CEE 123 Transport Systems 3: Planning & Forecasting

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Homework #6 -- Trip Distribution [S O L U T I O N S]

The following base and future data pertain to a hypothetical five zone region. The data set includes surveyed production, attractions, and activity system variables for 2020, as well as estimates of activity system variables for the year 2030. Note that some zones are **strict** productions and others are **strict** attractions (hint!).

Table 1a. Travel Times ; HBW Ps & As ; Base and Future Demographics

	2020					2020		2020		2030	
	-Base Travel Time-					-Base Trips-		-Base Demo-		-Future Demo-	
From\To	1	2	3	4	5	PROD	ATTR	WORK	EMPL	WORK	EMPL
1	1	3	3	6	3	0	450	0	220	0	216
2	3	1	2	6	5	0	250	0	110	0	118
3	3	2	1	5	6	300	0	140	0	250	0
4	6	6	5	1	4	0	300	0	140	0	166
5	3	5	6	4	1	700	0	360	0	472	166
Totals						1000	1000	500	470	722	666

Table 1b. Base 2020 Trip Distribution

FROM\TO	1	2	4	Prod
3	125	125	50	300
5	325	125	250	700
Attr	450	250	300	1000

Problem 1. Trip Generation (10 points)

Household HBW trip production and attraction models for the region have been estimated as functions of workers per zone (WORK) and employees per zone (EMPL), respectively:

$$P_i = 50.0 + 1.8\ WORK_i \qquad A_j = 30.0 + 1.9\ EMPL_j$$

a. **Estimate** a measure of goodness-of-fit for each of the above models using the base data. **Comment** on fit.
b. Use the demographic forecasts provided to **predict** future trip ends for the P and A models. **Tabulate**.

Solution: *Validation: note the dependent variable (Pi or Aj) is set to zero when the explanatory variable (WORKi or EMPLj) is zero so that trips are not generated in zones which do not have activity. RMS Error provides a suitable measure of Goodness-of-Fit to supplement the tabulated relative (percent) errors.*

Table 1A. Trip Generation: (a) Validation and (b) Forecasts

	a1. Validation 1 HBW P(i)			a2. Validation 2 HBW A(j)				(b) Forecast HBW Forecast		
Zone	Base	Est	Err(%)	Base	Est	Bal	Err(%)	P(i)	A(j)	A(j)*
1				450	448	456	1.33	0	440	445
2				250	239	243	-2.80	0	254	257
3	300	302	0.67					500	0	0
4				300	296	301	0.33	0	345	349
5	700	698	-0.29					900	345	349
Total	1000	1000		1000	983	1000		1400	1385	1400
RMSE			2.00				5.35			

Note: The forecast A(j)* values are normalized to forecast P(i). RMSE=sqrt[(Σ(est-obs)^2)/n]

Problem 2. Trip Distribution: Calibration (20 points)
Calibrate a HBW singly-constrained gravity model for trip distribution for the base year data in Table 1.

a. **Develop** the travel time frequency distribution based on one minute travel time intervals. Set all initial friction factors equal to one. **Complete** a minimum of 3 iterations. Use a 5 percent convergence tolerance. **Apply** Attraction Factoring or Column and Row factoring at each iteration. **Show** all work.
b. **How** close are the trip matrix cells to the base distribution? **How** could you adjust the cells for a better fit? **What** are the limitations of your adjustment process?
c. **Estimate** the mean trip length (time) for the base trip distribution results (note: these estimates do not reflect congested travel times).

(a) Solution:

Table 2. Friction Factor Calibration Iterations (with Attraction Factoring)

Travel Time Category	O-D Pairs in Time Category	Observed Trips	Observed (%)	Observed Fk	Iter #1 (%)	Iter #1 Fk	Iter #2 (%)	Iter #2 Fk	Iter #3 (%)	Iter #3 Fk
1 < t <= 2	32	125	12.5	1.00	7.5	1.67	11.7	1.78	12.7	1.75
2 < t <= 3	31,51	450	45.0	1.00	45.0	1.00	45.1	1.00	45.0	1.00
3 < t <= 4	54	250	25.0	1.00	21.0	1.19	25.7	1.16	24.4	1.19
4 < t	34,42	175	17.5	1.00	26.5	0.66	17.5	0.66	18.0	0.65

1. *If Attraction Factoring is NOT done at each iteration, only the 3rd iteration changes, with final frequencies of 12.2, 45.0, 25.3, and 17.5, and final friction factors of 1.82, 1.00, 1.15, and 0.66*
2. *Results differ if Column & Row factoring is used at each iteration. First, convergence occurs after two iterations (the first iteration in all three cases is the same). Final category frequencies would be 12.25, 45.02, 24.8, and 17.93 and final friction factors would be 1.70, 1.00, 1.20, and 0.64*
3. *See attached for BURPP! software outputs, including details for the above table.*

(b) Solution:

The individual cells of the matrix are quite close (a RMS or similar error term could be computed). The fit could be improved by using Kij-factors to adjust individual matrix cells but these are somewhat arbitrary parameters that are difficult to assess in terms of validity in forecasting. Appended are model outputs for three calibration runs (with Destination Balancing, with Column and Row Factoring, and with no attraction adjustments).

1. Without A Adjustment: RMSE(Wj)=6.1042; RMSE(Tij)=3.28
2. Attraction Factoring: RMSE(Wj)=4.1096; RMSE(Tij)=3.67
3. Column+Row Factoring: RMSE(Wj)=0.7272; RMSE(Tij)=1.86

(c) Solution:

The mean trip length (time) for the base trip distribution: = $[\Sigma_i \Sigma_j T_{ij} t_{ij}] / \Sigma_i \Sigma_j T_{ij}$ = 3.475 minutes

Table 1a. Base Travel Times and Base Trip Distribution

From\To	-Base Travel Time- 1	2	3	4	5	FROM\TO	-- Base Trip Distribution -- 1	2	4	Prod
1	1	3	3	6	3	1	0	0	0	0
2	3	1	2	6	5	2	0	0	0	0
3	3	2	1	5	6	3	125	125	50	300
4	6	6	5	1	4	4	0	0	0	0
5	3	5	6	4	1	5	325	125	250	700
						Attr	450	250	300	1000

Problem 3. Trip Distribution: Application (10 points)
Using future forecasts from the trip generation models in Problem 1 and an effective change in travel time to 2 minutes for Zone 3 to Zone 1, **estimate** future trip distribution. **Estimate** the mean trip length (time) for the future distribution and compare to the base mean trip length.

Solution:
The presence of both trip productions and attractions in zone 5 (as computed in Problem 1) means that the prior representation of the problem as a 2 by 3 matrix must be changed to a 2 by 4. Using the calibrated model (with destination balancing), the output for the full 5 by 5 matrix problem is shown below. Note that not only does the Fij-factor for cell (3,1) change (due to its change in travel time), but also trips are now distributed to zone 5, travel times for which are 6 minutes from zone 3 and 1 minute intrazonal. Since friction factors were not calibrated for these trip lengths (due to the absence of trips of this length in the base year), the factor for category 1 (1-2 minutes) is used for (0-1 minutes) and that for category 4 (4-5 minutes) is used for (5-6 minutes) (the last category is always used for any travel times in excess of the maximum calibrated). Appended is a BURPP! SCGM prediction output.

```
Table 3. Future Productions, Attractions & Travel Times (2030)
------------------------------------------------------------------------
       Fut. Travel Time Future Trips   ----- Future Trip Matrix -----
From\To  1  2  3  4  5   P(i)  A(j)*     1    2    3    4    5   P(i)
------------------------------------------------------------------------
   1     1  3  3  6  3     0    444      0    0    0    0    0     0
   2     3  1  2  6  5     0    258      0    0    0    0    0     0
   3     2  2  1  5  6   500      0    213  151    0   78   57   500
   4     6  6  5  1  4     0    349      0    0    0    0    0     0
   5     3  5  6  4  1   900    349    230  105    0  272  293   900
------------------------------------------------------------------------
Totals  Change in (3,1) 1400   1400    443  256    0  350  350  1400
------------------------------------------------------------------------
```

mean travel time = $[\Sigma_i \Sigma_j T_{ij} t_{ij}] / \Sigma_i \Sigma_j T_{ij}$ = 2.897 minutes

The base mean travel time was 3.475 minutes. The decrease is due to the reduction in travel time for trips from 3 to 1 and the new intrazonal trips in zone 5 with a 1 minute travel time.

• Do Either Problem 4a or 4b • (a little advanced thinking)

Problem 4a. Trip Distribution: DCGM (10 points)
Using the *calibrated* friction factors from the HBW Singly-Constrained Gravity Model of Problem 2, complete one iteration of a Doubly-Constrained Gravity Model.

a. **Compute** the balancing terms (a_i and b_j) and **estimate** the trip matrix.

   Solution: *Results attached for (a) one iteration of DCGM starting with SCG (w/ Attr Factoring) results, and (b) two iterations starting with initial F(k)=1.0 (results include balancing terms, friction factors, and the estimated matrix). The two results, summarized below for (a), are virtually identical.* Note that the balancing terms are normalized to equate their scale.

```
         BALANCING  CONSTRAINTS
----------------------------------------
 ZONE   A(i) FACTOR   B(j) FACTOR  ZONE
----------------------------------------
   1      0.029651      0.031158     1
   2      0.033141      0.033172     2
   3                    0.029858     3
----------------------------------------

       CALIBRATED FRICTION FACTORS
-------------------------------------------
 CATEGORY   RANGE      TRIPS(%) Fij FACTOR
-------------------------------------------
     1    1.0 -  2.0   12.5000    1.6945
     2    2.0 -  3.0   45.0000    1.0000
     3    3.0 -  4.0   25.0000    1.2031
     4    4.0 -  5.0   17.5000    0.6432

        ESTIMATED TRIP INTERCHANGE
 FROM\TO    1      2      4    Prod
    3    124.7  122.9   52.6  300.3
```

```
      5    325.3  127.1  247.4  699.7
   Attr    450.0  250.0  300.0 1000.0
```

b. **Determine** the corresponding Trip Length Frequency Distribution. Is the DCGM within the final convergence tolerance of the SCGM in Problem 2?

Solution: *Results in both cases were improved over the SCGM results. TLFD varying little from the observed (note RMSE and chi^2 stats in attached BURPP! output). Also note that this software solution stops prematurely with a column balancing rather than with a row balancing, thus, the row sums do not exactly match.*

Problem 4b. Trip Distribution: Growth Factors (10 points)
Using future forecasts from the trip generation models in Problem 1, estimate future HBW trip distribution using the Furness growth factor model (Row and Column Factoring). Use a 5 percent convergence tolerance or a maximum of two iterations. Growth Factor Models cannot project growth in zones where no base activity exists, so ignore the added future employment in Zone 5. **Hint:** use future productions and attractions to "column and row factor" the base trip matrix.

```
Table 4b1. Base Trip Distribution
--------------------------------------------------------
          ----- Base O/D -----   ---- TG Forecast -----
 FROM\TO    1    2    4   Prod   P(i)  A(j)  A(j)*  Adj
--------------------------------------------------------
    1       0    0    0     0      0    464   464   591
    2       0    0    0     0      0    270   270   344
    3     125  125   50   300    500      0     0     0
    4       0    0    0     0      0    365   365   465
    5     325  125  250   700    900    365*    0     0
--------------------------------------------------------
  Attr    450  250  300  1000   1400   1465  1099  1400
--------------------------------------------------------
  * Ignore future growth in Zone 5 for GF-model

Table 4b2. Base Growth Factor Matrix
-------------------------------------
          ----- Base O/D -----  Future
 FROM\TO    1    2    4   Prod   P(i)
-------------------------------------
    3     125  125   50   300    500
    5     325  125  250   700    900
-------------------------------------
Base Aj   450  250  300  1000   1400
-------------------------------------
Fut. Aj   591  344  465  1400
-------------------------------------
Col Fact  1.31 1.38 1.55
-------------------------------------

Table 4b3. Column-factored Matrix 1
--------------------------------------------
           -- Est O/D --  Est.   Fut.  Row
 FROM\TO    1    2    4   P(i)   P(i)  Fact.
--------------------------------------------
    3     164  172   78  414    500    1.21
    5     427  172  387  986    900    0.91
--------------------------------------------
Est. Aj   591  344  465 1400   1400
--------------------------------------------
Fut. Aj   591  344  465 1400
--------------------------------------------

Table 4b4. Row-factored Matrix 1
-------------------------------------
          ----- Base O/D -----  Future
 FROM\TO    1    2    4   Prod   P(i)
-------------------------------------
```

3	198	208	94	500	500
5	390	157	353	900	900
Est. Aj	588	365	447	1400	1400
Fut. Aj	591	344	465	1400	
Col Fact	1.01	0.94	1.04		

Table 4b5. Column-factored Matrix 2

FROM\TO	-- Est O/D -- 1	2	4	Est. P(i)	Fut. P(i)	Row Fact.
3	199	196	98	493	500	1.01
5	392	148	367	907	900	0.99
Est. Aj	591	344	465	1400	1400	
Fut. Aj	591	344	465	1400		

Note: within tolerance but always end on a RF!

Table 4b6. Row-factored Matrix 2

FROM\TO	----- Base O/D ----- 1	2	4	Prod	Future P(i)
3	202	199	99	500	500
5	389	147	364	900	900
Est. Aj	591	346	463	1400	1400
Fut. Aj	591	344	465	1400	
Col Fact	1.00	0.99	1.00		

Problem 5. Travel Surveys (20 points)
The spreadsheet provides 2020 household socio-economic and travel diary data for a sub-sample of Miasma Beach households. **Use only households 10 through 12 in this exercise**.

a. **Calculate** the trip travel time, activity duration, and trip purpose classification (HBW, HBO, or NHB) for each trip and append to the table. **Compute** the mean travel time by mode and mean activity duration by purpose. Submit a hardcopy (e-copy optional) of the updated spreadsheet.

   SOLUTION: *Calculation results. Mean travel time was 12 minutes (5 min for 6 walk trips (27%); no bike trips (0%); 20 minutes for 5 bus trips (23%); and 13 min for 11 car trips (50%)). Mean activity duration was 4:05, with 7:42 for work/school activities linked to home (HBW); 1:00 for non-work activities linked to home (HBO); and 1:00 for non-home activities (NHB). At home activity duration was not compluted for return home trips).*

b. **Plot** the travel patterns on a Miasma Beach network map. Label each trip end as a production (P) or attraction (A) and label the trip type (HBW, HBO, NHB). Use color and/or line types to distinguish individuals and/or trip types. You may need to plot households on separate maps.

   Solution Map *not shown in this solution key. Trips can be drawn as straight lines between the origin and destination centroids, and should be color-coded by trip type (e.g., HBW).*

c. **Calculate** the associated OD trip table and the PA trip table.

   Solution 2024 (23 trips for HH10, HH11, and HH12)

PA Table	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	2	0	0	0	0
3	1	2	4	0	0	0
4	0	0	0	0	0	0

```
        5     0   0   0   0   1   0
        6     5   2   4   0   2   0
    ======== === === === === === ===,

    OD Table  1   2   3   4   5   6
    ======== === === === === === ===
        1     0   0   0   0   0   3
        2     0   2   1   0   0   1
        3     1   1   4   0   0   1
        4     0   0   0   0   0   0
        5     0   0   0   0   1   1
        6     2   1   2   0   1   0
    ======== === === === === === ===
```

Appendices -- BURPP! SCGM and DCGM outputs.

```
           *** Calibration *WITH* Attraction Factoring ***

           S I N G L Y - C O N S T R A I N E D   M O D E L
 ------------------------------------------------------------------
                                  ---- DESTINATIONS ----
  ZONE     ORIGINS  ATTRACTION     OBSERVED   PREDICTED   Zone
 ------------------------------------------------------------------
    3        300.      450.00       450.        450.       1
    5        700.      250.00       250.        255.       2
                       300.00       300.        295.       4
 ------------------------------------------------------------------
  TOTAL      1000.                 1000.       1000.
 ------------------------------------------------------------------

                      *  FHWA FRICTION FACTOR  *
               PROPORTIONALITY CONSTANT   =     1.0000
               MEAN TRIP LENGTH (COST)    =     3.4758
               DESTINATION  BALANCING

                        ***  CALIBRATION  ***
                     CALIBRATED FRICTION FACTORS
               RMS ERROR [Destinations]   =     4.1096
             -------------------------------------------
              CATEGORY   RANGE      TRIPS(%) Fij FACTOR
             -------------------------------------------
                   1    1.0 -  2.0   12.5000    1.7454
                   2    2.0 -  3.0   45.0000    0.9990
                   3    3.0 -  4.0   25.0000    1.1876
                   4    4.0 -  5.0   17.5000    0.6446

                   ADJUSTED DESTINATION ATTRACTORS
                  ---------------------------------
                    ZONE    ORIGINAL     ADJUSTED
                  ---------------------------------
                      1       450.00       449.56
                      2       250.00       259.15
                      3       300.00       292.31

  ESTIMATED TRIP INTERCHANGE            OBSERVED TRIP INTERCHANGE
  FROM\TO  C #1   C #2   C #4   P(i)    FROM\TO  C #1   C #2   C #4   P(i)
   C #3   121.4  127.1   51.5  300.0     C #3   125.0  125.0   50.0  300.0
   C #5   328.3  128.1  243.6  700.0     C #5   325.0  125.0  250.0  700.0
   A(j)   449.7  255.2  295.1 1000.0     A(j)   450.0  250.0  300.0 1000.0
```

```
          *** Calibration *WITH* Column & Row Factoring ***

           S I N G L Y - C O N S T R A I N E D   M O D E L
 ------------------------------------------------------------------
                                  ---- DESTINATIONS ----
  ZONE     ORIGINS  ATTRACTION     OBSERVED   PREDICTED   Zone
 ------------------------------------------------------------------
    3        300.      450.00       450.        450.       1
```

```
    5        700.      250.00        250.        249.      2
                       300.00        300.        301.      4
  ------------------------------------------------------------------
   TOTAL      1000.                  1000.       1000.
  ------------------------------------------------------------------

                      *  FHWA FRICTION FACTOR  *
               PROPORTIONALITY CONSTANT   =     1.0000
               MEAN TRIP LENGTH (COST)    =     3.4840
               COLUMN & ROW FACTORING

                        ***  CALIBRATION  ***
                     CALIBRATED FRICTION FACTORS
               RMS ERROR [Destinations]   =     0.7272
             -------------------------------------------
              CATEGORY   RANGE      TRIPS(%) Fij FACTOR
             -------------------------------------------
                  1    1.0 -  2.0   12.5000    1.7045
                  2    2.0 -  3.0   45.0000    0.9995
                  3    3.0 -  4.0   25.0000    1.2000
                  4    4.0 -  5.0   17.5000    0.6445

  ESTIMATED TRIP INTERCHANGE           OBSERVED TRIP INTERCHANGE
  FROM\TO  C #1   C #2   C #4   P(i)    FROM\TO  C #1   C #2   C #4   P(i)
   C #3   124.8  122.5   52.8  300.0     C #3   125.0  125.0   50.0  300.0
   C #5   325.4  126.6  248.0  700.0     C #5   325.0  125.0  250.0  700.0
   A(j)   450.2  249.1  300.8 1000.0     A(j)   450.0  250.0  300.0 1000.0
```

```
           *** Calibration WITHOUT Attraction Factoring ***

           S I N G L Y - C O N S T R A I N E D   M O D E L
                      *  FHWA FRICTION FACTOR  *
  ------------------------------------------------------------------
                                   ---- DESTINATIONS ----
   ZONE     ORIGINS  ATTRACTION     OBSERVED   PREDICTED   Zone
  ------------------------------------------------------------------
    3        300.      450.00        450.        450.      1
    5        700.      250.00        250.        242.      2
                       300.00        300.        307.      4
  ------------------------------------------------------------------
   TOTAL      1000.                  1000.       1000.
  ------------------------------------------------------------------

                      *  FHWA FRICTION FACTOR  *
               PROPORTIONALITY CONSTANT   =     1.0000
               MEAN TRIP LENGTH (COST)    =     3.4806
               DESTIN. UNCONSTRAINED

                        ***  CALIBRATION  ***
                     CALIBRATED FRICTION FACTORS
               RMS ERROR [Destinations]   =     6.1042
             -------------------------------------------
              CATEGORY   RANGE      TRIPS(%) Fij FACTOR
             -------------------------------------------
                  1    1.0 <= 2.0   12.5000    1.8189
                  2    2.0 <= 3.0   45.0000    0.9973
                  3    3.0 <= 4.0   25.0000    1.1450
                  4    4.0 <= 5.0   17.5000    0.6619

  ESTIMATED TRIP INTERCHANGE           OBSERVED TRIP INTERCHANGE
  FROM\TO  C #1   C #2   C #4   P(i)    FROM\TO  C #1   C #2   C #4   P(i)
   C #3   123.5  122.0   54.6  300.0     C #3   125.0  125.0   50.0  300.0
   C #5   326.9  120.4  252.7  700.0     C #5   325.0  125.0  250.0  700.0
   A(j)   450.4  242.3  307.3 1000.0     A(j)   450.0  250.0  300.0 1000.0
```

```
    *** Prediction with Future Times and Zone 5 Activity ***

   PREDICTION SUMMARY [with Furness (Column & Row) Balancing]
```

```
---------------------------------------------------------------------
            PRODUCTIONS                    ATTRACTIONS
 ZONE  ----------------------------  ----------------------------
       BASE   FORECAST   DIFF(%)     BASE   FORECAST   DIFF(%)
---------------------------------------------------------------------
   1                                 450.      444.    -1.33
   2                                 250.      258.     3.20
   3    300.      500.    66.67
   4                                 300.      349.    16.33
   5    700.      900.    28.57                349.     *.**
---------------------------------------------------------------------
 TOT   1000.     1400.              1000.     1400.
---------------------------------------------------------------------

        S I N G L Y - C O N S T R A I N E D   M O D E L
---------------------------------------------------------------------
                                   ---- DESTINATIONS ----
  ZONE     ORIGINS  ATTRACTION     OBSERVED   PREDICTED   Zone
---------------------------------------------------------------------
   1          0.      444.00        444.        443.      1
   2          0.      258.00        258.        257.      2
   3        500.        0.00          0.          0.      3
   4          0.      349.00        349.        350.      4
   5        900.      349.00        349.        350.      5
-----------------------------------------------------------------
TOTAL       1400.                  1400.       1400.
-----------------------------------------------------------------

                  *  FHWA FRICTION FACTOR  *
           MEAN TRIP LENGTH (COST)    =     3.4009
           FINAL: C & R FACTORING

                  CALIBRATED FRICTION FACTORS
         -------------------------------------------
          CATEGORY   RANGE      TRIPS(%) Fij FACTOR
         -------------------------------------------
               1    0.0 -  1.0    0.0000    1.7450
               2    1.0 -  2.0    0.0000    1.7450
               3    2.0 -  3.0    0.0000    0.9990
               4    3.0 -  4.0    0.0000    1.1880
               5    4.0 -  5.0    0.0000    0.6450
               6    5.0 -  6.0    0.0000    0.6450

 PREDICTED TRIP INTERCHANGE
 FROM\TO    1      2      3      4      5    P(I)
    3    213.0  151.3    0.0   78.3   57.4  500.0
    5    229.9  105.4    0.0  271.7  293.0  900.0
  A(J)   442.8  256.7    0.0  350.0  350.4 1400.0
```

```
                      DOUBLY - CONSTRAINED  GRAVITY  MODEL
                    *** Starting with all F(k) =     1.0 ***

               ------------  C A L I B R A T I O N  ------------
                FHWA GRAVITY MODEL: FRICTION FACTOR ESTIMATION
               -----------  PARAMETER SPECIFICATION  ------------
                  1. Initial Factors Set to . . . . . . . =  1
                     [If 0, Fij are User supplied]
                  2. Factor Smoothing (%) . . . . . . . . =  0
                  3. K-Factors (1; 0=calculated). . . . . =  1
                  4. Convergence Tolerance (10ths of %) . = 50
                  5. Maximum Steps. . . . . . . . . . . . = 10
                  6. Intermediate Output (1,2,3=yes). . . =  1
                  7. Matrix Output Precision. . . . . . . =  0
                  8. Constraint Balancing . . . . . . . . =  0
                  9. Balancing  Tolerance (10ths of %). . = 10
                 10. Balancing  Iterations. . . . . . . . =  5
               ----------------------------------------------

                           *  FHWA FRICTION FACTOR  *
                    IMPEDANCE PARAMETER        =     0.0000
```

```
                    MEAN TRIP LENGTH (COST)    =     3.4838

                             ***  CALIBRATION  ***
                    Root Mean Squared Error    =     1.9266
                    CHI-SQ [df=  2] Statistic  =     0.2326

                             BALANCING  CONSTRAINTS
                    ----------------------------------------
                     ZONE   A(i) FACTOR   B(j) FACTOR  ZONE
                    ----------------------------------------
                        1      0.029651      0.031158     1
                        2      0.033141      0.033172     2
                        3                    0.029858     3
                    ----------------------------------------

                          CALIBRATED FRICTION FACTORS
                  -------------------------------------------
                   CATEGORY   RANGE      TRIPS(%) Fij FACTOR
                  -------------------------------------------
                        1    1.0 -  2.0   12.5000    1.6945
                        2    2.0 -  3.0   45.0000    1.0000
                        3    3.0 -  4.0   25.0000    1.2031
                        4    4.0 -  5.0   17.5000    0.6432

 ESTIMATED TRIP INTERCHANGE
 FROM\TO    1      2      4    Prod
    3    124.7  122.9   52.6  300.3
    5    325.3  127.1  247.4  699.7
 Attr    450.0  250.0  300.0 1000.0
```

```
                D O U B L Y - C O N S T R A I N E D   M O D E L
                *** Starting with F(k) = SCG (w/AF) results ***

               ------------  C A L I B R A T I O N  -------------
                 FHWA GRAVITY MODEL: FRICTION FACTOR ESTIMATION
               -----------  PARAMETER SPECIFICATION  ------------
                  1. Initial Factors Set to . . . . . . . =  0
                     [If 0, Fij are User supplied]
                  2. Factor Smoothing (%) . . . . . . . . =  0
                  3. K-Factors (1; 0=calculated). . . . . =  1
                  4. Convergence Tolerance (10ths of %) . = 10
                  5. Maximum Steps. . . . . . . . . . . . = 10
                  6. Intermediate Output (1,2,3=yes). . . =  1
                  7. Matrix Output Precision. . . . . . . =  0
                  8. Constraint Balancing . . . . . . . . =  0
                  9. Balancing  Tolerance (10ths of %). . = 10
                 10. Balancing  Iterations. . . . . . . . =  5
               --------------------------------------------------

                           *  FHWA FRICTION FACTOR  *
                    IMPEDANCE PARAMETER        =     0.0000
                    MEAN TRIP LENGTH (COST)    =     3.4747

                             ***  CALIBRATION  ***
                    Root Mean Squared Error    =     0.7974
                    CHI-SQ [df=  2] Statistic  =     0.0326

                             BALANCING  CONSTRAINTS
                    ----------------------------------------
                     ZONE   A(i) FACTOR   B(j) FACTOR  ZONE
                    ----------------------------------------
                        1      0.029512      0.031149     1
                        2      0.033238      0.033238     2
                        3                    0.029739     3
                    ----------------------------------------

                          CALIBRATED FRICTION FACTORS
              --------------------------------------------------
               CATEGORY   RANGE      TRIPS(%)   Fij-IN   Fij-OUT
              --------------------------------------------------
```

```
                 1    1.0 -  2.0   12.5000    1.7045   1.6991
                 2    2.0 -  3.0   45.0000    0.9995   0.9995
                 3    3.0 -  4.0   25.0000    1.2000   1.2044
                 4    4.0 -  5.0   17.5000    0.6445   0.6426

 ESTIMATED TRIP INTERCHANGE
 FROM\TO    1      2      4    Prod
    3    124.0  125.4   50.9  300.3
    5    326.0  124.6  249.1  699.7
 Attr    450.0  250.0  300.0 1000.0
```

Intermediate Results for Calibration *WITH* Attraction Factoring

```
                       Observed Frequency Distribution
 CAT          RANGE               10        20        30        40        50
  1       1.0 -     2.0     *************
  2       2.0 -     3.0     *********************************************
  3       3.0 -     4.0     *************************
  4       4.0 -     5.0     ******************

                  Observed Mean Trip Cost =    3.4750
```

Itertion 1. Estimated Trip Matrix:

```
 FROM\TO    1      2      4     TOT
    3    135.0   75.0   90.0    300
    5    315.0  175.0  210.0    700
 TOT     450.0  250.0  300.0   1000
```

```
 ESTIMATED TRAVEL TIME DISTRIBUTION                       ITERATION NO.  1
 CAT          RANGE               10        20        30        40        50
  1       1.0 -     2.0     ********
  2       2.0 -     3.0     *********************************************
  3       3.0 -     4.0     *********************
  4       4.0 -     5.0     ***************************

   R-SQ ATTRACTIVENESS =   1.0000           MEAN TRIP COST: OBS =    3.4750
   CHI-SQ FREQUENCIES  =   0.4501 (df=  3)                  EST =    3.6650
```

```
 COMPUTATION OF NEW FRICTION FACTORS                      ITERATION NO.  1
                       O/D    INITIAL  MODEL    DEVIATION          NEW   EXCEED
 CAT    RANGE       PERCENT   FF(K)    PCNT  ABSOLUTE (PCNT)      FF(K)  TOLER?

  1   1.0 -  2.0    12.50    1.0000   7.50   -5.00  -40.00      1.6667    Yes
  2   2.0 -  3.0    45.00    1.0000  45.00    0.00    0.00      1.0000
  3   3.0 -  4.0    25.00    1.0000  21.00   -4.00  -16.00      1.1905    Yes
  4   4.0 -  5.0    17.50    1.0000  26.50    9.00   51.43      0.6604    Yes
```

Itertion 2. Estimated Trip Matrix:

FROM\TO	1	2	4	TOT
3	126.8	117.4	55.8	300
5	324.0	118.9	257.1	700
TOT	450.8	236.3	312.9	1000

```
ESTIMATED TRAVEL TIME DISTRIBUTION                       ITERATION NO.  2
CAT |       RANGE        |         10        20        30        40        50
 1  |     1.0 -    2.0   |************
 2  |     2.0 -    3.0   |*********************************************
 3  |     3.0 -    4.0   |**************************
 4  |     4.0 -    5.0   |*****************

R-SQ ATTRACTIVENESS =   0.9861           MEAN TRIP COST: OBS =   3.4750
CHI-SQ FREQUENCIES  =   0.0045 (df=  3)                  EST =   3.4891
```

COMPUTATION OF NEW FRICTION FACTORS — ITERATION NO. 2

CAT	RANGE	O/D PERCENT	INITIAL FF(K)	MODEL PCNT	DEVIATION ABSOLUTE	DEVIATION (PCNT)	NEW FF(K)	EXCEED TOLER?
1	1.0 - 2.0	12.50	1.6667	11.74	-0.76	-6.08	1.7746	Yes
2	2.0 - 3.0	45.00	1.0000	45.08	0.08	0.17	0.9983	
3	3.0 - 4.0	25.00	1.1905	25.71	0.71	2.86	1.1574	
4	4.0 - 5.0	17.50	0.6604	17.47	-0.03	-0.18	0.6616	

Itertion 3. Estimated Trip Matrix:

FROM\TO	1	2	4	TOT
3	121.4	127.1	51.5	300
5	328.3	128.1	243.6	700
TOT	449.7	255.2	295.1	1000

ESTIMATED TRAVEL TIME DISTRIBUTION ITERATION NO. 3

CAT	RANGE	10 20 30 40 50
1	1.0 - 2.0	xxxxxxxxxxxxx
2	2.0 - 3.0	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
3	3.0 - 4.0	xxxxxxxxxxxxxxxxxxxxxxxx
4	4.0 - 5.0	xxxxxxxxxxxxxxxxxx

R-SQ ATTRACTIVENESS =	0.9978	MEAN TRIP COST: OBS =	3.4750
CHI-SQ FREQUENCIES =	0.0016 (df= 3)	EST =	3.4758

COMPUTATION OF NEW FRICTION FACTORS ITERATION NO. 3

CAT	RANGE	O/D PERCENT	INITIAL FF(K)	MODEL PCNT	DEVIATION ABSOLUTE	DEVIATION (PCNT)	NEW FF(K)	EXCEED TOLER?
1	1.0 - 2.0	12.50	1.7746	12.71	0.21	1.67	1.7454	
2	2.0 - 3.0	45.00	0.9983	44.97	-0.03	-0.08	0.9990	
3	3.0 - 4.0	25.00	1.1574	24.36	-0.64	-2.54	1.1876	
4	4.0 - 5.0	17.50	0.6616	17.96	0.46	2.63	0.6446	

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