Modifying Transit Mode Share in Household Survey Expansion

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A procedure to modify the proportion of expanded trips by different travel modes from the 1991 Boston Regional Household-Based Travel Survey is presented; it is based on two data sources: the Census journey-to-work data and local transit ridership estimates. The procedure is a two-step adjustment applied to the existing survey trip expansion factors, which yielded a much higher volume of transit trips than the regional ridership estimates. The first adjustment step adjusts the expansion factors of commuters (persons who reported work trips in Survey) by matching the distribution of commuters in the Survey to the Census journey-to-work data by travel modes and residence-workplace locations. The second adjustment step is an iterative process that revises the expansion factors of other individuals (noncommuters) in the Survey by matching the expanded transit trips to the regional transit ridership estimates by transit submodes. It is assumed that the adopted procedure improves the randomness of the survey sample for modeling purposes. The adjusted trip expansion factors produced from the procedure are used to weigh the survey sample for mode choice model estimation, trip distribution model calibration, or other model evaluation purposes.

This paper presents a procedure to modify the proportion of expanded trips by different travel modes from the 1991 Boston Regional Household–Based Travel Survey. The Survey used an activity-based diary as a survey instrument and was designed following the small-sample technique (*1,2*). Despite taking precautions to avoid biases, analysis of the sample indicated a significant nonresponse bias leading to an overestimation of transit use. This procedure was thus developed to alleviate the nonresponse bias for applying the survey findings to regional mode choice model estimation, trip distribution model calibration, and other descriptive purposes.

The procedure is a two-step adjustment applied to the existing household survey trip expansion factors. The first adjustment step adjusts the expansion factors of commuters by matching the distribution of Household Survey commuters (persons who made work trips) by travel modes and residence-workplace locations to the Census journey-to-work data. The second adjustment step is an iterative process that revises the expansion factors of other individuals (noncommuters) in the Survey by matching the expanded transit trips by submodes to the regional transit ridership estimates.

The existing trip expansion factors from the 1991 Boston Regional Household–based Travel Survey were developed through a series of data processing. The primary expansion was performed by matching the Survey expanded households to the 1990 Census Transportation Planning Package by ring (geographical subregion), household size, and vehicle availability. The expansion was further modified by matching the expanded household totals to the Census household totals at a land use zone level and by synthesizing unreported trips for the missing-one-diary households. The expansion yielded a comparable number of total households in the region but did not produce a favorable total regional transit ridership estimate.

Through expansion of a sample of nearly 4,000 survey households, the number of intraregional linked transit trips was estimated to be about 974,000, which is about 30 percent higher than the regional transit ridership estimate. As considered from available sources of local transit ridership estimates (*3–5*), the regional total linked transit ridership was estimated as 747,000 trips in this study. Moreover, when disaggregated by transit submodes, the magnitude of overestimations is significantly different. Commuter rail trips were highly overestimated, and the overestimation of bus only trips was as serious as rapid transit trips.

These estimations divulge the complexity of bias problems involved in the survey. The survey response data were reviewed for possible information on sample bias, but the information available on the selected households that did not respond to the survey was inadequate for analysis. In addition, analysis of changes in survey responses with respect to lateness of diary return, another possible source of bias information (*6*), proved inconclusive.

The overestimation of transit trips might be caused by oversampling or undersampling of certain categories of households (nonresponse bias) or by inaccurate reporting of transit trips by individuals (inaccurate response bias). In this study, it was assumed that the former is the major cause of the problem, and the adjustment was therefore primarily developed at household and person levels, not at the trip level. By making the sample more representative of the population, based on the Census journey-to-work data and the local transit ridership estimates, the proposed procedure was expected to improve the randomness of the survey sample for various modeling purposes.

ADJUSTMENT STEP 1: MATCHING TO CENSUS JOURNEY-TO-WORK DATA

This adjustment step was conducted by using the Census journey-to-work data, which are deemed more reliable than the Household Survey because of the Census' larger sample size (about 17 percent compared with about 0.25 percent). The journey-to-work data from the 1990 Census Transportation Planning Package for the Boston metropolitan region provide estimates of residence-workplace flows by a longest-distance travel mode for all working people (16 years or older) living or working in the region. The Household Survey, on the other hand, provides information of origin-destination flows by multiple (if not single) travel modes for all work purpose trips (including home-based and nonhome-based) produced by survey households in the region.

To be analogous to the Census data, the Survey data were processed by tracing the work trip maker's residence and workplace locations and linking the multiple-mode trips into single-mode

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ones. The two data sets were then compared by travel modes and residence-workplace locations at the ring level. The comparison yielded a set of adjustment factors. Each survey work trip maker (simply referred to as commuter hereafter) was associated with an adjustment factor by mode and residence-workplace locations. In application, the adjustment factor was then applied to all the trips (not just work trips) made by the commuter.

Identification of Commuters and Their Residence-Workplace Locations

The Household Survey data are organized in three components: household, person, and trip files. The identification of commuters and their residence-workplace locations was done by using the household and trip files because the trip origin and destination information was not available from the person file.

The survey trips file includes information on each trip's origin purpose and destination purpose. A trip was regarded as a work trip if the origin or destination purpose is to work. Once the work trips in the trips file were identified, the associated commuters and their workplace locations were acquired from the trips file directly as well. However, their residence locations were obtained by tracing the commuters' household locations from the survey households file.

The intra-regional trips (both residence and workplace in the region) were included for this study. School bus and taxi trips reported in the Survey and the Census were left out of this study because separate models are used for estimating the generation rates of those trips. In some cases, one commuter produced several work trips with different workplace locations. The first work trip of the day with an identifiable mode, residence, and workplace by each commuter was thus chosen for identification because the Census journey-to-work questions focus on the travel from home to work.

Categorizing Single Travel Mode for Survey Journey-to-Work Trips

As mentioned, the Survey trips were recorded in a multiple-mode fashion (up to six modes), and the Census journey-to-work data manifest the single longest-distance mode by a worker. The identified Survey journey-to-work trips using more than one mode were thus required to be categorized in a single-mode format.

The categorizing is complicated by the fact that the Census uses trip and mode definitions that differ from those used by the household survey. As presented in Table 1, the definitions of the various travel modes in the Survey and the Census are different, especially the transit submodes. Also, the definition of trip (or journey) is different. The Census asks its respondents to describe how they travel from their residence to their workplace. In the case that more than one mode is used in the journey, the respondent is asked to state which mode is used over the greatest distance.

The Household Survey asked respondents to describe trips between activities. If the respondent traveled from activity "At Home" to activity "Work," this trip would be a Home-Based-Work trip and is directly comparable to the journey-to-work inquiry made by the Census. If, however, the commuter goes to an intermediate activity between home and work (convenience store, health club, and such), then the journey was viewed as two distinct trips: a home-based-other trip (HBO) and a nonhome-based-work trip (NHBW). To compare the Survey and Census data sets, it is necessary to concatenate the multiple-trip work journey in the Survey, especially that involved with any transit mode.

The Survey journey-to-work mode was categorized at two levels: (*a*) automobile, transit, and nonvehicular and (*b*) transit subdivided as bus, subway, and commuter rail. First a trip was regarded as transit if any one of the modes it used was bus, rapid transit, or commuter rail. It was regarded as a nonvehicular trip if all of the modes it used were not involved with private or public vehicles. Other trips not included in the above two groups were categorized as auto trips.

Second a transit trip was further categorized into commuter rail, rapid transit (including subway and trolley, for simplification just referred to as subway hereafter), or bus-only trip by a simple rule that commuter rail overrides subway, and subway overrides bus. This assumes that the commuter rail usually is the longest part in a journey and that the subway ride is longer than the bus. The assumption was made because the travel time or distance of a separate mode in a trip was not available in the Survey and neither was the location where transfer between modes was made.

However, manual path building for all Survey transit work trips involving multiple modes was performed to accurately compare the journeys-to-work as reported in the Survey with those reported in the Census. By examining the origin, destination, parking, and other activities of each identified transit work trip, it was possible to specify a mode for each trip presumably the same as the Survey respondent would have reported to the Census.

Once the residence-workplace locations and the single travel mode of the Survey commuters were identified, the Survey journey-to-work flows then could be synthesized. Before matching the Survey journey-to-work flows to the Census, the transit share of the two data sets was analyzed.

TABLE 1 Definitions of Survey and Census Travel Modes for Analysis

Mode of Travel		Household-Based	Census
Major Mode	Sub-Mode	Survey	Journey-To-Work
Auto		Car, Van, or Truck	Drive Alone or 2+ Carpool
Transit	Bus Only	MBTA Bus, Private Bus, and the RIDE	Bus or Trolley Bus
	Subway	Red, Green, Blue or Orange Line Rapid Transit Service	Subway or Elevated, and Streetcar or Trolley car
	Railroad	Commuter Railroad	Railroad
Non-Vehicular		Bike, Walk, and Others	Bicycle, Walk, Motorcycle, Ferry, and Others

Analysis of Transit Share by Travel Modes

The Survey transit share was first examined by separating the total flows by travel modes. The identified commuters with their identified single travel modes to work were expanded to be compared with the Census. Table 2 presents the synthesized Survey journey-to-work and the Census journey-to-work flows by travel modes.

As shown in Table 2, the Survey yielded somewhat comparable shares of total travel in the region by major mode (i.e., automobile, transit, or nonvehicular). However, at the transit submode level (i.e., bus only, subway, and railroad), the Survey yielded a much different proportion of transit trips from the Census.

It was also noted that the Survey expansion yielded less commuters (by about 12.6 percent) than the Census. There are several reasons for this disparity. First the Census requested the most frequently used means of journey during the week before receiving the Census survey form, whereas the Survey requested the journey information for a certain date, which excluded people who did not work on that exact date. Second, the Census included working persons living in group quarters, whereas the Survey did not. Also, the commuters with unknown modes (about 2,000 commuters) were simply left out of the Survey totals, whereas in the Census this portion presumably has been taken into account.

Analysis of Transit Share by Residence-Workplace Locations

The Survey transit share was further analyzed by grouping the flows by the residence-workplace locations. As shown in Table 3, the synthesized Survey journey-to-work flows were grouped into 25 residence-workplace exchanges (at ring level) and were displayed by transit share to the total flows of each group. The Census journey-to-work flows are also displayed in Table 2 for comparison. The definition of geographical rings in the study area is shown in Figure 1.

In general, the Survey yielded a transit share distribution that is incompatible with the Census. Among the 25 residence-workplace exchanges, only nine pairs had the Survey and Census transit share estimates within 20 percent of each other (i.e., transit share ratio ranging from 0.8 to 1.2). When compared with the Census, the Survey produced higher transit shares for the flows from the outer rings to the inner rings (Rings 0 and 1) especially central area (Ring 0); about the same shares for intra-ring or neighboring ring pairs; and lower transit shares for the flows from the inner rings to the outer rings (Rings 2, 3, and 4).

The overestimation portion (the first group, i.e., flows with workplace in Ring 0 or 1) required major attention because the Census indicated that 85 percent of the regional transit journey-to-work flows was in travel to the inner rings. It was postulated that this excessive transit flow was one potential source of bias that caused the overestimation of Survey transit trips. Therefore, the synthesized Survey journey-to-work flows were matched to the Census by not only travel modes but also residence-workplace locations.

Correspondence Between Survey and Census by Modes and Locations

The correspondence is a cell-to-cell adjustment between the two tabulated data sets. The synthesized Survey journey-to-work flows were tabulated by the 25 residence-workplace exchanges and five travel modes (Table 4). The Census journey-to-work data were processed in the same manner (Table 5).

To produce the adjustment factors, the cell values of the two tabulations were transformed from numbers of commuters to shares of subregion (ring) total by residence location. The cell adjustment factor was then obtained by simply comparing the share from the Survey with, that from the Census. In formulation, the adjustment factor for the commuters traveling from r to w by mode m can be expressed as

$$A_{rwm} = \frac{C_{rwm} / \sum_w \sum_m C_{rwm}}{S_{rwm} / \sum_w \sum_m S_{rwm}} \tag{1}$$

where

r = residence location, Ring 0 to Ring 4;
w = workplace location, Ring 0 to Ring 4;
m = travel mode in which 1 is auto, 2 is bus, 3 is rapid transit (subway and trolley), 4 is commuter rail, and, 5 is nonvehicular;
A_{rwm} = adjustment factor for identified Survey commuters residing in ring r, working in ring w, and traveling via mode m;
C_{rwm} = Census estimates of number of commuters residing in ring r, working in ring w, and traveling via mode m; and
S_{rwm} = expanded Survey estimates of number of commuters residing in ring r, working in ring w, and traveling via mode m.

The resulting adjustment factors for the Survey commuters vary from 0.12 to 5.41, with half of them ranging from 0.50 to 1.50.

TABLE 2 Summary of Commuters by Travel Modes in Region

Journey To Work Within the Region		Mode of Travel					All-Mode Total
		Auto	Bus Only	Subway	Railroad	Non-Veh.	
Survey	Total	1,366,741	49,854	129,121	37,936	118,956	1,702,608
	Percent	80.3%	2.9%	7.6%	2.2%	7.0%	100.0%
Census	Total	1,586,413	86,057	106,694	27,774	133,993	1,940,931
	Percent	81.8%	4.4%	5.5%	1.4%	6.9%	100.0%

Note: about 2,000 commuters with unknown modes were not included in the Survey totals.

TABLE 3 Comparison of Survey and Census Journey-to-Work Transit Share by Residence-Workplace Locations Before Adjustment

		"Survey" Journey-To-Work			Census Journey-To-Work			Ratio of
Residence Ring	Workplace Ring	Total Workers	Transit Users	Transit Share	Total Workers	Transit Users	Transit Share	Transit Share =Sur./Cen.
0	0	54,827	23,163	42.2%	54,503	15913	29.2%	1.45
1	0	108,785	60,018	55.2%	119,087	58802	49.4%	1.12
2	0	82,282	35,639	43.3%	82,301	29998	36.4%	1.19
3	0	72,876	26,761	36.7%	72,609	20050	27.6%	1.33
4	0	26,722	7,627	28.5%	25,549	6767	26.5%	1.08
0	1	14,369	5,723	39.8%	21,743	8394	38.6%	1.03
1	1	130,404	24,759	19.0%	155,061	32968	21.3%	0.89
2	1	52,070	9,516	18.3%	65,532	10516	16.0%	1.14
3	1	40,168	7,136	17.8%	43,379	3782	8.7%	2.04
4	1	10,044	750	7.5%	14,581	1337	9.2%	0.81
0	2	6,757	1,676	24.8%	9,408	2499	26.6%	0.93
1	2	42,521	2,828	6.7%	49,142	7728	15.7%	0.42
2	2	127,882	2,632	2.1%	156,319	5869	3.8%	0.55
3	2	74,570	1,917	2.6%	85,694	1545	1.8%	1.43
4	2	25,276	0	0.0%	31,765	335	1.1%	0.00
0	3	4,294	777	18.1%	6,139	613	10.0%	1.81
1	3	23,223	2,263	9.7%	28,636	3106	10.8%	0.90
2	3	64,363	0	0.0%	69,841	1953	2.8%	0.00
3	3	288,573	1,779	0.6%	336,898	3190	0.9%	0.65
4	3	126,204	447	0.4%	149,897	683	0.5%	0.78
0	4	543	0	0.0%	1,509	124	8.2%	0.00
1	4	3,993	173	4.3%	5,668	530	9.4%	0.46
2	4	10,928	0	0.0%	9,971	241	2.4%	0.00
3	4	47,391	0	0.0%	47,471	212	0.4%	0.00
4	4	263,543	1,327	0.5%	298,228	3370	1.1%	0.45
Regional Total		1,702,608	216,911	12.7%	1,940,931	220,525	11.4%	1.12

There were 36 cells with missing adjustment factors because those cells had zero identified Survey commuters. They were then assigned an adjustment factor of 1.00 in applications.

Application of Adjustment Factor

The identified commuters from the Survey then were assigned an adjustment factor based on each commuter's identified modes and residence-workplace locations. For each commuter, the adjustment was applied to all the trips, not just work trips, he or she made on the survey day. This was based on the assumption that oversampling and undersampling of individuals, not of trips, is the major source of bias. It was also assumed that all of the trips made by a working person on an average work day are basically related to his or her journey-to-work life style.

Effects on Expansion after First Adjustment Step

As indicated in Table 6, the procedure did reduce the total number of transit trips by about 9.3 percent. It also produced more comparable estimates of subway and commuter railroad trips.

This adjustment to the expansion yielded 490,200 subway trips (which is about 15.3 percent different from the ridership estimate of 425,200 trips) and yielded 71,300 commuter rail trips (which is 13.5 percent higher than the estimate of 62,800 trips). These two transit submode ridership estimates were deemed to be composed mostly of work trips, especially the commuter rail.

The reduction of transit trips was attributed mainly to the modification of mode share and residence-workplace distribution for the working population in the Survey. However, the number of expanded transit trips was still much larger than the transit ridership estimates, especially in the bus only trips. This leads to the next step of adjustment, which was aimed to modify the mode share of the nonworking population in the Survey.

ADJUSTMENT STEP 2: MATCHING TO REGIONAL TRANSIT SUBMODE RIDERSHIP ESTIMATES

Although the previous step adjusted work trips by mode according to the estimates in the 1990 Census Transportation Planning Package, the volume of expanded survey trips using transit still far ex-

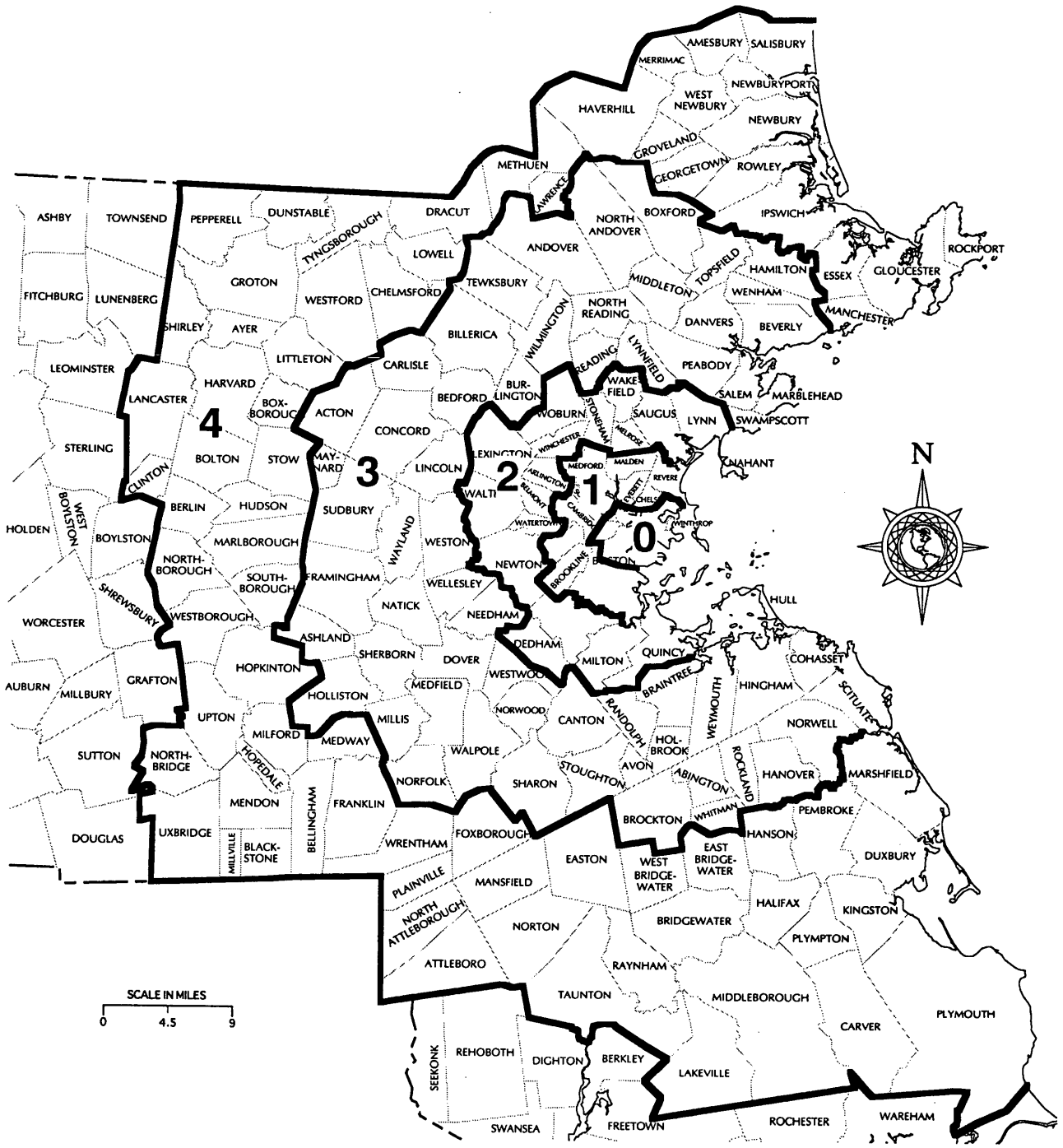

FIGURE 1 Geographical rings in eastern Massachusetts region.

ceeds the regional estimates. The only remaining measure available for adjustment of the survey is the regional transit ridership estimates by submode, so the final adjustment step is weighting the trips taken by nonworkers to match the transit submode ridership totals.

Altering the expansion factors according to mode of travel could dramatically alter the expanded number of trips within a household, so this adjustment was performed in an iterative fashion. At each iteration, after adjusting the weights applied to each nonworker according to the transit submode ridership totals, the expansion factors were revised to keep the expanded total number of trips taken by the households within each ring constant. The process continued until the submode adjustment factors were close to 1.

TABLE 4 Synthesized Survey Journey-to-Work Flows by Residence-Workplace Locations and Travel Modes

Residence Ring	Workplace Ring	Mode of Travel						Ring Total
		Auto	Bus Only	Subway	Railroad	Non-Veh.	Total	
0	0	12,709	7,041	16,004	118	18,955	54,827	
0	1	6,370	1,431	4,292	0	2,276	14,369	
0	2	4,989	155	1,521	0	92	6,757	
0	3	3,517	251	526	0	0	4,294	
0	4	543	0	0	0	0	543	80,790
1	0	35,270	8,556	51,462	0	13,497	108,785	
1	1	77,573	7,479	17,280	0	28,072	130,404	
1	2	38,267	0	1,535	1,293	1,426	42,521	
1	3	20,960	773	1,302	188	0	23,223	
1	4	3,820	0	0	173	0	3,993	308,926
2	0	43,116	4,036	22,252	9,351	3,527	82,282	
2	1	39,554	5,927	2,494	1,095	3,000	52,070	
2	2	117,208	2,267	365	0	8,042	127,882	
2	3	62,529	0	0	0	1,834	64,363	
2	4	10,684	0	0	0	244	10,928	337,525
3	0	41,879	3,538	6,469	16,754	4,236	72,876	
3	1	32,203	3,408	2,310	1,418	829	40,168	
3	2	71,456	1,376	541	0	1,197	74,570	
3	3	271,886	1,436	0	343	14,908	288,573	
3	4	46,690	0	0	0	701	47,391	523,578
4	0	18,385	1,036	412	6,179	710	26,722	
4	1	9,294	0	0	750	0	10,044	
4	2	25,276	0	0	0	0	25,276	
4	3	125,401	447	0	0	356	126,204	
4	4	247,162	697	356	274	15,054	263,543	451,789
Total by Modes		1,366,741	49,854	129,121	37,936	118,956	1,702,608	1,702,608
Percent of Total		80.3%	2.9%	7.6%	2.2%	7.0%	100.0%	100.0%

Estimation of Regional Transit Submode Ridership Totals

An extensive effort was undertaken to obtain an estimate of the regional total linked transit ridership by submode on an average 1991 weekday. The estimation was derived by incorporating estimates of (Massachusetts Bay Transportation Authority (MBTA), commuter rail, rapid transit, and bus ridership (*3*), Logan Airport bus ridership (*4*), ridership on services by other regional transit agencies within the Eastern Massachusetts region (based on unpublished estimates from the Massachusetts Executive Office of Transportation and Construction, regional planning agencies, and regional transit authorities), and private bus schedules (*5*), together with estimated transfers between submodes (based on unpublished reports of the 1993 systemwide commuter rail and 1994 systemwide rapid transit surveys conducted by the Central Transportation Planning Staff) for the period of household survey (March, April, and May 1991).

The rule of linking multiple-mode trips is the same as that used to identify single travel mode for the Household Survey work trips (see previous adjustment step). As a result, the total intraregional linked transit trips made by the regional residents on an average weekday for the three transit submodes was estimated as

- Commuter rail: 62,800 trips,
- Bus: 259,100 trips, and
- Rapid transit: 425,200 trips.

Starting Point of Iterative Process

Assuming the journey-to-work adjustments reflect the undersampling or oversampling of the sampled households as well as the workers, the starting point of the iterative process was to adjust the expansion factor applied to each nonworker by the average journey-to-work adjustment factor for the workers in his or her household. This is computed using the following formula:

$$B_h = \sum_{\substack{p=1 \\ p=\text{worker}}}^{n} \frac{A_{hp}}{n} \tag{2}$$

where

h = household series number,
p = person series number,
n = number of workers in household h,

TABLE 5 Census Journey-to-Work Flows by Residence-Workplace Locations and Travel Modes

Residence Ring	Workplace Ring	Mode of Travel						Ring Total
		Auto	Bus Only	Subway	Railroad	Non-Veh.	Total	
0	0	13,697	5,851	9,947	115	24,893	54,503	
0	1	11,233	3,363	4,998	33	2,116	21,743	
0	2	6,372	975	1,440	84	537	9,408	
0	3	5,225	266	284	63	301	6,139	
0	4	1,247	38	59	27	138	1,509	93,302
1	0	55,265	18,946	39,274	582	5,020	119,087	
1	1	84,713	17,853	14,885	230	37,380	155,061	
1	2	39,874	4,108	3,426	194	1,540	49,142	
1	3	24,945	1,420	1,527	159	585	28,636	
1	4	5,047	153	337	40	91	5,668	357,594
2	0	51,515	9,298	16,276	4,424	788	82,301	
2	1	53,803	5,462	4,411	643	1,213	65,532	
2	2	134,187	4,161	1,443	265	16,263	156,319	
2	3	67,279	1,173	583	197	609	69,841	
2	4	9,602	100	85	56	128	9,971	383,964
3	0	51,111	3,126	5,275	11,649	1,448	72,609	
3	1	39,113	728	1,076	1,978	484	43,379	
3	2	83,642	788	342	415	507	85,694	
3	3	315,139	2,486	250	454	18,569	336,898	
3	4	46,861	138	12	62	398	47,471	586,051
4	0	18,568	1,483	471	4,813	214	25,549	
4	1	13,119	320	179	838	125	14,581	
4	2	31,173	105	33	197	257	31,765	
4	3	148,070	478	33	172	1,144	149,897	
4	4	275,613	3,238	48	84	19,245	298,228	520,020
Total by Modes		1,586,413	86,057	106,694	27,774	133,993	1,940,931	1,940,931
Percent of Total		81.7%	4.4%	5.5%	1.4%	6.9%	100.0%	100.0%

B_h = adjustment factor for nonworkers in household h, and
A_{hp} = journey-to-work adjustment factor for worker p in household h.

$$W_m = \sum_{hpm}^{p \neq \text{worker}} (T_{hpm} \cdot E_{hp} \cdot A_{hp}) \tag{3}$$

The regional total expanded trips by mode were obtained from the previous steps and were divided into total submodal trips by workers (Wm) and nonworkers (Vm). They can be shown as

$$V_m = \sum_{hpm}^{p \neq \text{worker}} (T_{hpm} \cdot E_{hp} \cdot B_h) \tag{4}$$

TABLE 6 Summary of Expanded Trips by Mode and Purpose after Journey-to-Work Adjustment

Trip Purpose	Mode of Travel						All-Mode Total
	Auto	Bus Only	Subway	Railroad	Non-Veh	Unknown	
HB Work	2,370,200	83,800	178,300	40,700	192,000	5,900	2,870,900
HB School	469,400	47,300	72,300	4,900	310,700	800	905,400
HB Other	5,228,800	122,200	102,200	18,400	716,700	5,800	6,194,100
NHB Work	1,529,500	30,400	70,200	3,700	458,900	900	2,093,600
NHB Other	1,448,600	38,800	62,400	3,100	343,800	400	1,897,100
Total	11,046,500	322,500	485,400	70,800	2,022,100	13,800	13,961,100
Percent	79.1%	2.3%	3.5%	0.5%	14.5%	0.1%	100.0%
Before Adj.	10,975,400	291,400	578,900	104,100	2,063,200	13,500	14,026,500
	78.5%	2.1%	4.1%	0.7%	14.7%	0.1%	100.0%

where

m = 1,2,3,4 in which 1 is bus, 2 is rapid transit, 3 is commuter rail, and 4 is others;
W_m = regional total number of trips using mode m by workers;
V_m = regional total number of trips using mode m by nonworkers;
T_{hpm} = number of trips using mode m by individual p in household h;
E_{hp} = existing expansion factor for individual p in household h;
B_h = adjustment factor for nonworkers in household h; and
A_{hp} = journey-to-work adjustment factor for worker p in household h.

Submodal Ridership Adjustment

In the iteration procedure, the trips by workers were kept constant because their expansion factors were unadjusted, whereas, the trips by nonworkers were revised from iteration to iteration. The first step of the procedure was to produce estimated adjustment factors for each transit submode by comparing expanded trips totals with the regional transit ridership estimates by transit submode. Suppose the targeted regional transit ridership estimates are $K1$, $K2$, and $K3$ for the bus, subway, and commuter rail, respectively; the mode share adjustment for each transit submode (m = 1, 2, or 3) at the first iteration (i = 1) is computed as

$$A_m^i = \frac{(K_m - W_m)}{V_m^{i-1}} \tag{5}$$

where

A_m^i = mode share adjustment factor for transit mode m at iteration i,
K_m = targeted transit ridership estimates for transit mode m,
W_m = regional total number of trips using mode m by workers,
V_m = regional total number of trips using mode m by nonworkers, and
V_m^{i-1} = expanded volume of trips by all nonworkers using transit mode m from previous iteration where at first iteration $V_m^0 = V_m$.

The adjustment factor for the nontransit trips is then determined as a function of the ridership estimates and various expanded trip volumes. In formulation, it is computed as

$$A_m^i = \frac{\left[\sum_{m=\text{all}} V_m^{i-1} - \sum_{m=\text{transit}} (K_m - W_m) - N^{i-1}\right]}{V_m^{i-1}} \tag{6}$$

where

A_m^i = mode share adjustment factor for all nontransit modes m at iteration i,
K_m = targeted transit ridership estimates for transit mode m,
W_m = regional total number of trips using mode m by workers,
N^{i-1} = total expanded trips of unknown mode by all nonworkers at iteration $i - 1$, and
V_m^{i-1} = expanded volume of trips by all nonworkers using nontransit mode m from the previous iteration.

Individual Weighting Adjustment

It is assumed that the individuals (not their trips) have been oversampled or undersampled so the nonworker adjustment factor is estimated as a weighted average of the submodal adjustment factors, with the weighting done by the modal distribution of the individual non-worker's trips. This is reflected in the following equation:

$$A_{hp}^i = \frac{\sum_m (T_{hpm} \cdot E_{hp} \cdot B_h \cdot A_m^i)}{\sum_m (T_{hpm} \cdot E_{hp} \cdot B_h)} \tag{7}$$

where

A_{hp}^i = individual weighting adjustment factor at iteration i for nonworker p in household h,
T_{hpm} = number of trips using mode m by individual p in household h,
E_{hp} = existing expansion factor for individual p in household h,
B_h = adjustment factor for nonworkers in household h, and
A_m^i = mode share adjustment factor for transit mode m at iteration i.

Adjustment of Trip Production Totals at Ring Level

To prevent this adjustment from altering the volume of trips produced in the region, the expanded volumes of trips by nonworkers by ring of residence after the nonworker individual weighting adjustment are matched to the preadjustment expanded totals by ring of residence. This is illustrated in the following equation:

$$A_r^i = \frac{\sum_{hpm}^{\text{all}} (T_{hpmr} \cdot E_{hp} \cdot B_h)}{\sum_{hpm}^{\text{all}} (T_{hpmr} \cdot E_{hp} \cdot B_h \cdot A_{hp}^i)} \tag{8}$$

where

A_r^i = ring adjustment factor at iteration i for ring r,
T_{hpmr} = number of trips using mode m by nonworker p from household h residing in ring r,
E_{hp} = existing expansion factor for individual p in household h,
B_h = adjustment factor for nonworkers in household h, and
A_{hp}^i = individual weighting adjustment factor at iteration i.

Final Adjustment Factor

The iteration procedure is repeated until the submodal adjustment factors are close to 1. The final modal adjustment factor for nonworker p in household h within ring r can then be shown as:

$$A_{hpr} = B_h \cdot \prod_i (A_{hp}^i \cdot A_r^i) \tag{9}$$

Results of Second Adjustment Step

Before the first iteration, commuter rail trips by nonworkers were 63 percent of their estimated total, rapid transit trips were 68 per-

TABLE 7 Summary of Expanded Trips by Mode and Purpose after Transit Ridership Adjustment

Trip	Mode of Travel						All-Mode
Purpose	Auto	Bus Only	Subway	Railroad	Non-Veh	Unknown	Total
HB Work	2,372,000	83,000	175,900	40,400	191,800	5,900	2,869,000
HB School	478,100	30,700	50,800	3,400	328,500	600	892,100
HB Other	5,311,800	87,700	79,700	12,700	717,800	5,900	6,215,600
NHB Work	1,531,200	29,900	69,700	3,700	459,000	900	2,094,400
NHB Other	1,477,600	30,300	50,300	2,300	331,400	400	1,892,300
Total	11,170,700	261,600	426,400	62,500	2,028,500	13,700	13,963,400
Percent	80.0%	1.9%	3.1%	0.4%	14.5%	0.1%	100.0%
Before Adj.	11,046,500	322,500	485,400	70,800	2,022,100	13,800	13,961,100
	79.1%	2.3%	3.5%	0.5%	14.5%	0.1%	100.0%

cent of their estimated total, and bus trips were 62 percent of their estimated total. At the initial iteration, about 90 percent of the individual weighting adjustment factors were between 0.95 and 1.05, less than 2 percent of them are less than 0.65, and none of them are over 1.05. The ring adjustment factors for the first iteration ranged from 0.98 to 1.04.

The ridership estimate-survey estimate ratios (i.e., the mode share adjustment factors) after five iterations were 0.98 for commuter rail, 0.99 for rapid transit, and 0.98 for bus, and all of the fifth iteration personal adjustment factors were between 0.95 and 1.05. Also, at the fifth iteration, the ring adjustment factors ranged from 0.999 to 1.002. These ratios appeared acceptable, so the combination of factors from the first five iterations were applied to the appropriate records in the survey trips file.

As indicated in Table 7, while making this adjustment, the transit trips were reduced by 14.9 percent (by about 131,000 trips) from the previous adjustment step. The largest reduction is in the bus only trips (reduced by 18.3 percent). As a result, the three transit submode trips are all within 1 percent of the regional transit ridership estimates.

CONCLUSIONS

The household survey information generally is organized into three components: household, person, and trip files. Ideally, the expansion factors computed for the household file are adequate for the person and trip files, and additional weights need not be computed (*7*). In some cases, however, the additional adjustments are necessary in application of the survey data because of the poor matching of regional totals of persons or trips.

It is desirable that the adjusted expansion factors are distributed similar to that of the original expansion (developed at household level). Table 8 summarizes the ranges of expansion factors from

TABLE 8 Comparative Distributions of Households by Expansion Factor Ranges

Range of Expansion Factors	Step 0: Original Expansion		Step 1: Journey-To-Work Adjustment		Step 2: Transit Ridership Adjustment	
0 - 50	12	0.3%	16	0.4%	17	0.4%
50 - 150	309	8.0%	367	9.5%	391	10.2%
150 - 250	735	19.1%	719	18.7%	715	18.6%
250 - 350	847	22.0%	865	22.5%	838	21.8%
350 - 450	884	23.0%	837	21.8%	832	21.6%
450 - 550	484	12.6%	457	11.9%	447	11.6%
550 - 650	242	6.3%	232	6.0%	256	6.7%
650 - 750	123	3.2%	137	3.6%	142	3.7%
750 - 850	78	2.0%	70	1.8%	64	1.7%
850 - 950	29	0.8%	34	0.9%	32	0.8%
950 - 1,050	17	0.4%	18	0.5%	19	0.5%
1,050 - 1,550	45	1.2%	53	1.4%	52	1.4%
1,550 - 2,050	17	0.4%	15	0.4%	18	0.5%
2,050 - 2,550	8	0.2%	12	0.3%	13	0.3%
2,550 - 3,050	14	0.4%	12	0.3%	7	0.2%
> 3,050	0	0.0%	0	0.0%	1	0.0%
Total	3,844	100.0%	3,844	100.0%	3,844	100.0%

Note: In Adjustment Steps 1 and 2, the expansion factors for a survey household is a weighted average of all the persons in the household.

TABLE 9 Comparison of Expanded Trips by Trip Purpose

Trip Purpose	Unexpanded Data	Before Adjustment	Adjustment Step 1	Adjustment Step 2
HB Work	20.9%	20.6%	20.6%	20.5%
HB School	6.3%	6.5%	6.5%	6.4%
HB Other	43.2%	44.1%	44.4%	44.5%
NHB Work	16.3%	15.2%	15.0%	15.0%
NHB Other	13.3%	13.6%	13.5%	13.6%
Total	35,318	14,026,500	13,960,100	13,963,400

TABLE 10 Comparison of Expanded Trips by Transit Submode

Transit	Regional Transit Ridership Estimates		Original Expansion		Journey-To-Work Adjustment		Transit Ridership Adjustment	
Sub-Mode	Trips	Share	Trips	Share	Trips	Share	Trips	Share
Bus Only	259,100	34.7%	291,400	29.9%	322,500	36.7%	261,600	34.9%
Subway	425,200	56.9%	578,900	59.4%	485,400	55.2%	426,400	56.8%
Railroad	62,800	8.4%	104,100	10.7%	70,800	8.1%	62,500	8.3%
Total	747,100	100.0%	974,400	100.0%	878,700	100.0%	750,500	100.0%

the original expansion to the transit ridership adjustment step. The factors in the two adjustment steps were developed at the person level, so they are average factors of the persons within a household. As shown, the distributions of factors that form the two steps are not very different from that of the original expansion, and over 80 percent of the expansion factors are concentrated in the range of 150 to 650 (the average expansion factor from the original expansion is 393).

Meanwhile, the distributions of trips by trip purpose from step to step were examined. As indicated in Table 9, there were no significant changes in the distribution of trips by trip purpose while making the two adjustments.

This study proposed a procedure that adjusts the proportion of trips by travel mode in household survey, based on two relatively more reliable data sources: the Census journey-to-work data and local transit ridership estimates. Through the two adjustment steps, the expanded transit trips by submode were matched to transit ridership estimates (Table 10). In application, the adjusted expansion factors from the journey-to-work adjustment can be applied to trip distribution calibration, and that from the transit ridership adjustment can be applied to mode choice model estimation.

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