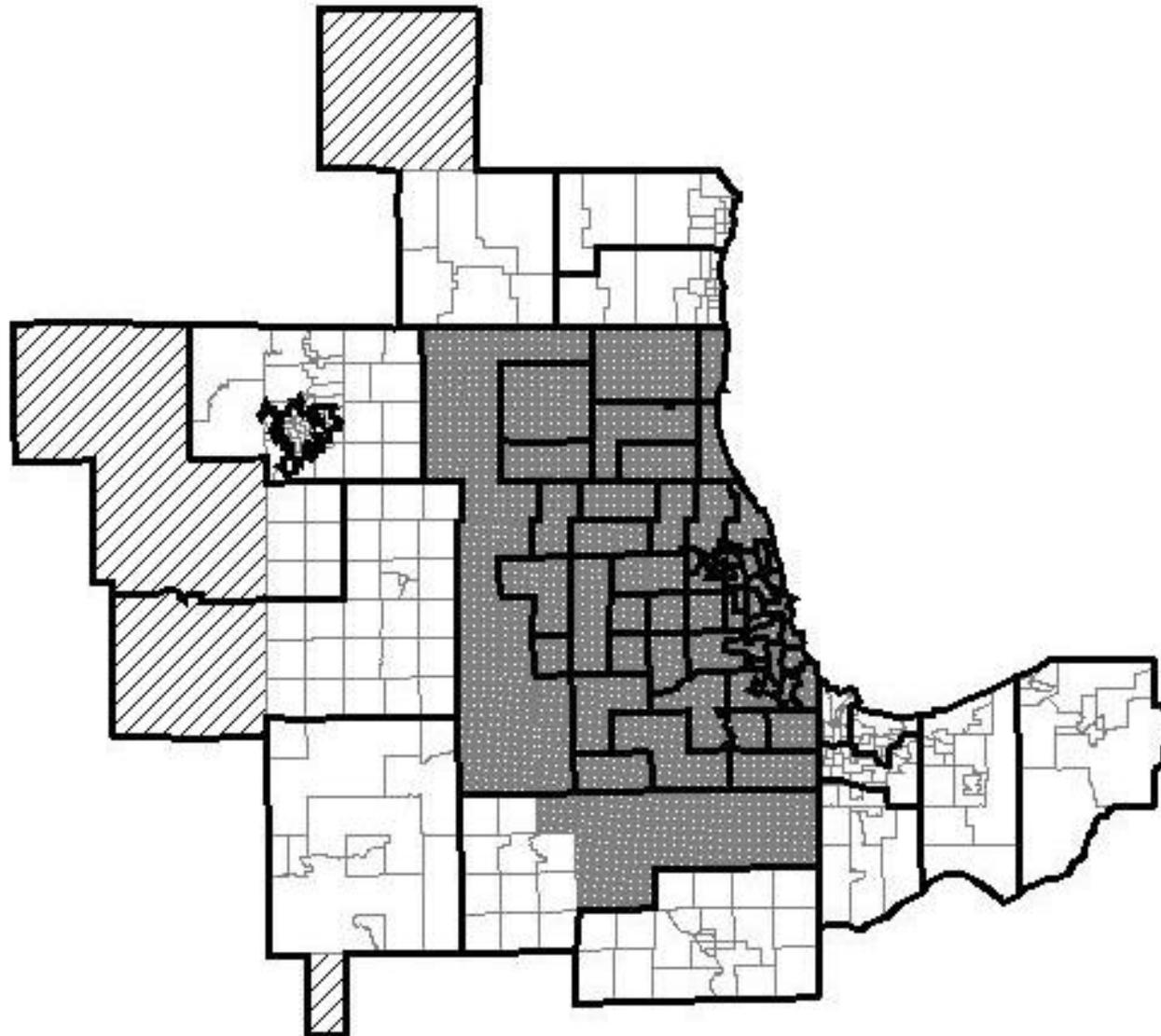
Geographic Areas Input File. Geographic areas are entered into the model through a file named **GEOG_IN.TXT.** This input file has one record per trip generation subzone and it is a comma delimited file, a format with variables separated by commas. This is a popular format that can be read and exported by nearly all commercial software for statistical analyses and management of large data sets. As a precaution, successive commas should be avoided in these types of files. The FORTRAN language strictly interprets them as missing values and does not load any value into a variable when encountered, which can have unanticipated consequences.

Variables in the **GEOG_IN.TXT** are listed in Table 1. This version of the trip generation model has been coded to allow for up to 25,000 trip generation subzones, 5000 model zones, 30 counties, 30 one percent PUMAs, and 100 five percent PUMAs.

Table 1. GEOG_IN.TXT Input File

SUBZONE	Integer (1-25000)	The trip generation subzone, which must be in sequence in the file from low to high values.
COUNTY	Integer (1-99999)	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)
COUNTY NAME	Alphanumeric	Ten character county name enclosed in double quotes.
STATE	Alphanumeric	Two character state code enclosed in double quotes.
ONE PERCENT PUMA	Integer (1-99999)	Five digit numeric code for one percent PUMAs
FIVE PERCENT PUMA	Integer (1-99999)	Five digit numeric code for five percent PUMAs
ZONE	Integer (1-5000)	Modeling zone
CHICAGO	Integer (0 or 1)	Variable is set to 1 when trip generation subzone is inside Chicago; 0 elsewhere.
CBD	Integer (0 or 1)	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.
ROW-COLUMN	Integer (1-4)	Variable identifies the portion of the region that provides the tables of cross-classified households for the procedure to disaggregate households within smaller trip generation subzones. These areas are mapped in Figure 8. 1 = Inner Chicago 2 = Outer Chicago and Inner Suburbs 3 = Mid Suburban 4 = Fringe and External Areas
AREA	Real Number	Area of the trip generation subzone in square miles.

Cross-Classified Household Input Tables. The first substantial calculations in the model are an algorithm that estimates subzone level tables of households cross-classified by: (1) adults (1, 2, 3, 4 or more adults); (2) workers (0, 1, 2, 3, 4 or more workers), (3) children fifteen years and younger (0, 1, 2, 3 or more children), and; (4) income quartiles (four categories). This algorithm is variously known as iterative proportional fitting (IPF) or matrix balancing. Transportation planners know it as the Fratar method for trip table expansion. It is an iterative procedure that takes an initial table (more generally, a multi-dimensioned array since the algorithm is not restricted to two dimensions) and adjusts cell values in the table to equal new row and column totals (again more generally, new vector sums in all dimensions). In the trip generation model, the initial table is an observed table of households in a one percent PUMA cross-classified by the four household characteristics described above.

Figure 6. Household Types

a. Possible Adult-Worker Combinations

Adults

		1	2	3	4+
	0	1	2	3	4
W o r k e r s	**1**	5	6	7	8
	2		9	10	11
	3			12	13
	4+				14

b. Numbering of Household Types

Household Type	Children	Income Quartile
1-14	0	0
15-28	1	0
29-42	2	0
43-56	≥ 3	0
57-70	0	1
71-84	1	1
85-98	2	1
99-112	≥ 3	1
113-126	0	2
127-140	1	2
141-154	2	2
155-168	≥ 3	2
169-182	0	≥ 3
183-196	1	≥ 3
197-210	2	≥ 3
211-224	≥ 3	≥ 3

Two hundred twenty-four different types of households result from the above cross-classification scheme. This is fewer than all combinations of the household categories (320) because a household must have more adults than workers, and there are only fourteen possible combinations of adults and workers rather than twenty. The fourteen adult-worker categories are illustrated in Figure 6a.

Figure 6b is a key to the numbering of all 224 household types in the model's code. Households are numbered in increments of fourteen in Figure 6b matching the fourteen adult-worker categories.

The one percent PUMA household tables (the initial tables for the IPF algorithm) are read into the model via the file **P1_HHTAB_IN.TXT**. Table 2 shows the variables in this file with household type referring to the numbering scheme in Figure 6. This input file is also a comma delimited file with one record for each one percent PUMA and household type combination. The records do not have to be ordered but for readability it is preferable to order the file by PUMA and household type. No input record is required when a household type is missing in the sample households in a one percent PUMA.

Table 2. P1_HHTAB_IN.TXT Input File

ONE PERCENT PUMA	Integer (1-99999)	Five digit numeric code for one percent PUMAs.
HOUSEHOLD TYPE	Integer (1-224)	Code indicating cross-classification of household (as per numbering in Figure 6).
ONE PERCENT PUMA HOUSEHOLDS	Integer	Number of households matching household type code in the one percent PUMA.

The input household tables for development and testing of the revised model were total expanded households in the combined 2005, 2006 and 2007 ACS PUMS data for the three-state modeled area. Combining multiple years of PUMS is permitted because the model converts the input tables into proportions since the IPF algorithm operates on the proportions of households rather then the numbers of households.

The combined three year ACS PUMS household tables contained data for more than eighty percent of 4480 possible entries (224 household types for each of twenty PUMAs). However, about a third of all entries had less than five households sampled in the combined three year ACS.

While missing values and limited household samples in a large number of table cells are a concern, these cells match extremely unlikely household categories, such as four or more worker households in the lowest income quartile. Combining more years of ACS PUMS data is desirable from the viewpoint of more complete tables, but there is a tradeoff to consider since the tables are less current as additional years of ACS PUMS are included in the totals.

Household Income Quartiles. Household income quartiles for study area households were also estimated from the combined PUMS household files. Three yearly household-income distributions were tabulated from the three annual files of PUMS household records. Quartile household incomes were identified for each year and they are listed in Table 3.

Table 3. Study Area Household Income Quartiles

Household Income Quartile	ACS PUMS		
	2005	2006	2007
1	≤ $27,000	≤ $28,000	≤ $29,900
2	$27,001 TO $52,300	$28,001 TO $55,000	$29,901 TO $57,000
3	$52,301 TO $89,000	$55,001 TO $92,200	$57,001 TO $96,000
4	> $89,000	> $92,200	> $96,000

Disaggregate Households by Subzone

The initial table in the IPF process that cross-classifies households in a subzone is one of the PUMA tables of households. This initial table is then manipulated to agree with the household

characteristics of the subzone. For the IPF procedure, the households in each of the seventeen categories (four adult categories plus five worker categories plus four children categories plus four income quartiles) must be known. For example, the number of households in the subarea in each of the four income quartiles has to be determined. The calculations then proceed iteratively from household characteristic to household characteristic. During an iteration of the algorithm, the households in the table are factored to sum to the desired households within the categories of one household characteristic. The algorithm iterates until the differences between the desired numbers of households and the table sums become negligible.

Subzone Household Input File. Prior to initiating the subzone by subzone application of the IPF algorithm, a file with average subzone household characteristics is read. Two other quantities that characterize a subzone, the proportion of work trips made by private automobile and the pedestrian environment factor, are also included in this file. These two quantities have been required inputs for the CMAP trip generation model for some years, and procedures for preparing them from regional socioeconomic and census data are well established in the agency.

The data are read from a subzone level file named **HH_IN.TXT**, which is again a comma delimited file. The eight variables in the **HH_IN.TXT** are listed in Table 4.

Table 4. HH_IN.TXT Input File

SUBZONE	Integer (1-25000)	The trip generation subzone, which must be in sequence in the file from low to high values.
SUBZONE HOUSEHOLDS	Integer	Households in the trip generation subzone.
AVERAGE ADULTS PER HOUSEHOLD	Real Number	Average adults (sixteen and older) per household in the subzone.
AVERAGE WORKERS PER HOUSEHOLD	Real Number	Average adult workers per household in the subzone.
AVERAGE CHILDREN PER HOUSEHOLD	Real Number	Average children (fifteen and younger) per household in the subzone.
INCOME QUARTILE INDEX	Real Number	This index is defined as the average subzone household income divided by the regional **median** household income.
PRIVATE AUTO COMMUTE MODE SHARE	Real Number	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.
PEDESTRIAN ENVIRONMENT FACTOR	Real Number	The average number of census blocks per quarter-square mile. See comments in text for details on how this quantity is calculated.

When the trip generation subzone is a quarter-section or smaller, the pedestrian environment factor is calculated by averaging the census blocks within an area 1.5 mile by 1.5 mile. The area for the average pedestrian environment factor is normally defined by the subzone plus the eight abutting subzones centered on the subzone of interest. For larger subzones on the periphery of the region, a simple subzone average is used.

Figure 7. Sample Household Distribution

Inner Chicago
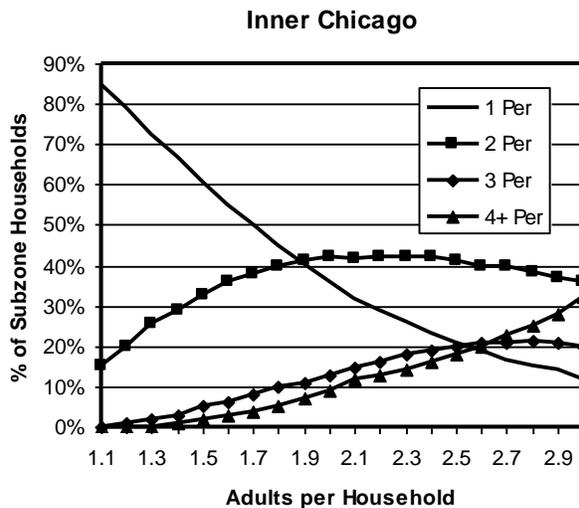
Subzone Household Distribution Tables.
The link between the average household characteristics in **HH_IN.TXT** and the IPF algorithm are tables that relate average subzone household characteristic to the distribution of households across the four or five categories associated with that characteristic. Figure 7 is a plot of one of these tables. It graphs the relationship between the average adults per household and the distribution of households by adults for subzones within inner city Chicago.

The full set of these tables for a subzone includes three more similar tables for workers, children, and income quartiles

These tables are arduous to prepare and require a significant number of trip generation subzone observations. This means that the same tables must be used for groups of subzones. Four ring-like areas were somewhat arbitrarily defined for this purpose, inner city Chicago, remainder of Chicago and inner suburbs, middle suburbs, and far suburbs-fringe. These areas were developed from five percent PUMAs, and are generally similar in demographic character. They are shown in Figure 8. The ROW-COLUMN variable read from **GEOG_IN.TXT** indicates which area tables are to be used for a subzone.

Appendix C contains the full set of tables that are included in the model code. The adult, worker, and income quartile tables were developed from several 2000 CTPP TAZ level residential tables. After compiling the data, it became obvious that many of these tables could be combined even more. In particular, the same table of households by workers applies for all areas. The middle suburban and fringe tables are also the same for the households by adults table. The table for the distribution of households by children was estimated from the CMAP household travel survey, and the same table for children is used in all areas due to the smaller household sample in the CMAP survey.

Adjustment of Income Quartile Index. The household income distribution table is indexed by the ratio of a subzone's average household income to the median regional household income (a subzone with an index of one has an average household income equal to the regional median household income). Since small area household income figures are difficult to determine and even more difficult to project into the future, it is not surprising that total estimated households within one or more income quartiles rarely equal a quarter of the regional households..

The approach undertaken in the model is to factor the input subzone average household income indices to improve the distribution of households by income quartile. Therefore, the model

determines a new "true" median regional household income given the input subzone households and income indices. All subzone income indices are then adjusted by this factor, which should not be too large.

Figure 8. Areas for Household Distribution Tables
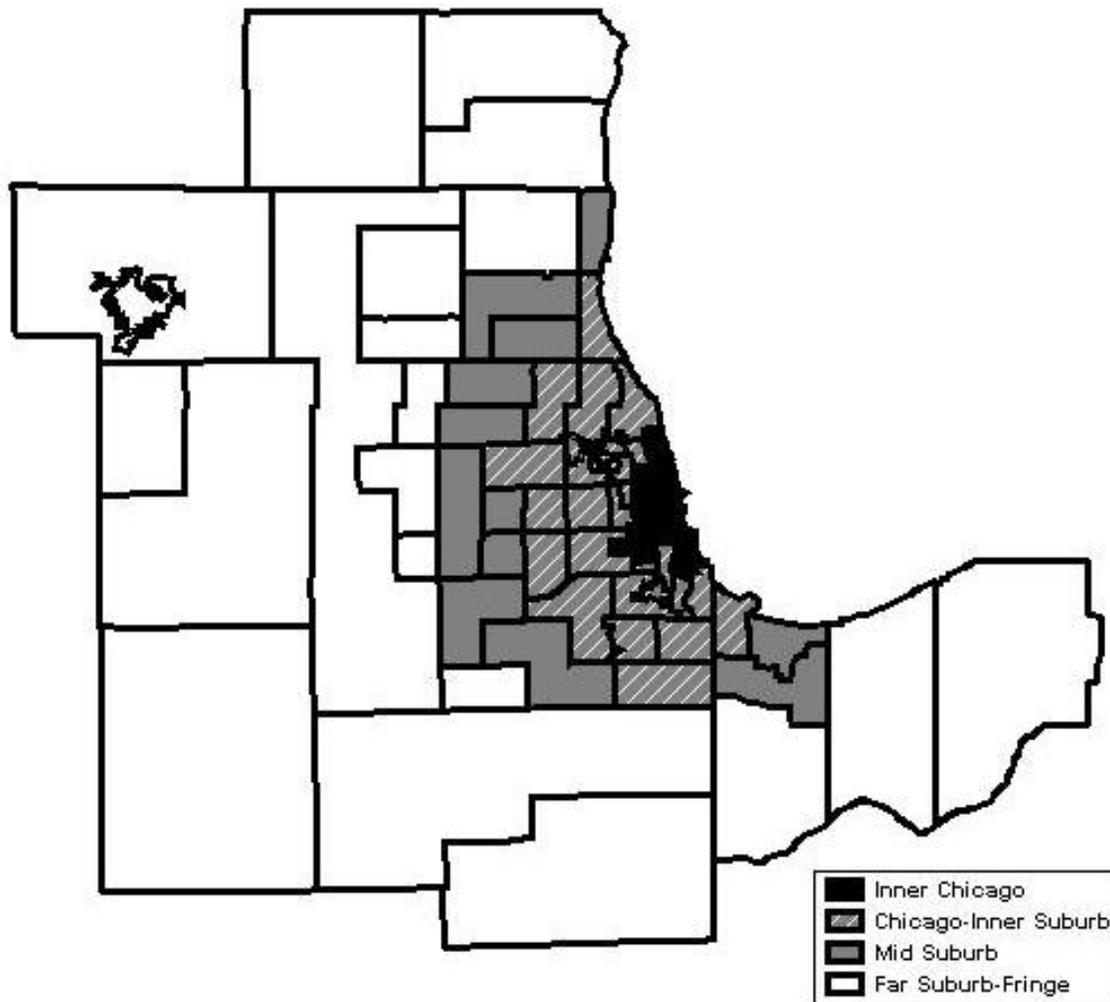
Figure 9. Updating Household Cross-Classification Tables

a. Tabulate Base Table by Five Percent PUMAs

Adults/HH	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
1						
2						
3						
4+						
Total HHs						

Workers/HH	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
0						
1						
2						
3						
4+						
Total HHs						

Children/HH	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
0						
1						
2						
3+						
Total HHs						

Income Quartile	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
1						
2						
3						
4						
Total HHs						

b. Add New Row-Column Totals

Adults/HH	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
1						
2						
3						
4+						
Total HHs						

New Total HHs						

From P5_HH_IN.TXT Input File

5% PUMA HHs ← **From Household Distribution Tables**
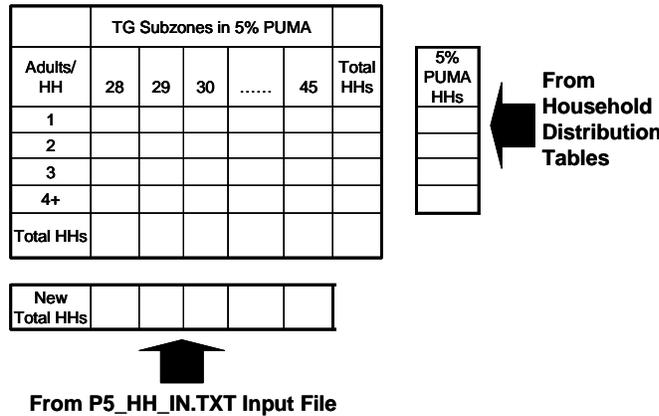
c. IPF Balance Five Percent PUMA Tables

d. New Totals for Subzone Cross-Classified Tables

Adults/HH	TG Subzones in 5% PUMA					Total HHs
	28	29	30	......	45	
1						
2						
3						
4+						
Total HHs						

Adults/HH	Sub-Zone 28
1	
2	
3	
4+	

Optional Updating of Subzone Household Cross-Classification Tables.

Figure 9 illustrates the logic of a program option that was added to allow updated or future household cross-classification tables to be created from average five percent PUMA household characteristics. This option means that base year household tables can be readily updated with annual or three year average ACS data. It also permits future household tables to be created without estimating household characteristics for small subzones, arguably an unreasonable and impractical forecasting exercise.

When the program control variable **PUMA_TG** is true, an additional step is added to the program. It occurs after base year households have been cross-classified within subzones (see Figure 1). The future household cross-classification tables are then effectively a rebalancing of the base tables to new - albeit more aggregate - row-column totals. After completion the updated subzone household cross-classification tables are substituted for the original base household table in the remaining steps of the model.

The base household table is first created in the standard fashion. It is then reorganized into a set of new tables by five percent PUMAs. There are four tables for each PUMA one for each of the four household characteristics. Each column in one of these PUMA tables corresponds to a trip generation subzone located in the PUMA (illustrated in Figure 9a).

Row-column totals are then determined for each of these PUMA tables. Total households for each subzone (the column totals in Figure 9b) are read from a new input file **P5_HH_IN.TXT.** This file has the same variables as the original **HH_IN.TXT** file except that the average

household characteristics are now five percent PUMA averages. The row totals illustrated in Figure 9b are obtained from the subzone household distribution tables using the PUMA average household characteristics in **P5_HH_IN.TXT**.

The five percent PUMA tables are next IPFed to these row-column totals. Cells in the columns in the rebalanced PUMA tables correspond to revised row-column sums for the base subzone cross-classified household tables (illustrated in Figure 9d). The final step is to IPF the original base subzone household tables to these new totals.

Temporary File FIRST_HHTEMP.TXT. The subroutines that disaggregate households write out scratch files that are passed to the next subroutine. This file is named **FIRST_HHTEMP.TXT** and it has the fixed format in Table 5. If the control variable **PUMA_TG** is true, a second file **FIRST_P5_HHTEMP.TXT** is also written, which has the identical format. Both files are retained at the end of the model run when control variable **SAVE_FILE** is true.

Table 5. FIRST_HHTEMP.TXT and FIRST_P5_HHTEMP.TXT Temporary Files

SUBZONE	Integer (I6)	Trip generation subzone (6 characters)
HH TYPE 1	Real Number (F12.4)	Type 1 households (12 characters, 4 decimal places)
HH TYPE 2	Real Number (F12.4)	Type 2 households (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
HH TYPE 224	Real Number (F12.4)	Type 224 households (12 characters, 4 decimal places)

Validation of the Procedure to Disaggregate Households. Validation of the results from disaggregating the households is something of a problem. Summarizing the results in one dimension - county summaries of the households by workers, for example - only allows an evaluation of the input data from **HH_IN.TXT**, not of the process itself. At the same time, it is difficult to display results from the procedure in more than two dimensions.

The CMAP trip generation model was first run for the base year using household data directly from CMAP. Households in this base year data have been extrapolated by CMAP staff to represent the region in 2010. As a result, the regional households modeled in the trip generation should be slightly greater than the number in the average 2005-2007 PUMS data used for comparison.

The conclusion drawn from the first evaluation of the updated household allocation procedure was that results were not nearly as acceptable as earlier versions of the procedure developed from the 2000 decennial Census and 1990 CATS household travel survey. After some analyses, it was clear that the average household characteristics in the base year household input file were somewhat different from the PUMS data. For the purposes of comparison, the base year

household input file was factored so that average household characteristics in the input data matched those of PUMS households within five percent PUMAs. This is not any implied criticism of the input data since the purpose of this comparison is to make sure that the household allocation within the model is working, and the only way this can be accomplished is to have the model input data match observed households.

The resulting comparison between modeled households based upon the factored household input data and PUMS households showed substantial agreement between the two with the exception of the distribution of households by children. Tables in the model's code matching subzone average children per household with the proportion of households by children were again investigated. The tables were initially estimated using weighted households tabulated from the CMAP household travel survey. It was suspected that some exceptionally large household weights may have overly affected results and the arrays were re-estimated using unexpanded households from the CMAP survey.

After incorporating these changes the household allocation part of the model was again evaluated. These results are listed in Tables 6-8. Households are cross-tabulated by adults and workers, adults and children, and workers and income so that the four characteristics by which households are disaggregated are represented. Results are listed by parts of the regions that can be summarized from five percent PUMAs, the smallest geography in the PUMS data. Several counties are combined because of larger than county PUMAs, and some counties on the edges of the modeled area are omitted because PUMAs extend beyond area boundaries. The percentages shown in these tables are the percents of total households in an area.

The PUMS households in the tables are the average (one-third) of total weighted households from the three annual ACS. Even though the PUMS figures in these tables haven't been rounded to larger increments, it should be emphasized that they are estimates from a sample of households and subject to sampling error.

The main conclusion from these tables is that the IPF procedure to disaggregate households seems to work quite well, especially in light of the differing years for the trip generation run and averaged PUMS data. But it must be emphasized that this observation applies to the mechanics of the procedure - selection of an initial household table for the IPF algorithm, the appropriateness of the tables to estimate the distribution of households across categories of household characteristics, and the implementation of the IPF algorithm in the software – since the tables compare the same PUMS household data before and after application of the IPF. One would expect them to match closely if the procedure is implemented correctly since subzone average household characteristics input to the IPF procedure have been factored to those of the initial PUMS source table.

Table 6. Disaggregated Households: Adults and Workers

| | | Workers per Household | | | | | | | | | | | | |
| | | 0 Worker | | | | 1 Worker | | | | 2 or More Workers | | | |
	Adults/ Household	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%
Chicago	1	162,650	16.0	200,881	17.9	246,911	24.2	244,935	21.8				
	2	75,143	7.4	94,983	8.5	150,624	14.8	155,985	13.9	176,527	17.3	225,640	20.1
	≥ 3	20,184	2.0	20,008	1.8	53,628	5.3	47,108	4.2	132,827	13.0	132,723	11.8
Suburban Cook	1	119,273	13.0	123,866	13.2	160,670	17.5	167,989	17.9				
	2	78,612	8.6	80,640	8.6	157,857	17.2	161,590	17.2	196,899	21.5	208,190	22.2
	≥ 3	10,402	1.1	10,934	1.2	40,310	4.4	40,709	4.3	151,768	16.6	143,107	15.3
DuPage	1	31,593	9.4	36,801	10.9	60,478	18.1	60,032	17.8				
	2	21,979	6.6	25,128	7.4	59,644	17.8	55,213	16.3	88,672	26.5	88,089	26.1
	≥ 3	2,682	0.8	3,559	1.1	12,425	3.7	11,905	3.5	57,209	17.1	57,210	16.9
Lake-IL	1	21,787	9.3	26,359	10.9	38,292	16.4	38,250	15.8				
	2	15,447	6.6	19,881	8.2	45,248	19.4	42,695	17.7	64,771	27.8	63,377	26.2
	≥ 3	1,802	0.8	2,960	1.2	9,238	4.0	9,643	4.0	36,547	15.7	38,386	15.9
Will, Grundy	1	19,681	7.6	28,338	11.5	32,179	12.5	35,012	14.2				
	2	45,302	17.6	19,661	8.0	45,419	17.6	43,701	17.7	65,097	25.3	63,751	25.9
	≥ 3	1,965	0.8	3,736	1.5	8,273	3.2	9,280	3.8	39,508	15.3	42,863	17.4
Kane, Kendall, McHenry	1	23,902	8.1	32,868	10.4	44,911	15.2	45,913	14.5				
	2	22,193	7.5	25,757	8.1	59,184	20.0	55,732	17.6	82,804	28.0	84,108	26.5
	≥ 3	1,454	0.5	2,751	0.9	9,270	3.1	11,436	3.6	51,561	17.5	58,334	18.4
Lake-IN	1	28,789	15.6	24,874	13.1	34,528	18.7	32,645	17.2				
	2	19,964	10.8	24,338	12.8	28,301	15.3	36,313	19.1	36,348	19.7	38,235	20.2
	≥ 3	2,936	1.6	2,980	1.6	8,398	4.5	8,487	4.5	25,565	13.8	21,761	11.5
Kenosha	1	8,034	13.4	6,519	11.0	10,082	16.9	10,120	17.0				
	2	4,967	8.3	5,924	10.0	10,281	17.2	11,815	19.9	15,228	25.5	14,343	24.1
	≥ 3	139	0.2	293	0.5	2,039	3.4	2,159	3.6	9,046	15.1	8,226	13.8

Table 7. Disaggregated Households: Adults and Children

		Children per Household											
		0 Children				1 Child				2 or More Children			
	Adults/ Household	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%
Chicago	1	596,852	30.9	643,588	31.3	45,290	2.3	46,840	2.3	47,362	2.4	47,242	2.3
	2	512,274	26.5	563,930	27.4	122,029	6.3	136,094	6.6	201,361	10.4	227,003	11.0
	≥ 3	225,076	11.6	207,128	10.1	93,105	4.8	85,525	4.2	90,938	4.7	101,937	5.0
Suburban Cook	1	351,538	34.5	387,128	34.5	26,641	2.6	27,326	2.4	31,383	3.1	31,362	2.8
	2	255,762	25.1	297,483	26.5	59,536	5.8	70,418	6.3	86,996	8.5	108,707	9.7
	≥ 3	110,703	10.9	100,928	9.0	46,992	4.6	42,199	3.8	48,945	4.8	56,712	5.1
DuPage	1	245,314	26.8	256,460	27.4	18,650	2.0	19,514	2.1	15,979	1.7	15,880	1.7
	2	256,511	28.0	266,447	28.4	62,493	6.8	65,676	7.0	114,365	12.5	118,296	12.6
	≥ 3	114,373	12.5	106,200	11.3	46,113	5.0	43,326	4.6	41,994	4.6	45,225	4.8
Lake-IL	1	82,297	24.6	87,240	25.8	4,979	1.5	5,090	1.5	4,794	1.4	4,503	1.3
	2	94,959	28.4	94,181	27.9	25,095	7.5	25,066	7.4	50,241	15.0	49,182	14.6
	≥ 3	44,216	13.2	42,921	12.7	16,716	5.0	16,225	4.8	11,384	3.4	13,529	4.0
Will, Grundy	1	51,022	21.9	55,563	23.0	4,686	2.0	4,526	1.9	4,372	1.9	4,520	1.9
	2	66,045	28.3	68,455	28.3	19,287	8.3	17,130	7.1	40,133	17.2	40,368	16.7
	≥ 3	25,883	11.1	27,296	11.3	11,451	4.9	10,721	4.4	10,253	4.4	12,972	5.4
Kane, Kendall, McHenry	1	43,569	19.1	53,730	21.8	3,948	1.7	4,419	1.8	4,342	1.9	5,201	2.1
	2	61,970	27.2	66,827	27.1	21,049	9.2	16,462	6.7	43,016	18.9	43,825	17.8
	≥ 3	26,491	11.6	31,012	12.6	12,478	5.5	10,506	4.3	10,778	4.7	14,362	5.8
Lake-IN	1	57,678	19.5	66,599	21.0	5,237	1.8	5,733	1.8	5,898	2.0	6,450	2.0
	2	84,959	28.8	89,212	28.2	25,344	8.6	20,952	6.6	53,879	18.2	55,433	17.5
	≥ 3	32,050	10.9	38,140	12.0	16,086	5.4	15,072	4.8	14,149	4.8	19,308	6.1
Kenosha	1	51,582	27.9	46,576	24.6	5,601	3.0	5,445	2.9	6,134	3.3	5,498	2.9
	2	53,906	29.2	63,362	33.4	11,537	6.2	14,035	7.4	19,171	10.4	21,488	11.3
	≥ 3	21,155	11.4	18,848	9.9	9,232	5.0	8,593	4.5	6,512	3.5	5,786	3.1

Table 8. Disaggregated Households: Workers and Income

	Workers/ Household	Income Quartile 1				Income Quartile 2				Income Quartile 3				Income Quartile 4			
		PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%	PUMS	%	Trip Generation	%
Chicago	0	301,637	15.6	339,761	16.5	99,038	5.1	106,382	5.2	39,861	2.1	49,182	2.4	25,729	1.3	35,987	1.7
	1	203,120	10.5	216,490	10.5	265,359	13.7	265,604	12.9	201,689	10.4	204,106	9.9	139,832	7.2	132,115	6.4
	2	30,860	1.6	46,524	2.3	95,094	4.9	119,358	5.8	161,052	8.3	182,563	8.9	229,308	11.9	221,200	10.7
	≥ 3	2,911	0.2	4,427	0.2	17,086	0.9	22,141	1.1	44,233	2.3	47,941	2.3	77,478	4.0	65,507	3.2
Suburban Cook	0	191,067	18.8	227,015	20.2	41,925	4.1	52,987	4.7	15,868	1.6	21,794	1.9	9,118	0.9	14,077	1.3
	1	137,152	13.5	141,242	12.6	147,374	14.5	148,466	13.2	101,665	10.0	100,668	9.0	64,973	6.4	57,651	5.1
	2	21,836	2.1	32,863	2.9	53,701	5.3	70,744	6.3	71,930	7.1	85,805	7.6	97,119	9.5	101,296	9.0
	≥ 3	1,507	0.1	2,510	0.2	11,065	1.1	14,898	1.3	22,550	2.2	24,349	2.2	29,646	2.9	25,899	2.3
DuPage	0	110,570	12.1	112,747	12.0	57,113	6.2	53,394	5.7	23,993	2.6	27,389	2.9	16,611	1.8	21,910	2.3
	1	65,968	7.2	75,249	8.0	117,985	12.9	117,138	12.5	100,024	10.9	103,437	11.0	74,859	8.2	74,464	7.9
	2	9,024	1.0	13,661	1.5	41,393	4.5	48,615	5.2	89,121	9.7	96,758	10.3	132,189	14.4	119,904	12.8
	≥ 3	1,404	0.2	1,918	0.2	6,021	0.7	7,243	0.8	21,683	2.4	23,591	2.5	47,833	5.2	39,609	4.2
Lake-IL	0	25,074	7.5	26,973	8.0	15,451	4.6	16,191	4.8	9,105	2.7	11,776	3.5	6,623	2.0	10,548	3.1
	1	17,322	5.2	17,598	5.2	38,204	11.4	35,550	10.5	39,212	11.7	37,981	11.2	37,808	11.3	36,021	10.7
	2	2,736	0.8	4,087	1.2	13,994	4.2	15,156	4.5	34,722	10.4	37,225	11.0	64,700	19.3	56,265	16.6
	≥ 3	384	0.1	708	0.2	1,892	0.6	3,219	1.0	6,455	1.9	8,204	2.4	20,998	6.3	20,435	6.0
Will, Grundy	0	18,814	8.1	18,949	7.8	9,024	3.9	10,602	4.4	5,595	2.4	8,743	3.6	5,603	2.4	10,906	4.5
	1	15,129	6.5	14,707	6.1	26,999	11.6	24,739	10.2	23,541	10.1	24,458	10.1	27,110	11.6	26,684	11.0
	2	1,537	0.7	2,688	1.1	9,408	4.0	11,220	4.6	24,029	10.3	25,992	10.8	47,695	20.5	39,021	16.2
	≥ 3	218	0.1	843	0.3	1,891	0.8	3,052	1.3	5,304	2.3	7,332	3.0	11,237	4.8	11,615	4.8
Kane, Kendall, McHenry	0	17,726	7.8	22,203	9.0	11,582	5.1	14,660	6.0	5,197	2.3	7,908	3.2	2,660	1.2	6,964	2.8
	1	11,902	5.2	15,064	6.1	25,649	11.3	26,813	10.9	28,024	12.3	27,268	11.1	20,296	8.9	18,848	7.7
	2	2,270	1.0	3,883	1.6	10,347	4.5	13,892	5.6	30,062	13.2	29,705	12.1	40,340	17.7	33,535	13.6
	≥ 3	215	0.1	535	0.2	1,137	0.5	1,978	0.8	5,942	2.6	7,998	3.2	14,291	6.3	15,089	6.1
Lake-IN	0	23,621	8.0	25,384	8.0	13,289	4.5	15,798	5.0	5,950	2.0	10,364	3.3	4,689	1.6	9,830	3.1
	1	18,779	6.4	20,931	6.6	34,149	11.6	32,144	10.1	34,088	11.5	35,911	11.3	26,349	8.9	24,095	7.6
	2	3,060	1.0	5,768	1.8	15,493	5.2	20,330	6.4	34,895	11.8	39,301	12.4	50,839	17.2	43,194	13.6
	≥ 3	336	0.1	847	0.3	2,548	0.9	4,294	1.4	7,992	2.7	10,914	3.4	19,201	6.5	17,794	5.6
Kenosha	0	33,893	18.3	33,660	17.8	11,299	6.1	11,864	6.3	4,687	2.5	4,608	2.4	1,809	1.0	2,059	1.1
	1	20,361	11.0	22,836	12.0	25,765	13.9	28,653	15.1	17,881	9.7	18,683	9.9	7,221	3.9	7,272	3.8
	2	2,819	1.5	3,492	1.8	8,941	4.8	10,699	5.6	20,851	11.3	19,942	10.5	17,172	9.3	14,702	7.8
	≥ 3	76	0.0	85	0.0	1,032	0.6	1,221	0.6	4,595	2.5	4,309	2.3	6,427	3.5	5,546	2.9

Household Vehicle Availability Submodels

The household vehicle availability submodel is a discrete choice logit model similar to choice models to predict mode choice behavior. There are three or four possible vehicle level choices for each household depending on the adults (workers plus nonworking adults) in the household. Single adult households may have none, one, or two or more vehicles; larger households have the alternatives of none, 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 of the model. 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.

Re-Estimation of Vehicle Availability Submodels. The vehicle availability submodels have the following general form:

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

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 existing submodels were re-estimating with data from the CMAP household travel survey. After completing this re-estimation, several incremental changes to the submodels were introduced: (1) some model coefficients in the re-estimation 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 previously

marginally significant model coefficients became insignificant and were dropped, and; (3) a complete set of bias coefficients were estimated.

ALOGIT software ([6]) was used for this model re-estimation. The following work sequence describes the "ESTIMATION" mode of applying the ALOGIT software.

1. Prepare ALOGIT base data file from the CMAP household travel survey. A data set of household characteristics prepared as part of the previous CMAP project to create survey based model estimation and calibration data sets provided the source data.

2. Prepare ALOGIT control file. The control statements are essentially the same as those used in the original estimation of the submodels.

3. Re-estimate the existing submodels' coefficients while maintaining the same equations for the utility equations associated with different levels of vehicle ownership.

4. Evaluate significance of estimation results.

5. Test alternative formulations for the submodels' utility expressions by combining model coefficients and shuffling variables in and out of the utility expressions as indicated by intermediate results and statistical measures of the importance of the coefficients in the estimated utility expressions.

6. Specify final model.

ALOGIT was then rerun in the "APPLY" mode, which applies the specified model to predict the vehicle levels of households given their characteristics in the estimation data set. The "APPLY" results were compared with the actual levels in the estimation data set, and model calibration was completed by adjusting bias coefficients so that estimated and observed levels of household vehicle ownership matched within the parts of the region defined for the household distribution tables (the geographic areas shown in Figure 8). The re-estimated vehicle availability submodels were finally coded into the CMAP trip generation model code.

Vehicle Availability Utilities. Table 9 lists the coefficients in the logit equation utilities that comprise the household vehicle availability submodel. 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.

Temporary File SECOND_HHTEMP.TXT. The household vehicle availability subroutine writes a temporary file with households by type and vehicle availability. Note that the three or more vehicles value in the file is always zero for single person households. When the control variable **PUMA_TG** is turned on the file is named **SECOND_P5_HHTEMP.TXT.** This is a fixed format file as shown in Table 10, and it is retained when the control variable **SAVE_FILE** is true.

Validation. Household vehicle availability estimated by the submodels was compared against data from the 2007 ACS. This comparison is shown in Table 11. Given that the PUMS figures are themselves estimates surrounded by confidence intervals, the model estimates appear reasonable. The lowest vehicle availabilities are slightly overestimated while the highest levels are slightly underestimated. The great majority of households in the region have one and two vehicles available, and these two levels are generally modeled quite well.

Table 9. Vehicle Availability Submodel 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
Workers? ≥ 2 (0/1)						0.5198	0.5198			0.7934	0.7934
Workers? ≥ 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
Income Quartile? ≥ 3 (0/1)		0.9910	1.690			0.8650	0.8650			0.8723	1.571
Income Quartile? = 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					
Bias 1. Inner Chicago		-2.600	-5.077		2.018	-2.827	-4.393		2.806	-1.836	-1.631
Bias 2. Rest of Chicago and Inner Suburbs		-2.676	-4.823		2.259	-2.637	-3.944		2.552	-2.139	-1.789
Bias 3. Mid-Suburbs		-2.869	-4.914		2.151	-2.728	-4.126		1.547	-2.783	-2.668
Bias 4. Far Suburbs and Fringe		-3.082	-4.984		1.925	-3.144	-4.302		2.272	-2.430	-2.278
Goodness of Fit Measures ρ^2 with respect to zero		0.384			0.391				0.448		
ρ^2 with respect to constants		0.169			0.166				0.222		

Table 10. SECOND_HHTEMP.TXT and SECOND _P5_HHTEMP.TXT Temporary Files

SUBZONE	Integer (I6)	Trip generation subzone (6 characters)
HH TYPE 1, 0 VEH	Real Number (F12.4)	Type 1 households without vehicles (12 characters, 4 decimal places)
HH TYPE 1, 1 VEH	Real Number (F12.4)	Type 1 households with one vehicle (12 characters, 4 decimal places)
HH TYPE 1, 2 VEH	Real Number (F12.4)	Type 1 households with two vehicles (12 characters, 4 decimal places)
HH TYPE 1, ≥ 3 VEH	Real Number (F12.4)	Type 1 households with three or more vehicles (12 characters, 4 decimal places)
HH TYPE 2, 0 VEH	Real Number (F12.4)	Type 2 households without vehicles (12 characters, 4 decimal places)
HH TYPE 2, 1 VEH	Real Number (F12.4)	Type 2 households with one vehicle (12 characters, 4 decimal places)
HH TYPE 2, 2 VEH	Real Number (F12.4)	Type 2 households with two vehicles (12 characters, 4 decimal places)
HH TYPE 2, ≥ 3 VEH	Real Number (F12.4)	Type 2 households with three or more vehicles (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
HH TYPE 224, 0 VEH	Real Number (F12.4)	Type 224 households without vehicles (12 characters, 4 decimal places)
HH TYPE 224, 1 VEH	Real Number (F12.4)	Type 224 households with one vehicle (12 characters, 4 decimal places)
HH TYPE 224, 2 VEH	Real Number (F12.4)	Type 224 households with two vehicles (12 characters, 4 decimal places)
HH TYPE 224, ≥ 3 VEH	Real Number (F12.4)	Type 224 households with three or more vehicles (12 characters, 4 decimal places)

Table 11. Household Vehicle Availability: 2007 ACS and Base Year Trip Generation

	0 Vehicles				1 Vehicle				2 Vehicles				3 or More Vehicles			
	PUMS	%	Trip Generation	%	PUMS	%	Trip Gen.	%	PUMS	%	Trip Gen.	%	PUMS	%	Trip Gen.	%
Chicago	323,943	16.7	369,832	18.0	774,561	40.0	818,407	39.7	604,843	31.2	646,078	31.4	232,417	12.0	224,970	10.9
Sub Cook	259,754	25.6	300,177	26.7	443,303	43.7	486,767	43.4	235,644	23.2	262,929	23.4	75,419	7.4	72,390	6.5
DuPage	64,189	7.0	69,655	7.4	331,258	35.9	331,640	35.4	369,199	40.1	383,149	40.9	156,998	17.0	152,580	16.3
Kane	11,214	3.3	15,383	4.6	103,245	30.8	102,905	30.5	150,008	44.7	151,887	44.9	70,825	21.1	67,762	20.1
Kendall	7,705	4.8	9,653	5.7	43,279	27.0	47,747	28.0	72,468	45.2	75,787	44.4	36,950	23.0	37,326	21.9
Lake	777	2.7	945	2.8	5,971	20.7	6,912	20.2	14,574	50.6	16,266	47.6	7,471	25.9	10,067	29.4
McHenry	8,995	3.9	10,281	4.3	62,925	26.9	67,510	27.9	110,833	47.4	111,269	46.1	50,864	21.8	52,490	21.7
Will	3,363	3.2	4,360	3.9	23,228	21.9	29,661	26.4	52,256	49.3	51,001	45.5	27,054	25.5	27,174	24.2
Grundy	6,476	3.1	10,052	4.4	49,862	23.6	59,997	26.2	103,358	49.0	104,326	45.6	51,193	24.3	54,283	23.7
Boone	947	5.7	815	2.6	3,852	23.2	6,243	20.0	7,857	47.2	13,744	44.0	3,976	23.9	10,449	33.4
DeKalb	1,417	4.0	2,093	5.7	10,659	30.1	11,834	32.1	15,358	43.3	15,060	40.8	8,017	22.6	7,935	21.5
Kankakee	2,881	7.2	2,737	6.5	12,735	31.6	13,754	32.5	16,316	40.5	17,590	41.5	8,317	20.7	8,277	19.5
Winnebago	8,226	7.5	6,373	5.2	37,713	34.2	43,144	35.2	42,169	38.3	50,497	41.2	22,054	20.0	22,420	18.3
Lake	16,732	9.1	12,283	6.5	64,697	35.1	65,186	34.4	68,377	37.1	79,446	41.9	34,448	18.7	32,716	17.3
Porter	1,756	2.9	2,709	4.3	17,952	29.4	18,415	28.9	26,889	44.1	28,115	44.1	14,427	23.6	14,490	22.7
LaPorte	2,274	5.5	2,585	6.2	13,775	33.0	13,543	32.5	16,983	40.7	17,282	41.5	8,662	20.8	8,241	19.8
Kenosha	3,931	6.6	4,732	8.0	19,091	31.9	17,982	30.3	25,277	42.2	25,562	43.0	11,539	19.3	11,125	18.7
Racine	4,545	6.0	5,972	8.0	24,457	32.5	24,629	32.8	31,283	41.6	31,040	41.4	14,855	19.8	13,406	17.9
Walworth	1,538	4.0	1,617	4.4	11,659	30.2	11,074	30.3	16,328	42.3	15,414	42.1	9,054	23.5	8,477	23.2
Total	407,209	11.0	463,062	11.9	1,284,476	34.8	1,364,036	35.0	1,382,105	37.5	1,458,162	37.4	616,587	16.7	615,762	15.8

Household Trip Generation

With these preliminary steps completed, the model starts the estimation of trip ends. Trip ends generated by persons living in households are estimated first, followed by trip ends generated by persons living in non-institutional group quarters.

Although a data file for estimating household trip rates was recently prepared from the CMAP household travel survey as part of an earlier CMAP project, it proved advantageous to recreate this data set. Final survey data files were not available when the earlier household trip rate file was prepared, and a few additional households were added to the final files. Second, the original linking of trips – to eliminate change mode and serve passenger trip purposes, as well as incidental stops that occur during commuting trips - maintained only the summary trip purposes (home, work, shop, and nonhome/work) used in the existing CMAP models rather than the twenty-one trip purposes collected in the survey. It was soon apparent that additional trip purposes would be useful for trip linking and in the allocation of trip productions and attractions to trip generation subzones.

Trip Linking. The trip linking program was modified to take advantage of these added trip purposes and survey trips relinked. Three changes were introduced into the linking program: (1) the added survey trip purposes were carried into the linked trip records; (2) beginning and ending trip records for a linked trip record were recorded, and (3) minor changes were made in the logic for trip linking within work commutes.

Rules for eliminating intermediate stops during work commutes were altered to the following.

1. Intermediate trip purposes of: (1) attending class; (2) major purchase shopping; (3) eat meal outside home; (4) health care; and (5) civic religious activities within home-work trips were not considered incidental trip purposes and were not linked.

2. If the time spent at intermediate destinations during the commute trip is greater than thirty minutes than the intermediate destinations are retained.

3. The extra distance (total distance traveled minus the home-workplace distance) traveled to reach intermediate destinations during the home-workplace commute must be less than home-workplace distance for linking to occur. All distances are measured as straight line distances based on latitude-longitude coordinates.

After linking trips, several more variables were added to complete the file for estimating household trip generation rates. The type of person making the trip – worker, nonworking adult, or child between twelve and fifteen – and the household category (the 224 household types as per Figure 6) were added. Non-purposeful trips – mainly home to home or work to work nonmotorized movements – were also eliminated since the remaining models cannot model these types of movements.

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Weighting of Households.   Preliminary household trip generation rates were first calculated by summing trips by trip purpose into tables dimensioned by person type and household trip generation category. These rates were estimated without weighting survey households; but after reviewing these initial trip rates, they were recalculated because of known biases in the CMAP household sample. Trip rates were next re-estimated with households weighted by the expansion factors in the CMAP survey.

The CMAP household expansion factors also yielded suspicious trip rates due to some very large household factors, and it was decided to weight households with expansion factors developed from the combined and averaged three year (2005, 2006, and 2007) ACS PUMS household data. Control totals for each of the 224 household categories were determined from the combined and averaged PUMS annual data. Households in the trip generation data sets were then weighted to equal these control totals. This method for weighting households was selected primarily because of the large sample in the three year PUMS (more than 104,000 households).

Day of Survey. The CMAP survey collected two consecutive days of trip data from some surveyed households, and some two-day households reported trip data for a weekend day. Since the trip rates are for travel on a typical weekday, it was necessary to weight multiple day trips and eliminate weekend trips. For estimating average daily trip rates, trips reported by households submitting two weekday trip reports were weighted by 0.5.

Trip Purposes. A large spreadsheet containing multiple worksheets – the same calculations are repeated for workers, nonworking adults, and children - was developed to estimate household trip generation rates for nearly all trip purposes in the CMAP survey. These large tables were next collapsed into the trip purposes by person type listed in Table 12. The aggregation of trip purposes was largely determined by the number of observations available for estimating each trip rate. The end result is forty-eight different trip purposes; nineteen for workers, thirteen for nonworking adults, and sixteen for children between the ages of twelve and fifteen.

1. Rather than a single home-work trip type, home-workplace and home-related to work trip types (attendance at meetings away from workplace, for example) are differentiated because trips to workplaces tend to be longer. Home-workplace trips are also similar to the journey to work trips in the ACS so they can be compared more directly. Home-workplace trips are eventually divided into trips by low income workers earning less than regional median earnings and high income workers earning more than median earnings.

2. The trip purposes in the CMAP survey allow nonhome/work (workers) and nonhome (nonworkers) trip ends to be separated by whether the trip end is based at households (visits to the households of friends or relative) or not.

3. The school purpose is included recognizing that CMAP presently does not forecast school locations or the students in a subzone. This is thought to be a fairly straightforward enhancement of the model, and it makes sense to allow for school trip

ends in the revised model's code. Maintaining school trip ends may also prove beneficial for trip distribution since school trip lengths likely differ from those of other nonhome/work or nonhome purposes.

4. Home, work and school trip ends are identified as trip productions in this order of relative importance. Consider these examples. A home to workplace trip in the survey and the return workplace to home movement are counted as two home productions and two

Table 12. Trip Rates Tabulated from CMAP Survey

Worker		Nonworking Adults		Child 12 through 15	
Production or Origin	Attraction or Destination	Production or Origin	Attraction or Destination	Production or Origin	Attraction or Destination
Home (P)	Workplace (A) Work-Related (A) School (A) Nonhome/Work at Residence (A) Nonhome/Work Not at Residence (A) Shop (A)	Home (P)	School (A) Nonhome at Residence (A) Nonhome Not at Residence (A) Shop (A)	Home (P)	School (A) Nonhome at Residence (A) Nonhome Not at Residence (A) Shop (A)
Work (P)	Nonhome/Work at Residence (A) Nonhome/Work Not at Residence (A) Shop (A)			School (P)	Nonhome at Residence (A) Nonhome Not at Residence (A) Shop (A)
Work (O)	Work (D)				
Nonhome/Work at Residence (O)	Nonhome/Work at Residence (D) Nonhome/Work Not at Residence (D) Shop (D)	Nonhome at Residence (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)	Nonhome at Residence (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)
Nonhome/Work Not at Residence (O)	Nonhome/Work at Residence (D) Nonhome/Work Not at Residence (D) Shop (D)	Nonhome Not at Residence (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)	Nonhome Not at Residence (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)
Shop (O)	Nonhome/Work at Residence (D) Nonhome/Work Not at Residence (D) Shop (D)	Shop (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)	Shop (O)	Nonhome at Residence (D) Nonhome Not at Residence (D) Shop (D)

workplace attractions. Work (both workplace and work-related) trips are productions except when the other end of the trip is at home. Productions and attractions for work-work trips are equivalent. School trips by children are productions except when the other trip end is home. Trip ends for all remaining trip categories are directional by origin and destination.

Table 13. Grouped Households for Rates

Household Types for Worker Trip Rates

Children	Vehicles	Nonworkers
No	No	No
No	No	Yes
No	Vehicles < Workers	No
No	Vehicles < Workers	Yes
No	Vehicles □ Workers	No
No	Vehicles □ Workers	Yes
Yes	No	Yes or No
Yes	Vehicles < Workers	No
Yes	Vehicles < Workers	Yes
Yes	Vehicles □ Workers	No
Yes	Vehicles □ Workers	Yes

Household Types for Nonworking Adult Trip Rates

Children	Vehicles	Workers
No	No	No
No	No	Yes
No	Vehicles □□Workers	Yes
No	Vehicles > 0	No
No	Vehicles > Workers	Yes
Yes	No	Yes or No
Yes	Vehicles □□Workers	Yes
Yes	Vehicles > 0	No
Yes	Vehicles > Workers	Yes

Household Types for Children 12 - 15

Vehicles
No
Vehicles □□Workers
Vehicles > Workers

Trip Rate Aggregation by Household Types.
The spreadsheet's completed worksheets (one for each person type) are trip rates tabulated by household trip generation category and the above trip purposes. The observations (persons from the CMAP survey) contributing to each rate were again examined. Trip rates that still had too few observations were identified and trip rates were averaged across households with comparable trip generation properties. The scheme for combining households resulted in eleven household categories of trip generation rates for workers, nine household categories for nonworking adults, and three categories for children aged twelve to fifteen as shown in Table 13.

Fraction of Children 12 through 15. To recapitulate, the trip generation model code considers all children in the household when categorizing households, but only children between twelve and fifteen are included in household trip generation. Earlier versions of the model required the fraction of children aged twelve to fifteen in a subzone to be input on the **HH_IN.TXT** file. This is a difficult quantity to determine let alone estimate, and the model code was rewritten to replace the input value with an internal calculation. The three-year ACS PUMS data was again used as source data and an array was added to the code containing the observed fraction of children aged twelve to fifteen for each of the household types that include children.

Home-Workplace Productions by Earnings. It has long been argued that modeling work travel in the CMAP models could be improved by categorizing workers and employment. This would link different types of workers with appropriate employment opportunities, either by earnings or by type of employment. This revision of the trip generation code takes a first step toward that objective.

The revised model code incorporates an array that contains the fraction of workers in a household earning above the median regional worker earnings. Values in the array depend on the type of household (the 224 household types in the model), which distinguishes households by income quartile and number of workers. This array allocates home to workplace productions to workers earning above and below median regional earnings. The three-year regional ACS PUMS data files were summarized to estimate these values.

Trip Rates. The household trip generation rates for workers, nonworking adults, and children aged twelve to fifteen are in Tables 14 through 16. All rates are weekday trips per person. Household categories matching those in Table 13 are in the top rows of the tables. These rates were calculated from sample observations and have some implied confidence intervals around them. Even though they are shown with three decimal places, most of the rates are reasonably accurate only to one or two significant figures. Trip purposes are numbered as they are in the model code. Trip purpose number two in the worker tables is a row reserved for splitting home-workplace trips by worker earnings.

Table 17. 1990 and Current Trip Rates

	1990 CATS Survey	2007-2008 CMAP Survey
Worker		
Home-Work	1.62	1.37
Home-Shop	0.33	0.35
Home-Other	0.77	0.91
Work-Shop	0.08	0.07
Work-Other	0.34	0.29
Work-Work	0.25	0.44
Other-Other	0.28	0.46
All Types	3.67	3.88
Nonworker		
Home-Shop	0.71	0.56
Home-Other	1.40	1.48
Other-Other	0.60	0.77
All Types	2.71	2.81
Child 12-15		
Home-Other	1.45	1.77

Stability of Trip Rates. It has long been assumed that trip generation rates are fairly stable. Table 17 is a comparison of household trip generation rates estimated from the 1990 CATS household travel survey ([7]) versus rates from the 2007-2008 CMAP survey. The trip categories in the table are the eleven trip categories in the existing CMAP models. It should be noted that the figures in the table are averaged across all types of households, so changes in rates between 1990 and the present reflect changes in household composition as well as travel behavior. Rates for the 1990 survey are also not the product of weighted households since household types were not combined to calculate these earlier rates.

In spite of the differences between the two sets of trip rates, the general impression is that the new CMAP survey based trip rates are somewhat larger but still roughly comparable to those estimated from the 1990 CATS survey. The most important change appears to be in home-work travel. Possible reasons for this include more persons working at home or a tendency away from the traditional home-workplace commute trip to more complex trip making whereby several trip purposes are linked during travel between work and home. Additional trips by nonworking adults are probably the result of increased household vehicle ownership, which means that nonworkers are increasingly likely to have access to vehicles. Additional trips by children are also probably at least partly the result of increased auto availability. However, increased travel by children in 2007-2008 may just reflect the timing of the two surveys. The

CMAP survey was taken in the fall and winter during the school term while the 1990 survey was taken at different times throughout the year.

Table 14a. Trip Generation Rates for Workers: Households Without Children

No.	Production or Origin	Attraction or Destination	Trip Generation Rate Household Types					
			Children = 0					
			Vehicles = 0		Vehicles < Workers		Vehicles ≥ Workers	
			Nonworkers = 0	Nonworkers > 0	Nonworkers = 0	Nonworkers > 0	Nonworkers = 0	Nonworkers > 0
1	Home (P)	Workplace (A)	1.055	1.083	1.080	1.126	1.147	1.187
3		Work-Related (A)	0.113	0.076	0.145	0.132	0.179	0.151
4		School (A)	0.016	0.030	0.046	0.096	0.029	0.073
5		Nonhome/Work at Residence (A)	0.159	0.089	0.133	0.149	0.144	0.149
6		Nonhome/Work Not at Residence (A)	0.684	0.440	0.821	0.494	0.804	0.740
7		Shop (A)	0.295	0.349	0.342	0.334	0.335	0.349
8	Work (P)	Nonhome/Work at Residence (A)	0.032	0.009	0.014	0.012	0.026	0.020
9		Nonhome/Work Not at Residence (A)	0.273	0.056	0.257	0.082	0.320	0.233
10		Shop (A)	0.081	0.038	0.068	0.045	0.097	0.065
11	Work (O)	Work (D)	0.072	0.047	0.087	0.101	0.181	0.139
12	Nonhome/Work at Residence (O)	Nonhome/Work at Residence (D)	0.007	0.000	0.004	0.004	0.012	0.009
13		Nonhome/Work Not at Residence (D)	0.022	0.009	0.025	0.011	0.025	0.024
14		Shop (D)	0.008	0.005	0.007	0.013	0.015	0.011
15	Nonhome/Work Not at Residence (O)	Nonhome/Work at Residence (D)	0.019	0.010	0.031	0.030	0.036	0.031
16		Nonhome/Work Not at Residence (D)	0.175	0.109	0.150	0.114	0.193	0.146
17		Shop (D)	0.088	0.084	0.104	0.064	0.116	0.080
18	Shop (O)	Nonhome/Work at Residence (D)	0.012	0.009	0.010	0.000	0.015	0.011
19		Nonhome/Work Not at Residence (D)	0.050	0.033	0.046	0.048	0.069	0.056
20		Shop (D)	0.044	0.009	0.079	0.068	0.092	0.071

Table 14b. Trip Generation Rates for Workers: Households With Children

			Trip Generation Rate Household Types				
			Children > 0				
			Vehicles = 0	Vehicles < Workers		Vehicles ≥ Workers	
No.	Production or Origin	Attraction or Destination	Nonworkers ≥ 0	Nonworkers = 0	Nonworkers > 0	Nonworkers = 0	Nonworkers > 0
1	Home (P)	Workplace (A)	0.954	1.149	1.052	1.133	1.236
3		Work-Related (A)	0.080	0.110	0.213	0.173	0.145
4		School (A)	0.060	0.094	0.159	0.041	0.072
5		Nonhome/Work at Residence (A)	0.118	0.149	0.129	0.134	0.107
6		Nonhome/Work Not at Residence (A)	0.494	0.840	0.707	0.844	0.745
7		Shop (A)	0.401	0.369	0.265	0.382	0.331
8	Work (P)	Nonhome/Work at Residence (A)	0.035	0.024	0.026	0.017	0.018
9		Nonhome/Work Not at Residence (A)	0.106	0.253	0.045	0.280	0.258
10		Shop (A)	0.067	0.061	0.010	0.084	0.051
11	Work (O)	Work (D)	0.019	0.111	0.106	0.143	0.136
12	Nonhome/Work at Residence (O)	Nonhome/Work at Residence (D)	0.009	0.010	0.030	0.003	0.004
13		Nonhome/Work Not at Residence (D)	0.019	0.018	0.033	0.027	0.016
14		Shop (D)	0.000	0.001	0.022	0.013	0.004
15	Nonhome/Work Not at Residence (O)	Nonhome/Work at Residence (D)	0.025	0.021	0.034	0.027	0.019
16		Nonhome/Work Not at Residence (D)	0.088	0.120	0.051	0.158	0.130
17		Shop (D)	0.057	0.061	0.105	0.091	0.073
18	Shop (O)	Nonhome/Work at Residence (D)	0.000	0.006	0.042	0.014	0.007
19		Nonhome/Work Not at Residence (D)	0.063	0.040	0.020	0.045	0.043
20		Shop (D)	0.139	0.055	0.069	0.081	0.049

Table 15a. Trip Generation Rates for Nonworking Adults: Households Without Children

			Trip Generation Rate Household Types				
			Children = 0				
			Vehicles = 0		Vehicles ☐ Workers	Vehicles > 0	Vehicles > Workers
No.	Production or Origin	Attraction or Destination	Workers = 0	Workers > 0	Workers > 0	Workers = 0	Workers > 0
21	Home (P)	School (A)	0.034	0.164	0.244	0.016	0.251
22		Nonhome at Residence (A)	0.147	0.072	0.171	0.213	0.228
23		Nonhome Not at Residence (A)	0.884	0.719	0.808	1.366	1.009
24		Shop (A)	0.506	0.332	0.462	0.684	0.539
25	Nonhome at Residence (O)	Nonhome at Residence (D)	0.013	0.004	0.003	0.012	0.010
26		Nonhome Not at Residence (D)	0.018	0.005	0.021	0.038	0.039
27		Shop (D)	0.010	0.000	0.016	0.031	0.021
28	Nonhome Not at Residence (O)	Nonhome at Residence (D)	0.026	0.018	0.026	0.049	0.044
29		Nonhome Not at Residence (D)	0.112	0.082	0.147	0.342	0.233
30		Shop (D)	0.094	0.063	0.076	0.257	0.156
31	Shop (O)	Nonhome at Residence (D)	0.014	0.004	0.006	0.028	0.027
32		Nonhome Not at Residence (D)	0.059	0.040	0.052	0.137	0.085
33		Shop (D)	0.097	0.077	0.120	0.195	0.137

Table 15b. Trip Generation Rates for Nonworking Adults: Households With Children

No.	Production or Origin	Attraction or Destination	Trip Generation Rate Household Types			
			Children > 0			
			Vehicles = 0	Vehicles ☐ Workers	Vehicles > 0	Vehicles > Workers
			Workers ☐ 0	Workers > 0	Workers = 0	Workers > 0
21	Home (P)	School (A)	0.306	0.464	0.105	0.334
22		Nonhome at Residence (A)	0.181	0.174	0.325	0.219
23		Nonhome Not at Residence (A)	0.601	0.789	1.056	1.201
24		Shop (A)	0.479	0.340	0.742	0.553
25	Nonhome at Residence (O)	Nonhome at Residence (D)	0.017	0.013	0.026	0.007
26		Nonhome Not at Residence (D)	0.015	0.020	0.035	0.036
27		Shop (D)	0.025	0.009	0.033	0.014
28	Nonhome Not at Residence (O)	Nonhome at Residence (D)	0.008	0.030	0.048	0.039
29		Nonhome Not at Residence (D)	0.082	0.144	0.400	0.275
30		Shop (D)	0.116	0.096	0.187	0.157
31	Shop (O)	Nonhome at Residence (D)	0.012	0.012	0.024	0.012
32		Nonhome Not at Residence (D)	0.069	0.043	0.144	0.074
33		Shop (D)	0.078	0.060	0.120	0.104

Table 16. Trip Generation Rates for Children 12 Through 15

No.	Production or Origin	Attraction or Destination	Trip Generation Rate Household Types		
			Vehicles = 0	Vehicles □ Workers	Vehicles > Workers
34	Home (P)	School (A)	1.026	0.874	0.818
35		Nonhome at Residence (A)	0.217	0.178	0.178
36		Nonhome Not at Residence (A)	0.228	0.546	0.664
37		Shop (A)	0.150	0.110	0.193
38	School (P)	Nonhome at Residence (A)	0.078	0.042	0.028
39		Nonhome Not at Residence (A)	0.032	0.067	0.095
40		Shop (A)	0.016	0.013	0.027
41	Nonhome at Residence (O)	Nonhome at Residence (D)	0.014	0.012	0.008
42		Nonhome Not at Residence (D)	0.000	0.018	0.027
43		Shop (D)	0.040	0.005	0.007
44	Nonhome Not at Residence (O)	Nonhome at Residence (D)	0.000	0.032	0.017
45		Nonhome Not at Residence (D)	0.029	0.094	0.100
46		Shop (D)	0.056	0.018	0.042
47	Shop (O)	Nonhome at Residence (D)	0.008	0.008	0.007
48		Nonhome Not at Residence (D)	0.030	0.013	0.021
49		Shop (D)	0.046	0.018	0.021

Temporary File PRODS_HH.TXT. The subroutine that does the household trip generation writes a temporary file named **PRODS.HH.TXT** or **PRODS_P5_HH.TXT** when the control variable **PUMA_TG** is true. This file is kept after the model run is completed when the control variable **SAVE_FILE** is true, otherwise it is deleted.

There are forty-nine trip categories in this file, which are carried forward for the remaining calculations. The added trip category is due to the factoring of home-workplace trips into home-workplace trips for workers with less than median regional earnings and workers with greater than median earnings. Home-workplace trips are generated first using a single home-workplace rate. Then, the home-workplace trips by household type are factored using the proportion of high income workers by household type.

The format for this temporary file is listed in Table 18. This is a fixed format file with variables formatted as shown. The file contains four subzone household summaries varying with vehicle availability and the presence of children. These are followed by the worker trip categories, then trips for nonworkers, and finally trips made by children aged twelve through fifteen. The trip purposes are in order as listed in Tables 14 through 16.

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.

Trip Generation Rates. Since group quarters trip generation rates could not be obtained from the CMAP survey, it is necessary to assume that they are similar to those of persons in households who resemble persons in group quarters. Rates for workers or nonworking adults in single person households without children or vehicles are thought to most closely match the rates for workers and nonworkers in group quarters. For these calculations, all workers in group quarters are assumed to be in the low income category.

Single person household rates are used for group quarters trip generation rates with the exception of the home-workplace trip. Journey to work data from 2006 and 2007 ACS PUMS data are available for non-institutionalized group quarters workers in the ACS household and person files for these two years. Persons in group quarters ACS PUMS data were tabulated by five percent PUMS to estimate the weekday home-workplace trips per group quarters worker. The fraction of PUMS group quarters workers commuting was doubled to approximate a trip rate for weekday home-workplace trips.

The fraction of all group quarters workers' commuting trips completed by nonmotorized modes was also obtained from the group quarters person records in the two years of ACS PUMS. These factors were also estimated at the level of five percent PUMAs. .

Table 18. PRODS_HH.TXT and PRODS_P5_HH.TXT Temporary Files

SUBZONE	Integer (I6)	Trip generation subzone (6 characters)
HH 0 CHILD, 0 VEH	Real Number (F12.4)	Households without children and without vehicles (12 characters, 4 decimal places)
HH CHILD, 0 VEH	Real Number (F12.4)	Households with children and without vehicles (12 characters, 4 decimal places)
HH 0 CHILD, VEH	Real Number (F12.4)	Households without children and with vehicles (12 characters, 4 decimal places)
HH CHILD, VEH	Real Number (F12.4)	Households without children and with vehicles (12 characters, 4 decimal places)
WORKER TRIP PURPOSE 1	Real Number (F12.4)	Home-workplace trips by workers with low earnings (12 characters, 4 decimal places)
WORKER TRIP PURPOSE 2	Real Number (F12.4)	Home-workplace trips by workers with high earnings (12 characters, 4 decimal places)
WORKER TRIP PURPOSE 3	Real Number (F12.4)	Home-work related trips by workers (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
WORKER TRIP PURPOSE 19	Real Number (F12.4)	Shop-shop trips made by workers (12 characters, 4 decimal places)
NONWORKER TRIP PURPOSE 20	Real Number (F12.4)	Home-nonhome trips at residences by nonworking adults (12 characters, 4 decimal places)
NONWORKER TRIP PURPOSE 21	Real Number (F12.4)	Home-nonhome trips not at residences by nonworking adults (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
NONWORKER TRIP PURPOSE 33	Real Number (F12.4)	Shop-shop trips made by nonworking adults (12 characters, 4 decimal places)
CHILD TRIP PURPOSE 34	Real Number (F12.4)	Home-nonhome trips at residences by children 12-15 (12 characters, 4 decimal places)
CHILD TRIP PURPOSE 35	Real Number (F12.4)	Home-nonhome trips not at residences by children 12-15 (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
CHILD TRIP PURPOSE 49	Real Number (F12.4)	Shop-shop trips by children 12-15 (12 characters, 4 decimal places)

Group Quarters Input File. The subroutine that estimates group quarters trip generation reads an input file named **GQ_IN.TXT**. This is a comma delimited file with the format listed in Table 19. The group quarters home-workplace trip rates and fractions of group quarters persons commuting by nonmotorized means are entered into the model via this file. They were calculated within five percent PUMAs and the same values are repeated for all trip generation subzones in a PUMA. The nonmotorized fraction is the ratio of nonmotorized group quarters home-workplace commute trips to all group quarters home-workplace commute trips (a different definition than the auto mode share variable for household workers), and it is later used in the calculations that separate vehicular and nonmotorized trip ends.

Table 19. GQ_IN.TXT Input File

SUBZONE	Integer (1-25000)	The trip generation subzone, which must be in sequence in the file from low to high values.
GQ WORDERS	Integer	Non-institutionalized group quarters workers in the trip generation subzone.
GQ NONWORKERS	Integer	Non-institutionalized group quarters nonworkers in the trip generation subzone.
GQ WORKER WORK TRIP RATE	Real Number	Home-workplace trip generation rate for workers in group quarters.
GQ WORKER NON-MOTOR COMMUTE	Real Number	Fraction of all group quarters worker commute trips (excludes work at home) by nonmotorized modes.

Temporary File PRODS_GQ.TXT. The group quarters subroutine writes a temporary file named **PRODS_GQ.TXT**, which can be retained after the model run by setting the control variable **SAVE_FILE** to true. This file is nearly the same as **PRODS_HH.TXT** except it has fewer trip purposes because it lacks trips for children. For compatibility with the household file, a zero is placed in the second trip purpose for no group quarters high income home-workplace trips. The variables in this file are listed in Table 20.

ACS Journey to Work and Modeled Home-Workplace Trips. Since the CMAP survey was used to estimate the rates, it cannot be used to validate the resulting trip estimates. The other major source of data for the project, the ACS, has information only on the journey to work. Unfortunately, the journey to work questions on the census long-form deal with typical commuting during a week, which is not the same as reporting one's commute during a specific day. Table 21 compares the 2005-2007 three year average ACS journey to work figures with the modeled home-workplace trips.

In Table 21, work at home workers are removed from the ACS data to make the two sets of home-workplace trip more comparable. On the side of the table listing trip generation model estimates, home-workplace trips from persons in households and group quarters are totaled to be consistent with ACS workers. Counties that lie partially outside the modeled study area are again not included in the table.

Table 20. PRODS_GQ.TXT Temporary File

SUBZONE	Integer (I6)	Trip generation subzone (6 characters)
GQ WORKER TRIP PURPOSE 1	Real Number (F12.4)	Home-workplace trips by group quarters workers with low earnings. (12 characters, 4 decimal places)
ZERO	Real Number (F12.4)	Zero (12 characters, 4 decimal places)
GQ WORKER TRIP PURPOSE 3	Real Number (F12.4)	Home-work related trips by workers (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
GQ WORKER TRIP PURPOSE 19	Real Number (F12.4)	Shop-shop trips made by workers (12 characters, 4 decimal places)
GQ NONWORKER TRIP PURPOSE 20	Real Number (F12.4)	Home-nonhome trips at residences by nonworking adults. (12 characters, 4 decimal places)
GQ NONWORKER TRIP PURPOSE 21	Real Number (F12.4)	Home-nonhome trips not at residences by nonworking adults (12 characters, 4 decimal places)
. . . .	. . . .	. . . .
GQ NONWORKER TRIP PURPOSE 33	Real Number (F12.4)	Shop-shop trips by nonworking adults (12 characters, 4 decimal places)

Table 21. ACS Journey to Work Trips and Modeled Home-Workplace Trips

	2005-2007 ACS Journey to Work			Modeled Home-Workplace Trips			ACS/ Trip Generation
	Workers	Work at Home	ACS Commuters	Households	Group Quarters	Total	
Chicago	1,203,063	40,638	1,162,425	1,416,714	5,857	1,422,571	0.82
Sub Cook	1,176,899	36,980	1,139,919	1,351,024	3,771	1,354,795	0.84
DuPage	466,098	20,651	445,447	533,874	2,866	536,740	0.83
Kane	235,466	9,599	225,867	272,079	277	272,356	0.83
Kendall	44,626	1,474	43,152	61,827	11	61,838	0.70
Lake	342,154	17,219	324,935	376,026	10,561	386,587	0.84
McHenry	154,228	7,836	146,392	180,208	24	180,232	0.81
Will	314,656	11,216	303,440	364,380	588	364,968	0.83
Grundy	22,122	778	21,344	25,357	0	25,357	0.84
Boone	23,669	1,058	22,611	58,954	0	58,954	0.38
DeKalb	50,768	1,510	49,258	55,606	1,056	56,662	0.87
Kankakee	47,330	1,439	45,891	56,893	362	57,255	0.80
Winnebago	134,092	4,083	130,009	157,248	168	157,416	0.83
Lake	211,988	4,385	207,603	245,495	792	246,287	0.84
Porter	75,220	2,767	72,453	90,255	834	91,089	0.80
LaPorte	49,002	1,633	47,369	57,544	3	57,547	0.82
Kenosha	75,512	1,956	73,556	86,659	340	86,999	0.85
Racine	92,960	2,214	90,746	104,045	9	104,054	0.87
Walworth	51,575	1,770	49,805	54,960	1,230	56,190	0.89
Total	4,771,428	169,206	4,602,222	5,549,148	28,749	5,577,897	0.83

The ACS journey to work and the modeled home-workplace trips should be in roughly the same ratio throughout the region. There should be fewer ACS journey to work movements than the bidirectional home production-workplace attraction model estimates, yet this ratio should be somewhat more than 50 percent because the ACS includes all work travel taking

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place during a week while the CMAP survey records trips during one or two days. This is the case except for Boone and Kendall counties where the model estimates are inconsistent with the remainder of the modeled study area. Both counties are near the edges of the region and rapidly growing. The different years for the two sets of figures – the 2005-2007 average ACS versus the 2010 model target year – may partly explain why these two counties are so different from other counties.

Allocation of Nonhome 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. We also know the location of the trip end for all home production ends of trips. What remains to be determined is where the nonhome trip ends are located. These are allocated to trip generation subzones in this step of the model.

The allocation process is not complicated. An attractiveness share is calculated for each subzone, which depending on the trip's purpose is some function of employment or households in the 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.

Employment Input File. An input file is read before the allocation of nonhome trip ends takes place. This file is named **ATTR_IN.TXT** and it is analogous to the input files for households and group quarters. It is another comma delimited file with the format shown in Table 22.

Table 22. ATTR_IN.TXT Input File

SUBZONE	Integer (1-25000)	The trip generation subzone, which must be in sequence in the file from low to high values.
RETAIL EMP	Integer	Retail employment in the trip generation subzone.
TOTAL EMP	Integer	Total employment in the trip generation subzone.
FRAC HIGH EARN	Real Number	The fraction of workers working in the subzone with earnings above the regional median worker earnings.

The two employment quantities are prepared by CMAP as part of the regional socioeconomic forecast. The fraction of higher income workers working in the subzone is a new input variable associated with this revision of the CMAP trip generation. In the file created for model development this variable was estimated from the 2000 CTPP, Table 2-19 of the Part 2 summaries by workplace. It is anticipated that a CTPP-like product will be prepared from the five year cumulative ACS and it will allow this variable to be updated. Employment figures for Indiana and Wisconsin are factored by the control variables **WI_EMPFACT** and **IN_EMPFACT** immediately after the file is read.

Subzone Shares of Trip Ends. One problem encountered in estimating the share of nonhome trip ends that each subzone should receive was caused by the different household sample rates

in the CMAP survey in Illinois and Indiana. In calculating household trip generation rates, this was ignored and a single regional expansion factor was calculated for each household type. This is not unreasonable since one would not expect rates for the same categories of individuals in the same types of household to differ by state. However, the different sample rates do affect trips made because travelers are far more likely to complete trips, and have both trip ends, in their state of residence. If a single household type expansion factor were applied for households from Illinois and Indiana then Indiana trips would be substantially under represented and Illinois trips slightly over expanded due to the higher household sample rate in Indiana. As a result new household expansion factors were calculated for the 224 household types within each state that respected the different household sampling rates.

The newly expanded trips from the CMAP survey were tabulated into three spreadsheets for workers, nonworking adults, and children ages twelve thorough fifteen. Each spreadsheet includes tables of nonhome trip ends by purpose and by five percent PUMAs, and the Chicago CBD. Additional columns in the spreadsheets have households, retail, non-retail and total employment in the same geographic areas.

Linear regressions were repeatedly run for the estimation data in the spreadsheets. In these regressions, different combinations of employment and households were the independent variables and trip ends the dependent variable. These regression provided guidance as to which dependent variables should be linked with which trip purposes for allocation. For the majority of trip purposes, a single independent household/employment variable proved adequate and logical, workplace purposes were linked with total employment, shop purposes with retail employment, and so forth. A minority of trip purposes were linked to linear combinations of retail and non-retail employment.

When a single independent household/employment variable is used for the allocation, its weight is the average trip ends per type of employment or average trip ends per household. The weights are needed in this case only because separate averages are calculated for CBD and non-CBD subzones. When the allocation is a linear combination of retail and non-retail employment, the result is also weighted differently for CBD and non-CBD subzones. The added trip purposes carried through the calculations greatly simplify the linking of trip ends to household/employment variables.

Weights for allocation of nonhome productions or attractions are listed in Table 23. Table 24 is a similar table listing the weights for allocation of nonhome 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 23. Weights for Allocation of Production or Origin Nonhome Trip Ends

Production or Origin	Attraction or Destination	Households CBD	Households Non-CBD	Retail CBD	Retail Non-CBD	Non-Retail CBD	Non-Retail Non-CBD	Total CBD	Total Non-CBD
Worker									
Work (P)	Nonhome/Work at Residence (A)							0.018	0.018
Work (P)	Nonhome/Work Not at Residence (A)							0.399	0.217
	Shop (A)							0.087	0.070
Work (O)	Work (D)							0.093	0.140
Nonhome/Work at Residence (O)	All Destinations (D)	0.109	0.062						
Nonhome/Work Not at Residence (O)				1.591	1.356	0.017	0.064		
Shop (O)				0.684	1.070				
Nonworking Adult									
Nonhome at Residence (O)	All Destinations (D)	0.050	0.053						
Nonhome 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	
Nonhome at Residence (O)	All Destinations (D)	0.019	0.036						
Nonhome Not at Residence (O)					0.786		0.022	0.011	
Shop (O)				0.042	0.346				

Table 24. Weights for Allocation of Attraction or Destination Nonhome Trip Ends

Production or Origin	Attraction or Destination	Households CBD	Households Non-CBD	Retail CBD	Retail Non-CBD	Non-Retail CBD	Non-Retail Non-CBD	Total CBD	Total 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		
	Nonhome/Work at Residence (A)	0.363	0.170						
	Nonhome/Work Not at Residence (A)			3.340	3.879	0.068	0.216		
	Shop (A)			0.891	2.127				
Work (P)	Nonhome/Work at Residence (A)	0.129	0.025						
	Nonhome/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)	Nonhome/Work at Residence (D)	0.109	0.062						
	Nonhome/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	
	Nonhome at Residence (A)	0.100	0.197						
	Nonhome Not at Residence (A)				3.550		0.266	0.190	
	Shop (A)			0.545	2.218				
All Origins (O)	Nonhome at Residence (D)	0.050	0.053						
	Nonhome 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		
	Nonhome at Residence (A)	0.152	0.134						
	Nonhome Not at Residence (A)			0.644	3.346	0.006	0.233		
	Shop (A)			0.073	0.820				
School (P)	Nonhome at Residence (A)	0.019	0.036						
	Nonhome Not at Residence (A)				0.786		0.022	0.011	
	Shop (A)			0.042	0.346				
All Origins (O)	Nonhome at Residence (D)	0.019	0.036						
	Nonhome Not at Residence (D)				0.786		0.022	0.011	
	Shop (D)			0.042	0.346				

Optional Output File FIRST_PA.TXT. If the **SAVE_FILE** control variable is true an optional file is written with the household and group quarters trip ends - productions/origins and attractions/destinations at this point in the model. This file is in a fixed format designed to be

easily read by commercial data base management software. There is one record per subzone as shown in Table 25. The group quarters variables are zero for the second (high income home-workplace) trip type and for trip types 34-49 (child trip types).

Table 25. FIRST_PA.TXT Optional File

SUBZONE	Integer (I6)	Trip generation subzone (1-25000) (6 characters)
ZONE	Integer (I6)	Modeling zone number (1-5000) (6 characters).
TRIP TYPE	Integer (I2)	Trip type (1-49) as per Tables 14-16 (2 characters).
HH PRODS	Real Number (F9.1)	Household productions/origins for trip type (9 characters, 1 decimal place)
HH ATTRS	Real Number (F9.1)	Household attractions/destinations for trip type (9 characters, 1 decimal place)
GQ PRODS	Real Number (F9.1)	Group quarters productions/origins for trip type (9 characters, 1 decimal place)
GQ ATTRS	Real Number (F9.1)	Group quarters attractions/destinations for trip type (9 characters, 1 decimal place)

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.

External Trip Factor Input File. These external trip factors are entered in a new model input file named **EXT_IN.TXT.** This is a comma delimited with one record for every five percent PUMA with the variables listed in Table 26.

Table 26. EXT_IN.TXT Input File

FIVE PERCENT PUMA	Integer	Six digit numeric code for five percent PUMAs (two digit county FIPS code plus four digit code for five percent PUMA).
EXT PROD FACT	Real Number	Fraction of home productions in home-workplace trips linked to external workplace attractions.
EXT ATTR FACT	Real Number	Fraction of workplace attractions in home-workplace trips linked to external home productions.

Optional File EXTERNAL_PA.TXT. An optional output file with the externally linked trip ends is written when **SAVE_FILE** is true. These external trips should be helpful when creating trip tables between points of entry into the modeled study area and zones. This fixed format file has the variables in the format listed in Table 27.

Table 27. EXTERNAL_PA.TXT Optional File

SUBZONE	Integer (I6)	Trip generation subzone (1-25000) (6 characters)
ZONE	Integer (I6)	Modeling zone number (1-5000) (6 characters).
TRIP TYPE	Integer (I2)	Trip type (1-2 for home–workplace purposes) (2 characters).
EXT PRODS	Real Number (F9.1)	Household productions linked to workplaces outside the modeled study area. (9 characters, 1 decimal place)
EXT ATTRS	Real Number (F9.1)	Workplace attractions linked to households outside the modeled study area. (9 characters, 1 decimal place)

Optional Output File SECOND_PA.TXT. If the **SAVE_FILE** control variable is true, a second optional file is written by the external trips subroutine that contains the household trip productions/origins and attractions/destinations after removing external trip ends. Note that the production/origins and attractions/destinations for persons in group quarters are excluded from the external trip factoring and at this point do not change from the values in Table 25.

Table 28 lists the format for the **SECOND.PA.TXT** file. It is in the standard fixed format used previously for similar files (Table 25 and Table 27).

Table 28. SECOND_PA.TXT Optional File

SUBZONE	Integer (I6)	Trip generation subzone (1-25000) (6 characters)
ZONE	Integer (I6)	Modeling zone number (1-5000) (6 characters).
TRIP TYPE	Integer (I2)	Trip type (1-49) as per Tables 14-16 (2 characters).
HH PRODS	Real Number (F9.1)	Household trip productions/origins for trips within the modeled study area. (9 characters, 1 decimal place)
HH ATTRS	Real Number (F9.1)	Household trip attractions/destinations for trips within the modeled study area. (9 characters, 1 decimal place)

Nonmotorized Submodels

The final product of the CMAP trip generation model is person trip ends for vehicular trips wholly within the modeled area. The remaining step in the model is, therefore, to estimate and remove person trips that are made by nonmotorized modes. New nonmotorized mode choice models were developed in this model revision for this purpose.

Nonmotorized Vehicular Mode Choice. The nonmotorized submodels are all binary choice models that forecast the proportion of trip productions/origins that will be completed by nonmotorized modes. It is assumed that nonmotorized trips take place within a subzone or more generally that the nonmotorized productions/origins equals the nonmotorized attractions/destinations in the subzone.

Expanded trips from the CMAP survey were tabulated by vehicular and nonmotorized modes by trip purpose for five percent PUMAs and the Chicago CBD. Independent variables suspected of affecting nonmotorized-vehicular mode choice were next added to these tables, 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 five percent PUMA by their area.

Fairly simple aggregate logit models were then estimated from the quantities in these spreadsheets using the ALOGIT program. The combined home-workplace and home-work related nonmotorized submodel was also re-estimated using nonmotorized commuting proportions tabulated from the ACS PUMS data. There proved to be little difference between the two work submodels estimated with CMAP survey and ACS data, but the ACS submodel was coded into the trip generation model only because the ACS has a much larger sample of households.

The nonmotorized submodels plus their nonmotorized utility coefficients and vehicular bias are listed in Table 29.

Table 29. Utility Variables in the Nonmotorized Submodels

		Nonmotorized Utility Variables				Vehicle Bias	ρ^2 with respect to zero	ρ^2 with respect to constants
		Employment/ Area (1000's)	Pedestrian Environment Factor	No Vehicle Households/ All Households	Households/ Area (1000's)			
Worker								
Home	Workplace Work-Related	0.0799	0.0129	2.598		4.237	0.797	0.081
	Nonwork	0.0023	0.0724	2.398		4.133	0.632	0.131
Work	Nonhome	0.0089	0.0850			4.236	0.577	0.343
Nonhome/Work	Non-Home/Work	0.0082	0.0380		0.1380	3.835	0.656	0.224
Nonworking Adult								
Home	Nonhome		0.0551	1.530		3.399	0.546	0.077
Nonhome	Nonhome	0.0024	0.0855		0.0831	4.396	0.638	0.204
Child 12-15								
Home	Nonhome		0.0535			2.383	0.314	0.045
Nonhome	Nonhome		0.0625			3.137	0.498	0.059

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

1. The two density variables in the nonmotorized utility are average total employment and households per square mile within the subzone.

2. The pedestrian environment factor was input into the model in an earlier step.

3. The no vehicle household fraction is determined internally within the model by the submodel for household vehicle availability.

4. The utility for the vehicular choice is a constant in all the models and is essentially treated as bias toward the motorized choice.

The nonmotorized submodels implemented in the trip generation code are also bounded by the highest observed percentages of nonmotorized trips, the average nonmotorized fraction of trips in the Chicago CBD.

Optional Output File NONMOTOR_PA.TXT. The subroutine for the nonmotorized calculations can also output and optional file with the nonmotorized trip ends. This file is the **NONMOTOR_PA.TXT** file. It is another fixed format file similar to earlier output files of productions/origins and attractions/destinations. Variables in the **NONMOTOR_PA.TXT** file are listed in Table 30.

For households, the nonmotorized trip productions/origins should equal nonmotorized attractions/destinations except when the latter have been adjusted due to too few attractions in the subzone. The nonmotorized productions/origins for persons in group quarters always equal the nonmotorized attractions/destinations.

Table 30. NONMOTOR_PA.TXT Optional File

SUBZONE	Integer (I6)	Trip generation subzone (1-25000) (6 characters)
ZONE	Integer (I6)	Modeling zone number (1-5000) (6 characters)
TRIP TYPE	Integer (I2)	Trip type (1-49) as per Tables 14-16 (2 characters)
HH NM PRODS	Real Number (F9.1)	Household nonmotor productions/origins for trips within the modeled study area. (9 characters, 1 decimal place)
HH NM PRODS FRAC	Real Number (F6.3)	Household nonmotor productions/origins as a fraction of all household productions/origins. (6 characters, 3 decimal places)
HH NM ATTRS	Real Number (F9.1)	Household nonmotor attractions/destinations for trips within the modeled study area. (9 characters, 1 decimal place)
HH NM ATTRS FRAC	Real Number (F6.3)	Household nonmotor attractions/destinations as a fraction of all household attractions/destinations. (6 characters, 3 decimal places)
GQ NM TRIP P/A	Real Number (F9.1)	Group quarters nonmotor trip ends (productions/origins equal attractions/destinations). (9 characters, 1 decimal place)
GQ NM PRODS FRAC	Real Number (F6.3)	Group quarters nonmotor productions/origins as a fraction of all Group quarters productions/origins. (6 characters, 3 decimal places)
GQ NM ATTRS FRAC	Real Number (F6.3)	Group quarters nonmotor attractions/destinations as a fraction of all Group quarters attractions/destinations. (6 characters, 3 decimal places)

Final Reports and Trip Output Files

The last subroutine in the model code writes the final trip reports into **TG_OUTPUT.TXT.** It also creates an output file for use in the remaining CMAP models. The trip types included in this file are either the current CMAP model's eleven trip purposes or the expanded forty-nine purposes that are carried in this revision of the trip generation model. The control variable **EXP_TTYPE** determines the number of trip purposes included in this file.

The output files with the final vehicular trip ends for internal trips for all residents in the modeled study area are named either **TRIP49_PA.TXT** or **TRIP11_PA.TXT**, depending on the number of trip purposes requested by the user. Regardless of naming, the file is in by now familiar fixed format previously used. Variables in these output files are listed in Table 31.

Table 31. TRIP11_PA.TXT or TRIP49_PA.TXT Final Trip Ends File

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

Correspondence between the forty-nine expanded trip purposes and the eleven current CMAP trip purposes is shown in the concluding Table 32.

Table 32. Correspondence Between Expanded and Current Trip Purposes

	Expanded Trip Purposes			Current CMAP Trip Purposes	
1	**Worker**	Workplace-Low Income (A)	1	Home (P)	Work (A)
2		Workplace-High Income (A)			
3		Work-Related (A)			
4	Home (P)	School (A)			
5		Nonhome/Work at Residence (A)	3		Nonhome/Work (A)
6		Nonhome/Work Not at Residence (A)			
7		Shop (A)	2		Shop (A)
8		Nonhome/Work at Residence (A)	5	Work (P)	Nonhome/Work (A)
9	Work (P)	Nonhome/Work Not at Residence (A)			
10		Shop (A)	4		Shop (A)
11	Work (O)	Work (D)	6	Work (O)	Work (D)
12	Nonhome/Work at Residence (O)	Nonhome/Work at Residence (D)	7	Nonhome/Work (O)	Nonhome/Work (D)
13		Nonhome/Work Not at Residence (D)			
14		Shop (D)			
15	Nonhome/Work Not at Residence (O)	Nonhome/Work at Residence (D)			
16		Nonhome/Work Not at Residence (D)			
17		Shop (D)			
18	Shop (O)	Nonhome/Work at Residence (D)			
19		Nonhome/Work Not at Residence (D)			
20		Shop (D)			
21	**Nonworking Adult**	School (A)	1	Home (P)	Work (A)
22	Home (P)	Nonhome at Residence (A)	9		Nonhome (A)
23		Nonhome Not at Residence (A)	9		
24		Shop (A)	8		Shop (A)
25	Nonhome at Residence (O)	Nonhome at Residence (D)	10	Nonhome (O)	Nonhome (D)
26		Nonhome Not at Residence (D)			
27		Shop (D)			
28	Nonhome Not at Residence (O)	Nonhome at Residence (D)			
29		Nonhome Not at Residence (D)			
30		Shop (D)			
31	Shop (O)	Nonhome at Residence (D)			
32		Nonhome Not at Residence (D)			
33		Shop (D)			
34	**Child 12-15**	School (A)	11	Home (P)	Nonhome (A)
35	Home (P)	Nonhome at Residence (A)			
36		Nonhome Not at Residence (A)			
37		Shop (A)			
38	School (P)	Nonhome at Residence (A)			
39		Nonhome Not at Residence (A)			
40		Shop (A)			
41	Nonhome at Residence (O)	Nonhome at Residence (D)			
42		Nonhome Not at Residence (D)			
43		Shop (D)			
44	Nonhome Not at Residence (O)	Nonhome at Residence (D)			
45		Nonhome Not at Residence (D)			
46		Shop (D)			
47	Shop (O)	Nonhome at Residence (D)			
48		Nonhome Not at Residence (D)			
49		Shop (D)			

1. NuStats. Chicago Regional Household Travel Inventory: Draft Final Report prepared for Chicago Metropolitan Agency for Planning. Austin, TX, 2008.

2. U.S. Census Bureau. American Community Survey: Design and Methodology (Unedited Version). Economic and Statistics Administration, May 2006.

3. U.S. Census Bureau. Census Transportation Planning Package 2000 (CTPP2000): Definition of Subject Characteristics. No date.

4. *CTPP Status Report.* US Department of Transportation, American Association of State Highway and Transportation Officials, December 2008.

5. Transportation Research Board. Metropolitan Travel Forecasting: Current Practice and Future Direction. *Special Report 288*, 2007.

6. Hague Consulting Group. ALOGIT Users' Guide: Version 3.2, July 1992.

7. Christopher, Ed J., Alan R. Fijal, and Anne C. Ghislandi. CATS 1990 Household Travel Survey: A Methodological Overview. *Working Paper 94-05.* April 1994.

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