MATCHING WORKERS AND EMPLOYMENT OPPORTUNITIES: LINKING EMPLOYEES AND WORKPLACES BY EARNINGS IN REGIONAL TRAVEL MODELS

by

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The ability to accurately forecast journeys to work is critical for regional personal travel models. But in our region, as in most other large mature metropolitan areas, it is difficult to model the lengthy work commute trips that occur. These are most often very long work trips to the Chicago central area and reverse direction commutes of inner city residents to distant suburban employment locations. One approach to improving the modeling of work trips is to segment work trips by worker characteristics such as earnings or occupation. But even though it may seem obvious that worker characteristics affect the linking of workers' household and employment locations, implementing this logic in current travel models can be problematic.

In this paper, the authors review regional census journey to work data to show the need for model enhancement. A bi-segmentation of workers by earnings is then introduced into the Chicago Metropolitan Agency for Planning's (CMAP) trip generation, trip distribution, and mode choice models. The discussion identifies the appropriate earnings and wage data for estimation and calibration, and the required changes in the models' code and inputs. Finally, revised modeled distributions of regional home-work trips are evaluated.

Distribution Model Estimation and Calibration

The current "production" CMAP models are the traditional four-step models of trip generation, distribution, mode choice and assignment that continue to be used in a majority of Metropolitan Planning Organizations (MPOs). Trip distribution is the model that links trip ends in a transportation analysis zone into trip interchanges between zones. In terms of home-work trips, it is the model that links home locations to workplaces for home-work trips when the home location is known.

Nearly all trip distribution models, including CMAP's, are a variant of the gravity model, which is implemented for home-work interchanges by solving a set of simultaneous equations:

$$1.\ T_{i,j} = A_i B_j F_{i,j}$$

$$2.\ H_i = A_i \sum_j B_j F_{i,j}$$

$$3.\ W_j = B_j \sum_i A_i F_{i,j}$$

$$4.\ A_i, B_j, F_{i,j} \geq 0$$

Where: $T_{i,j} =$ the home to work trips (bidirectional) between a home zone *i* and work zone *j*.

$H_i =$ home to work trips with a home trip end in zone *i*.

$W_j =$ home to work trips with a work trip end in zone *j*.

$A_i =$ home zone *i* balancing coefficient.

$B_j =$ work zone *j* balancing coefficient.

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

In these equations, the A_i s and B_j s are determined through a matrix balancing – also known as iterative proportional fitting – procedure given the H_i s , W_j s and $F_{i,j}$ s .

In MPO practice, a functional relationship between $F_{i,j}$ and travel impedance $I_{i,j}$ is first assumed, a negative exponential ($e^{-\alpha I_{i,j}}$) or gamma ($\alpha I_{i,j}^{\beta} e^{-\gamma I_{i,j}}$) functions are the most popular. The CMAP distribution model is a negative exponential form with the difficulty of travel dependent on the number of closer work attractions (*1*). Coefficients in this relationship are then estimated using observed travel data. While there are different model estimation approaches followed by MPOs, they all have the objective of matching modeled travel time/cost trip frequency distributions or average travel times/costs to observed data. After estimating the model coefficients, an additional calibration adjustment or factoring of critical $F_{i,j}$ s is often undertaken to improve the fit of the model to observed data.

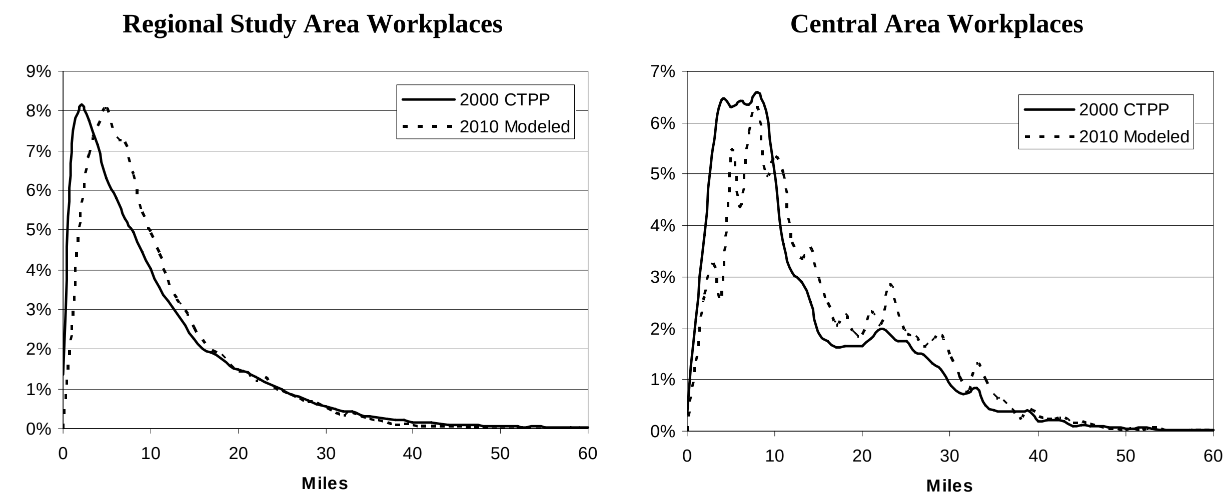
Observed and Modeled Trip Length Distributions

Commute length frequencies from the 2000 Census Transportation Planning Package (CTPP) are plotted in Figure 1 (*2*). The CTPP tabulates journey to work data by location of residence, place of work, and by paired home-workplace flow locations. Figure 1 was developed from the home-workplace flow tables (the journey to work questions from the Census 2000 long-form household sample) and include only commutes by motorized modes (workers who work at home are also obviously excluded). Distances are estimated from the geographic centroids of census tracts to the nearest half mile and y-axis percentages determined by the number of work journeys within a mile interval. The left diagram is the frequency of home-work tract pairs versus distance for all home and work tracts in the 21 county area modeled by CMAP. The right diagram is similar but includes only household workers who reported a work location in the Chicago central area.

Regional commute length frequency declines fairly regularly with increasing distance. The appearance of the diagram is similar to the functional relationships estimated between $F_{i,j}$ and travel impedance. After peaking, the number of commutes regularly decline with distance. In contrast, the distribution of central area oriented commutes is much less regular, even maintaining roughly the same frequency levels for distances between 15 and 25 miles.

Results from previous applications of the CMAP distribution model are also shown in Figure 1 for illustrative purposes. These are estimates of 2010 home-work motorized trips made some years ago as part of an air quality conformity determination. The modeled trips include home-work (both home to work and work to home directions) and the trip length frequency distributions are comparable to commute distances. Distances between home and workplace are measured between the geographic centroids of traffic analyses zones, which are similar in size and number to census tracts.

Figure 1. Commute Trip Length Frequency (Mile Intervals)



The census and modeled distributions match reasonably well. Average regional commute distances are quite close, 10.6 miles for the modeled distribution versus 10.7 miles for the CTPP journey to work. The regional modeled trip distribution does appear to under represent very short trips, over represent medium length trips, and then again under represent longer trips.

Average central area commute distances are less similar, 15.1 miles for the modeled trip length distribution and 13.0 for the census journey to work. Part of this difference can be explained by the two definitions of the central area used for the CTPP and model tabulations. The central area definition for the CTPP extends further into the industrial west side where shorter commutes are likely. The general pattern of the model under representing very short, over representing medium length, and under representing very long trips is still apparent.

Most analysts would agree that the model results in Figure 1 are more than acceptable; however, a satisfactory modeling of central area work trips was achieved only after ad hoc reduction of the travel impedances to the central area. Without this modification, the model distribution of central area work trips had much the same appearance as the regional distribution and failed to reproduce the proportions of central area commuters in the 15 to 25 mile distance from the central area. While there is some justification for adjusting central area travel impedances due to transit accessibility, which is unmatched elsewhere in the region, factoring impedances just to improve trip distribution has been subject to question in other MPOs (*3*). A better approach would be to change the structure of the distribution model to capture the specialized nature of central area employment and where appropriately skilled workers reside.

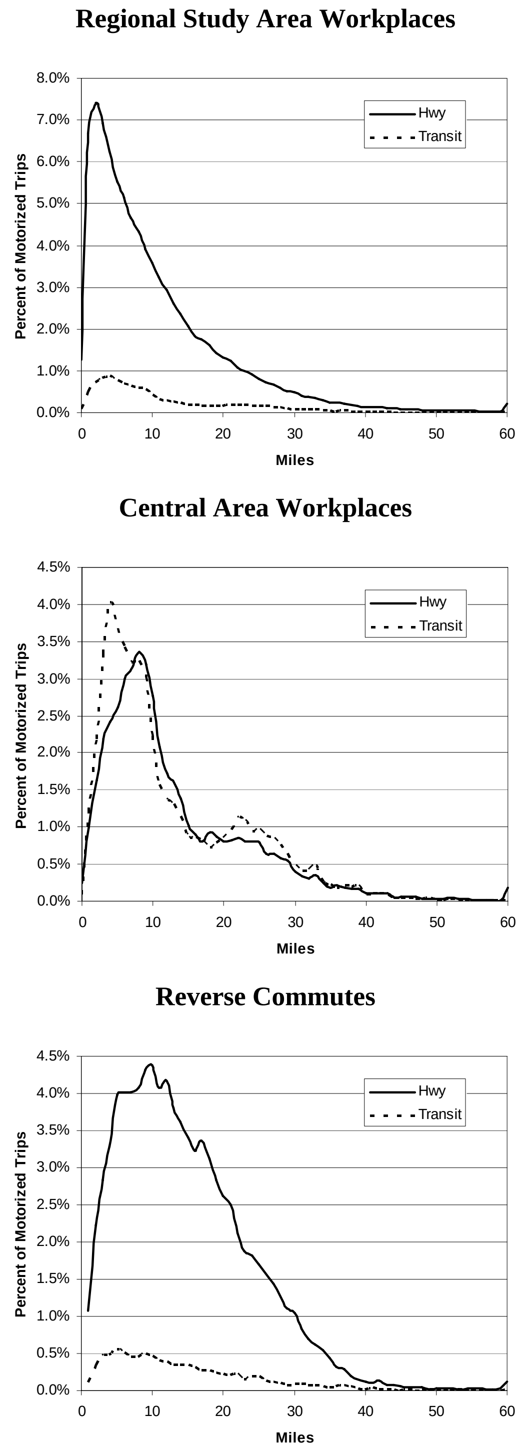
Mode Choice and Trip Length Frequency

Figure 2 contains three plots again created from the 2000 CTPP. Each depicts a trip length distribution for commutes by transit and highway modes. The highway mode is made up of all private vehicle commutes regardless of vehicle occupancy. The y-axis equals the percentage of (1) all regional motorized commutes, (2) all motorized commutes to the central area, or (3) all reverse motorized commutes from Chicago households to non-Chicago workplaces.

The top plot for all regional commutes reveals some differences between markets served by the two modes. While the largest numbers of commutes by highway and transit are both fairly short, around four or five miles, the transit plot is much less peaked indicating that transit tends to serve longer commutes than highway travel. Average trip lengths by transit are 11.8 miles via transit and 10.5 miles by highway. Transit's mode share of all regional commutes is only slightly more than 11 percent.

The clear point made by the second central area workplace plot is that commutes to central area workplaces are quite similar in distance and mode share regardless of mode used. Mode shares for central area commutes are nearly equal and average trip lengths are 13.2 miles for highway commutes and 12.9 miles for transit. Transit has a somewhat higher mode share for shorter "within Chicago" central area commutes and also carries slightly more workers who make longer 20-30 mile commutes to the central area. However, the central area is a vastly more important market for transit because more than two-thirds of all transit commuters are traveling to the central area. The importance of correctly modeling the distribution of work trips to the central area for accurately estimating transit ridership cannot be over emphasized.

Figure 2. Commute Trip Length Frequencies by Mode (Mile Intervals)



The bottom plot in Figure 1 shows the nature of reverse commute. They have the longest average trip lengths, 14.8 for highway commutes and 14.4 miles for transit commutes. The transit mode share of reverse commutes is less than the regional average and just under 10 percent.

Worker Characteristics and Travel Behavior

The three-year 2006-2008 American Community Survey (ACS) Public Use Microdata Set (PUMS) provided more recent data to explore how worker characteristics affect travel behavior (*4*). The ACS is a continuous replacement for the decennial census long-form survey with a smaller annual sample of households. A five-year accumulation of the annual ACS household sample is just slightly fewer households than the previous decennial long-form household sample. The PUMS consists of two files containing household and personal characteristics that are essentially the actual responses to the long-form. Both files are edited for confidentially reasons, and most importantly, contain only limited geographic identification of household and workplace locations.

The advantage of the ACS PUMS is the work mode, earnings and occupation data for workers. Its disadvantage is the lack of detailed workplace geography. The most detailed workplace geography in the ACS PUMS is the place of work Public Use Microdata Area (POWPUMA), which codes workplaces only to the City of Chicago, the more populated individual counties in the region, and groupings of the less populated counties. As a result it is not possible to accurately estimate journey to work distances from the PUMS, but reported travel times are available.

The average commute travel times of workers at different earnings levels were estimated and reviewed. In calculating the earnings quartiles, all workers are counted including those who work at home. Also, earnings differ from total income in that interest, real estate, retirement and other forms of income not obtained from wages or self-employment are excluded because there is generally no need for travel to obtain these forms of income.

Earnings quartile ranges were estimated from the PUMS data as follows:

1. Quartile 1 are all workers who earn less than $9000 annually (while this may seem too low a figure, the quartile includes workers who report no earnings).
2. Quartile 2 is $9000 to $28,000.
3. Quartile 3 is $28,000 to $52,000.
4. Quartile 4 includes all workers who earn more than $52,000.

Table 1 lists some commuting characteristics by the above earnings quartiles and by whether the workplace is inside or outside Chicago. While highway modes dominate commuting travel to workplaces outside Chicago for all earnings levels, transit captures nearly a third of all commutes to Chicago workplaces. Some other interesting features of Table 1 are the following:

- Commuting travel times to Chicago workplaces tend to be higher than travel times to non-Chicago workplaces for all earnings levels.
- The longest commutes are associated with workers in the highest earning quartile.

- The highest earning quartile contains the highest proportion of Chicago bound workers.
- A surprisingly large percentage of lower earning workers commute by non-motorized means indicating that many low earning workers work close to home.
- Transit commuters are most likely to be in the highest and lowest earning quartiles.

Table 1. Commuting Characteristics by Earnings Quartile and Workplace

	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
	Inside Chicago	Outside Chicago	Inside Chicago	Outside Chicago	Inside Chicago	Outside Chicago	Inside Chicago	Outside Chicago
Average Commute Time	33.7	20.1	34.4	24.6	37.8	28.5	41.7	32.0
Mode Shares								
Highway	48.9%	88.4%	61.9%	93.7%	66.9%	97.1%	61.3%	97.8%
Transit	37.8%	7.7%	31.1%	3.1%	29.3%	1.4%	34.4%	1.0%
Non-motor	13.2%	3.9%	7.0%	3.1%	3.8%	1.5%	4.3%	1.1%
Percent of Quartile Commuters	23.0%	77.0%	28.1%	71.9%	28.1%	71.9%	32.9%	67.1%

Table 2 has the same statistics for reverse commuters. Again, these are workers who live in Chicago and work outside Chicago. Reverse commuters are more typically workers with earnings in the middle quartiles. As might be expected, reverse commuters are more likely to commute by transit than all workers employed in the suburbs since Chicago residents usually have reasonable access to transit by their homes. Reverse commuters in the lowest earnings quartile have the shortest commutes and the highest transit share leading one to suspect that many low earnings reverse commuters work in suburbs adjacent to Chicago.

Table 2. Reverse Commute Characteristics by Earnings Quartile

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Average Commute Time	37.1	41.9	40.5	42.9
Mode Shares				
Highway	76.4%	84.1%	90.7%	91.6%
Transit	18.7%	13.9%	8.1%	6.9%
Non-motor	4.9%	2.0%	1.3%	1.5%
Percent of Reverse Commuters	10.8%	34.8%	30.5%	24.0%

The ACS PUMS has workers categorized by Standard Occupation Classifications (SOC) established by the Bureau of Labor Statistics (*5*). Commuting characteristics were summarized for the twenty-three SOC major groupings of employment. These are shown in Table 3 ranked by the number of commuters in each occupation.

Although a generalization, white collar occupations tend to have the highest transit mode shares and longest commuting times. These occupations include legal, business and financial operations, and computer and mathematical occupations, occupations typical of central area employment. The two largest occupations of commuters – office and administrative support and sales and related – are also occupations that are prevalent in the central area. With the exceptions of military and farming etc, the shortest commuting distances belong to workers in service industries. Some of the service occupations also feature fairly substantial transit commuting mode shares.

Table 3. Commuting Characteristics by Occupation

Occupation	Percent of all Commuters	Average Commute Time (Rank)	Commute Mode		
			Highway	Transit	Non-motor
Office and Administrative Support	15.1%	29.8 (10)	83.7%	13.3%	3.0%
Sales and Related	11.4%	28.2 (17)	84.9%	10.7%	4.4%
Management	9.8%	33.4 (7)	85.4%	11.8%	2.8%
Production	7.6%	29.0 (13)	91.2%	6.5%	2.3%
Transportation and Material Moving	6.9%	28.8 (15)	91.2%	6.2%	2.7%
Education, Training, and Library	5.4%	24.9 (21)	88.7%	6.6%	4.8%
Construction and Extraction	5.2%	37.9 (2)	94.7%	4.3%	1.1%
Healthcare Practitioners and Technical	5.0%	28.5 (16)	92.9%	4.9%	2.2%
Business and Financial Operations	5.0%	36.1 (4)	76.8%	20.8%	2.4%
Food Preparation and Serving Related	5.0%	22.5 (23)	76.9%	13.7%	9.4%
Building and Grounds Cleaning and Maintenance	3.5%	29.0 (14)	82.1%	13.1%	4.7%
Personal Care and Service	3.0%	25.4 (20)	81.8%	12.8%	5.4%
Installation, Maintenance, and Repair	3.0%	31.4 (9)	95.6%	2.8%	1.7%
Computer and Mathematical	2.5%	39.7 (1)	77.2%	19.5%	3.3%
Protective Service	2.2%	29.2 (11)	88.9%	8.1%	2.9%
Healthcare Support	1.9%	27.8 (18)	86.7%	11.0%	2.3%
Architecture and Engineering	1.8%	35.6 (5)	89.0%	9.0%	2.0%
Arts, Design, Entertainment, Sports, and Media	1.7%	32.1 (8)	75.7%	17.2%	7.1%
Community and Social Services	1.4%	29.1 (12)	85.6%	9.4%	5.0%
Legal	1.3%	36.8 (3)	59.5%	36.7%	3.9%
Life, Physical, and Social Science	0.9%	34.9 (6)	77.2%	16.3%	6.5%
Farming, Fishing, and Forestry	0.1%	26.3 (19)	90.1%	7.0%	2.9%
Military Specific	0.1%	23.6 (22)	51.4%	1.6%	47.0%

Modeling Workers by Earning Levels in the CMAP Models

The CMAP models were revised to allow for two worker earnings levels. This required altering the CMAP trip generation model to create two sets of home productions-work attractions, one for workers making less than median regional earnings and a second for workers with above median earnings. The distribution model was then re-estimated and calibrated for the two home-work trip types. The separate home-work trip types were maintained through mode choice by recalibrating the CMAP home-work mode choice model for low and high earnings workers.

Trip Generation. Home production trip ends for home-work trips were divided into low earnings and high earnings categories. ACS PUMS 2005-2007 person data were sorted into a table that estimated the probability that a worker was a high earnings worker given their household characteristics, number of workers, adults, children and household income quartile. These probabilities were then built into the CMAP trip generation model to factor the home production trip ends of home-work trips.

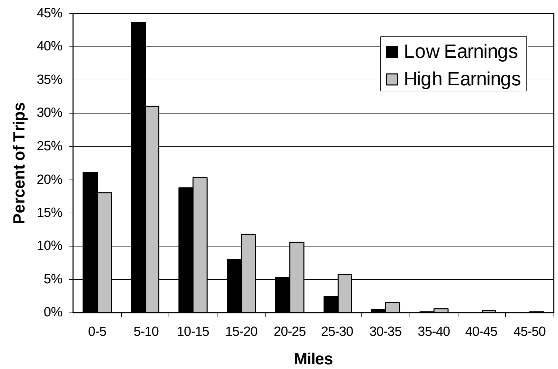
The work attraction trip ends of home-work trips were likewise factored into low and high earnings attractions. Table 2-19 from the CTPP provided the source data for these factors. Table 2-19 cross tabulates workers by earnings by reported travel times by workplace, and tract level factors for the fraction of work attraction trip ends that are restricted to high earnings workers were summarized from the table. These work attraction factors were added to one of the model input files and then applied within the model. Although only 2000 earnings data were available, a new CTPP will be created from a five-year 2006-2010 accumulation of ACS household samples (*6*).

Trip Distribution. New estimations of the distribution model were done following the procedure established by CMAP. These steps were repeated for the low and high worker earnings estimation/calibration:

1. Tabulate average home end and work end airline trip distances from 2000 CTPP by Public Use Microdata (PUMA).
2. Starting with an estimate of the distribution model's calibration coefficient for each PUMA, run distribution and compare resulting trip lengths with observed PUMA values, adjust calibration coefficient and rerun model until satisfactory closure with observed distances is achieved for each PUMA.
3. Develop a zone to zone generalized cost matrix based on weights for travel time and cost components from the CMAP mode choice model.
4. Estimate a relationship between the fitted PUMA distribution calibration coefficients and the average number of work attractions (the average for all zones within the PUMA) nearer than the mean regional generalized travel costs.
5. Rerun distribution model using calibration coefficients determined by the estimated "smoothed" relationship between calibration coefficients and accessible work attractions and evaluate.

Figure 3 is a bar chart showing the modeled trip length frequencies for home-work trips to central area workplaces. Average modeled trip length for high earnings workers is 12.6 miles and 9.5 miles for low earnings workers. The overall average trip length for central area workers is 11.2, which is somewhat less than the 12.6 miles obtained from the CTPP. However, the different zone systems – tracts versus traffic analysis zone – somewhat contribute to this difference. But most importantly, additional longer central area work trips in the 15 to 30 miles distance are supplied by the high earnings workers.

Figure 3. Modeled Home-Central Area Work Trip Lengths by Worker Earnings



Mode Choice. The basic CMAP binary – transit versus auto - model was recalibrated to observed CTPP mode shares for this work. This model has cost and time coefficients that weight the cost (fares, operating costs, etc) and time (in-vehicle, wait, transfer, walk, etc) components for travel between zones. The model also has a transit bias constant to account for factors that affect mode choice beyond the costs and times. Two separate models are applied, one for home-work trips with a work trip end inside the Chicago CBD and a second for home-work trips to non-CBD workplaces.

Table 4. Home-Work Transit Bias Constants

	Earnings Level	
Workplace	High	Low
CBD	0.70	0.41
Non-CBD	1.55	0.98

For this work only the transit bias constants were reset to reflect differences between low and high earnings workers. The sign on these constants are such that they make transit a less desirable option by increasing its cost. Table 4 lists the newly calibrated constants. These values are reassuring since one would anticipate that low earnings workers generally would be more likely to be transit commuters than high earnings workers when both face the same travel costs and times.

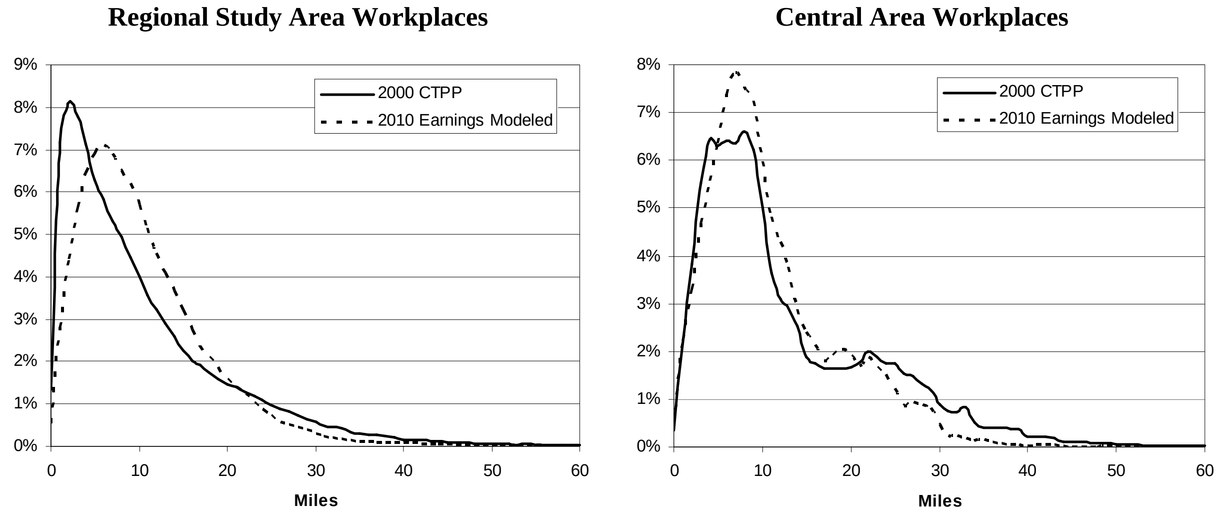
Traffic Assignment. There was no need to revise the CMAP assignment procedure, except that time of day factors were estimated for both worker earnings categories from the recent CMAP travel survey (*7*). These factors are used to subdivide the daily home-work trips from the mode choice model for workers commuting by auto into eight time periods before assignment.

Results and Conclusions

Some preliminary results from model runs incorporating the worker earnings based home-work trips are shown in Figure 4. This figure repeats Figure 1 substituting the modified modeled home-work trip distribution for the original modeled trip distribution.

There are some modest differences from the earlier figure. The revised regional home-work distribution is less peaked in the shorter distances although the average trip lengths for the original and modified model distributions are practically the same. The earnings based

Figure 4. Revised Commute Trip Length Frequency (Mile Intervals)



distribution of home-work trips to the central area appears to somewhat more closely track the CTPP central area commuting frequencies, although the improvement is modest.

Average trip lengths are compared in Table 5. These figures allow only a general comparison because they are tabulated in different geographies, census tracts and two different model zone systems. Combined with the above frequency distribution, they do provide a general sense of how the worker earnings based model performs relative to past modeling efforts. The inference is that the revised model is at worst roughly equivalent to the original model.

Table 5. Average CTPP Commuting Distances and Model Results

		Home-Work Trip Lengths	
Workplaces	2000 CTPP	Base Model	Worker Earnings Model
Regional	10.7	10.6	10.6
Central Area	13.1	15.1	11.2

One can draw from these comparisons is that modeling separate categories of workers reduces the need to overtly adjust network derived impedances for the purposes of improving the trip distribution to the central area and mode split estimates. Whether the simple earnings division followed here is the optimal approach remains open to question.

It is also recognized that many MPOs now applying the four step models will migrate to advance practice models or so-called activity models. The destination choice components of these new models will still have to face the question of how best to segment workers and employment and the problem of appropriate data for model estimation and calibration.

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