REFINEMENT OF FSUTMS TRIP DISTRIBUTION METHODOLOGY

Technical Memorandum No. 3

Calibration of an Intervening Opportunity Model For Palm Beach County

Prepared for
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1. INTRODUCTION

This technical memorandum documents an effort to calibrate an intervening opportunity model for Palm Beach County. Intervening opportunity models are investigated as an alternative to some of the gravity models currently used by some counties as a part of FSUTMS. This study has been motivated mainly by two reasons. First, Palm Beach County, like some other counties in Florida, has a narrow and long shape lying along the coast, with multiple city cores separated spatially. Gravity models tend to over-predict short trips in such cases. When the traditional gravity models do not perform well, *K* factors sometimes have to be used. Intervening opportunity models are believed to be able to better handle such urban development patterns. Another advantage of an intervening opportunity model over a gravity model is that it does not depend on a trip length frequency distribution as a gravity model does. For a gravity model, this trip length frequency distribution, typically obtained from a base year household survey, is assumed to remain unchanged for future model updates and forecasts. This assumption will be unlikely to hold in reality if there will be significant changes in future land uses. An intervening opportunity model uses attractions as the basis in model calibration, which may be updated when land uses have changed, thus making the model more adaptive to changes in trip patterns.

The basic idea behind intervening opportunity models is that the probability of choice of a particular destination is proportional to the opportunities for trip purpose satisfaction at the destination and inversely proportional to all such opportunities that are closer to the trip maker's origin, which are called the intervening opportunities. The model explicitly considers the opportunities available to satisfy a trip purpose at increased distance from the origin. Accordingly, for an origin zone, its possible destinations are ranked in order of increasing distance from the origin zone. A common intervening opportunity model for trip distribution between zones *i* and *j* takes the following form [Kanafani 1983, Ortuzar 1994]:

$$T_{ij} = P_i \left[\frac{\exp\left(-LV(j-1)\right) - \exp\left(-LV(j)\right)}{1 - \exp\left(-LV(J)\right)} \right]$$

where:

T_{ij} = the number of trips from zone *i* to zone *j*;
P_i = the number of trip productions in origin zone *i*;
L = the probability of accepting a destination opportunity;
$V(J)$ = the total destination opportunities in all *J* destinations;
$V(j)$ = the total destination opportunities from origin zone *i* to the *j*th ranked destination; and
$V(j-1)$ = the total destination opportunities from origin zone *i* to the (*j-1*)th ranked destination.

Although opportunity models are based on somewhat sophisticated principles, they are not often used in practice. Some of the possible reasons given by Ortuzar (1994) include:

1. The theoretical basis is less well known and more difficult to understand to practitioners.

2. The theoretical and practical advantages of opportunity models over gravity models are not so significant as to warrant their replacing gravity models.

3. There is a lack of suitable software to calibrate and use them.

To evaluate the potentials of intervening opportunity models as a possible replacement of the gravity models currently used in FSUTMS, we conducted an intervening opportunity model calibration using Palm Beach County as a case study since recent survey data (the 1999 Southeast Florida Travel Characteristic Study) are available, and a new gravity model has been calibrated based on the survey data, which can be used for comparison purposes.

Intervening opportunity models have been proven to be a member of the gravity model family. Therefore, an intervening model may be formulated as a gravity model and calibrated as such. In the next section, we first derive the gravity model form of the intervening model. The procedure used to calibrate the intervening opportunity model is then described in Section 3. Section 4 compares the intervening opportunity model to the Palm Beach gravity model using different techniques. Finally, problems related to model calibration are discussed and recommendations are provided in Section 5.

2. MODEL FORMULATION

An intervening opportunity model assumes that trip makers consider potential destinations sequentially, in order of their impedance away from the origin (Rogerson, 1993). The probability that a trip will terminate at one of a group of destinations is equal to the product of two probabilities: (1) the probability that an acceptable destination closer to the origin has not been chosen and (2) the probability that an acceptable destination exists in these destinations. The probability of a trip ending in a zone *j* may be expressed as (Eash, 1980):

$$P(A_j) = \{1-P(V_{j-1})\}\ L\ A_j$$

where V_j = the sum of the destination opportunities available from the origin zone to j^{th} zone, as ranked by travel impendence from the origin zone.
A_j = the number of destination opportunities considered in zone *j*.
$P(V_j)$ = the probability of finding an acceptable destination in Vj opportunities.
$P(A_j)$ = the probability of finding an acceptable destination in the A_j opportunities of zone *j*.
L = the constant probability of accepting a destination if it is considered.

Since the two probabilities may vary from point to point, the problem therefore may be stated in terms of limitingly small quantities assuming $P(A_j)$ to be a continuous function and zones and A_j are small. Thus, the above equation may be written as differentials:

$$dP(V_j) = \{1-P(V_j)\}\ L\ dV_j$$

$$\begin{aligned}
&\text{Let } V_j = x,\quad P(V_j) = f(x)\\
&\Rightarrow 1-P(V_j) = 1 - f(x) = g(x)\\
&\Rightarrow dg(x) = -df(x)\\
&\Rightarrow d\,f(x) = [1 - f(x)]\ L\ dx\\
&\Rightarrow -\ d\ g(x) = g(x)\ \ L\ dx\\
&\Rightarrow -\ d\ g(x)/g(x) = \ L\ dx\\
&\Rightarrow -\ \textstyle\int d\ g(x)/g(x) = \int L\ dx\\
&\Rightarrow \ln g(x) = -(L\ x + c)\\
&\Rightarrow g(x) = \exp[-(L\ x + c)] = \exp(-c)\ \exp(-L\ x) = k\ \exp(-L\ x)\\
&\Rightarrow f(x) = 1-\ k\ \exp(-L\ x)\\
&\Rightarrow P(V_j)= 1-\ k\ \exp(-L\ x)\\
&\because P(0) = 1-\ k\ \exp(0) = 1 - k = 0 \quad \therefore k = 1\\
&\Rightarrow P(V_j)= 1-\ \exp(-L\ V_j)
\end{aligned}$$

The number of trip movements between an origin zone i and a destination zone j equals to the probability of finding an acceptable destination opportunity in zone j times the number of trips from zone i, P_i:

$$T_{ij} = P_i\ \{\ P(V_j) - P(V_{j-1})\ \}$$

$$\Rightarrow\ T_{ij} = P_i\ \{\exp(-L\ V_{j-1}) - \exp(-L\ V_j)\ \}$$

$$\Rightarrow\ T_{ij} = P_i\ \{\exp(-L\ V_{j-1}) - \exp[-L\ (V_{j-1} + A_j)]\ \}$$

$$\Rightarrow\ T_{ij} = P_i\ [1 - \exp(-L\ A_j)\ ]\ \exp(-L\ V_{j-1})$$

where A_j is the number of trip attractions in zone j. If L is small, on the order of 0.1 or less, then $[1 - \exp(-L\ A_j)\ ]$ is nearly equal to $L\ A_j$. Therefore,

$$T_{ij} \approx P_i\ A_j\ L\ \exp(-L\ V_{j-1}) \tag{1}$$

A trip distribution model is constrained to distribute the same number of trips from a zone as there are trips originating from that zone, that is, $\sum_j T_{ij} = P_i$.

The above equation may be rewritten as

$$T_{ij}\ = f_i\ P_i\ A_j\ L\ \exp(-L\ V_{j-1})$$

where f_i is a factor to force all origin trips to be distributed. Summing all the trips originating from zone *i* and forcing the sum to be the total production of zone *i*, f_i may be solved:

$$\sum_j T_{ij} = \sum_j f_i P_i A_j L\, exp(-L\, V_{j-1}) = f_i P_i \sum_j A_j L\, exp(-L\, V_{j-1}) = P_i$$

$$\Rightarrow f_i = 1/\{\sum_j A_j L\, exp(-L\, V_{j-1})\}$$

Therefore,

$$T_{ij} = P_i \left[\frac{A_j\, e^{(-LV_{j-1})}}{\sum_k A_k e^{(-LV_{j-1})}} \right]$$

Replacing $exp(-L\ V_{j-1})$ with F_{ij}, it then has the form that gravity models generally take (Eash 1980):

$$\boldsymbol{T_{ij} = P_i \left(\frac{A_j F_{ij}}{\sum_k A_k F_{ik}} \right)}$$

where F_{ij} is the "friction factor" representing the spatial separation between zone *i* and zone *j*.

The most often used expression to determine the standard Gravity Model Friction *F(i,j)* is usually assumed to be a gamma function with some type of impedance between zones as an independent variable (alpha, beta and gamma are calibration coefficients):

$$F_{ij} = \alpha\ d_{ij}{}^{\beta}\, EXP(-\gamma\, d_{ij})$$

By setting $d_{ij} = V_{j-1}$, $\alpha = 1$, $\beta = 0$ and $\gamma = L$, respectively, the "friction factors" in an intervening opportunity model are:

$$\Rightarrow F_{ij} = 1 \times (V_{j-1}{}^{0})\, EXP(-L\ V_{j-1}) = EXP(-L\ V_{j-1})$$

By replacing the distance impendence in the standard gravity model with V_{j-1}, the *L* value can then be calibrated in the same manner as gamma in the standard gravity model software.

3. MODEL CALIBRATION PROCEDURE

The TRANPLAN program can be use to calibrate parameter *L* since the friction factor in TRANPLAN is formulated as $f_{ij} = EXP(-\theta\, d_{ij})$, where θ is a coefficient and d_{ij} is the minimum travel impedance between zones *i* and *j*. Replacing d_{ij} in TRANPLAN with V_{j-1} converts a gravity model to an intervening opportunity model.

The following ten steps explain the procedure of calibrating an intervening opportunity model using TRANPLAN:

(1) Run FSUTMS with 1999 Palm Beach data to obtain free-flow travel time impedance skim, and productions and attractions for HBW, HBS, HBSR, HBO, NHBW, and NHBO purposes, respectively.

(2) Convert the binary file of the impedance skim to text file and then to database file.

(3) Construct opportunity matrices for different trip purposes. Since there are 1172 zones in Palm Beach County, the matrices are 1172 x 1172. The content in the matrix cell (*i*, *j*) represents the cumulative attractions from zones *i* to *j - 1*, which have been ranked by travel impedance from zone *i*. The procedure involves selecting zone *i* and sorting all other zones in an ascending order based on the travel time t_{ij}. For each zone *k* in the sorted list, the attractions of zone *i* through zone *k - 1* (*k = i, ... j - 1*) are summed up and the sum is stored in the opportunity matrix cell (*i*, *k*).

(4) Replace the travel time impedance skim by the opportunity matrix for each trip purpose using the UPDATE MATRIX command in TRANPLAN. Note:
   (a) Due to a limitation on the number of transactions allowed in TRANPLAN scripts (32000), the 1172 x 1172 opportunity matrix is divided into 59 smaller matrices of 20 x 1172. The impedance matrix is then replaced with these small matrices one by one to avoid memory overflow in TRANPLAN.
   (b) Using a skim factor of 3,000 for opportunity to avoid overflow since the number of attraction trips are much larger than travel time (maximum allowable number is 327.67 in TRANPLAN).

(5) Calibrate IOM model and obtain OD matrix.
   (a) Using the 1999 SEFRTCS survey data and the opportunity matrices, find the frequency distribution for the destination opportunities, which replaces GT, the trip length frequency record in data specifications, for each trip purpose.
   (b) The F FACTOR CLOSURE is set to 5% as default so that the program will execute one additional iteration before termination if the ratio of the average destination opportunity at the end of each iteration to the surveyed average opportunity is within 5%.
   (c) Set GF in the data specification to 1 for initialization.
   (d) The maximum number of iterations to be executed during the calibration run, F FACTOR ITERATIONS, is set to 20.

Note that the selected summation file, which originally contains the interzonal skim impedance, is now used to store the accumulated opportunity matrix. Therefore, instead of calibrating the model to the surveyed trip length distribution as in the case of a gravity model calibration, the intervening opportunity model is calibrated to the surveyed opportunity distribution. The surveyed opportunity distribution is obtained as follows:

(1) For a particular trip purpose, the production and attraction zones of each sampled trip are identified.

(2) The total number of attractions from zones with free-flow travel times less than that between the observed zone pair are calculated (as described in Step 3 in the calibration procedure). These attractions represent the intervening opportunities that have met the trip maker's purpose but are not utilized.

(3) The opportunities are divided by 3,000 as in the case of the opportunity matrix stored in the summation file. The nearest integer of the new impedance unit is then recorded with one frequency.

(4) The same procedure is performed for every surveyed trip to obtain the total "intervening opportunities" frequency. The distribution of these opportunities for all surveyed trips is stored in a TRANPLAN input file TRANPLAN.IN.

4. EVALUATION OF INTERVENING OPPORTUNITY MODEL PERFORMANCES

An intervening opportunity model has been calibrated for different trip purposes for Palm Beach County using the 1999 Palm Beach model data. The model was calibrated using the free-flow skims from the gravity model. This section discusses the results of the calibration and the performance of the intervening opportunity model. Figure 1 shows the convergence of parameter L during the calibration. It may be seen that at 15th iteration, L has converged.

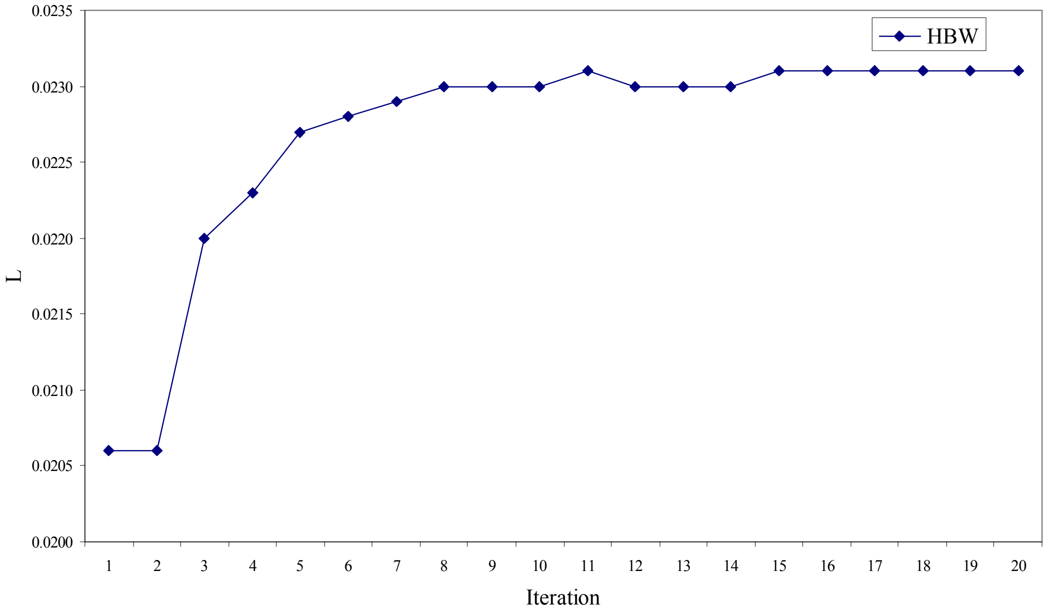

Figure 1. Convergence of L

In Figure 2, the calibrated friction factors (the curve with blue label points) are compared with their theoretical values (the fitted curve) for different impedance values (or attractions). The calibrated values resemble an exponential curve, and the theoretical curve is obtained by fitting an exponential curve based on the calibrated friction factors. The best fitting curve has an *L* value of 0.0231. It may be seen that the calibrated friction factors are initially smaller than the theoretical values, then at about impedance = 90 they became larger than the theoretical values. Compared to the theoretical values, the actual calibrated values of the friction factors produced more long trips. In other words, if friction factors obtained from the theoretical curve had been used, there would be fewer long trips and more short trips.

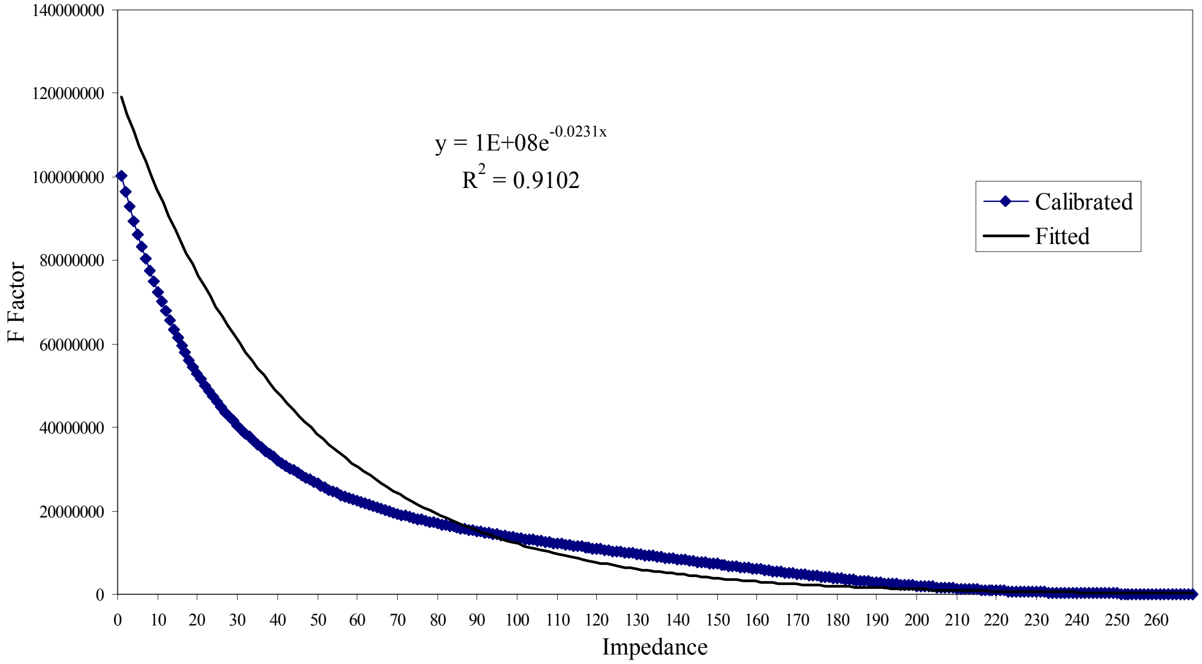

Figure 2. Friction Factor versus Impedance

To evaluate the model performance, the distributed trip length frequencies for different purposes were calculated based on the OD matrices and travel time impedance from the gravity model. The trip length frequencies from the survey data were compared with the results from the intervening opportunity model and gravity model. The performance of the intervening opportunity model was evaluated using a number of criteria, including the average trip lengths, the shapes of its trip length distribution curves, number of intrazonal trips produced, and trip interchanges between traffic analysis districts.

Table 1 compares the average trip lengths from the intervening opportunity model and from the gravity model, which was calibrated by Corradino, Inc. The first column in Table 1 shows the trip purposes, the second column is the average trip lengths from the 1999 survey data, the third column the average trip lengths from the intervening opportunity models, and the fourth column those from the gravity models. It may be seen that for work trips (including HBW and NHBW trips), the average trip lengths from the intervening opportunity model are longer than those from the gravity model and are closer to those from the survey data. This result agrees with the intuition that work trips tend to be longer because proximity is not as important to the choice of employment locations as for other trip purposes. For nonwork trip purposes, the gravity model produces average trip lengths closer to those from the survey data.

Table 1. Comparison of Average Trip Lengths

	Average Trip Length in Minutes		
	Surveyed Data	IOM	Gravity Model
HBW	16.71	16.87	16.02
HBS	11.43	13.13	11.29
HBSR	11.51	13.12	10.66
HBO	12.49	13.32	12.45
NHBW	13.08	13.53	11.13
NHBO	11.55	12.42	10.95

To further compare the gravity model and IOM, the shapes of the trip length distribution from the two models are compared in addition to the average trip length. The measure used for this comparison is the *coincidence ratio*, defined as follows:

$$Coincidence = \sum_{t=1}^{T} \min\left\{ \frac{f^{m}(t)}{F^{m}}, \frac{f^{o}(t)}{F^{o}} \right\}$$

$$Total = \sum_{t=1}^{T} \max\left\{ \frac{f^{m}(t)}{F^{m}}, \frac{f^{o}(t)}{F^{o}(t)} \right\}$$

$$coincidence\ ratio = \frac{Coincidence}{Total}$$

where $f^{m}(t)$ = frequency of trips at time *t* from model

$f^{o}(t)$ = frequency of trips at time *t* from survey data

$F^{m}(t)$ = total trips distributed from model

$F^{o}(t)$ = total trips from survey data

The coincidence ratio lies between zero and one, with zero indicating two disjoint distributions and one indicating identical distributions. Table 2 shows the coincidence ratios for the two models for different trip purposes. It may be seen that, for most of the trip purposes, the coincidence ratios for the two models are similar. However, the intervening opportunity model has a noticeably higher coincidence ratio than the gravity model for the HBW, HBO, and NHBW trips, while the gravity does better for the HBS and HBSR trips.

Table 2. Comparison of Coincidence Ratios of the Gravity Model and the IOM

	Coincidence Ratio	
	IOM	Gravity Model
HBW	0.856	0.816
HBS	0.745	0.751
HBSR	0.682	0.744
HBO	0.832	0.797
NHBW	0.787	0.761
NHBO	0.783	0.780

Table 3 compares the performance of the two models in terms of the intrazonal trips produced, which are shown as percentages of the total internal trips by purpose. While both models under-predicted intrazonal trips in general, it is more pronounced for the intervening opportunity model.

Table 3. Percentages of Intrazonal Trips

	Surveyed Data			IOM			Gravity Model		
	I-I trips	Intrazonal trips	%	I-I trips	Intrazonal trips	%	I-I trips	Intrazonal trips	%
HBW	1,869	53	2.84	684,678	4,058	0.59	684,744	6,291	0.92
HBS	1,273	41	3.22	599,254	8,152	1.36	600,051	32,445	5.41
HBSR	955	169	17.70	429,206	8,957	2.09	429,482	41,466	9.65
HBO	2,394	159	6.64	841,554	159,45	1.89	842,403	20,381	2.42
NHBW	776	56	7.22	348,261	8,282	2.38	348,305	24,290	6.97
NHBO	1,844	221	11.98	682,165	18,736	2.75	682,199	44,701	6.55

Figures 3 through 8 compare the trip length distribution by purpose from the two models against the survey data. It may be seen that the intervening opportunity model produces longer trips, and the curves do not decay as fast as the survey data and the gravity model for trip lengths over 15 minutes.

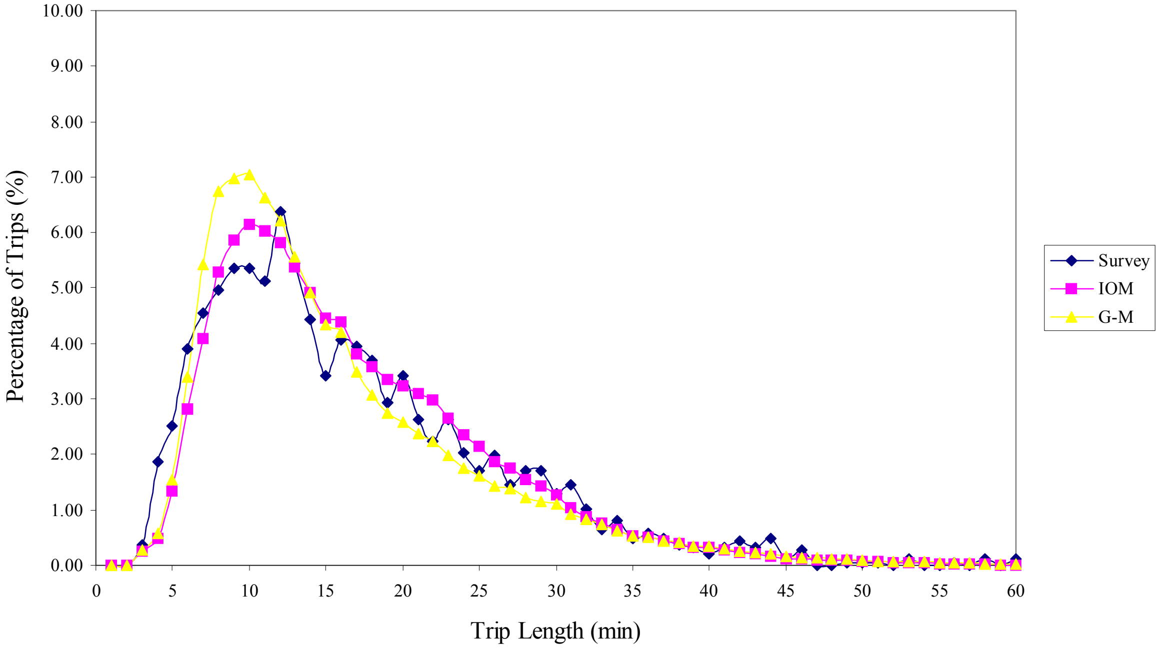

Figure 3. HBW Trip Length Distributions

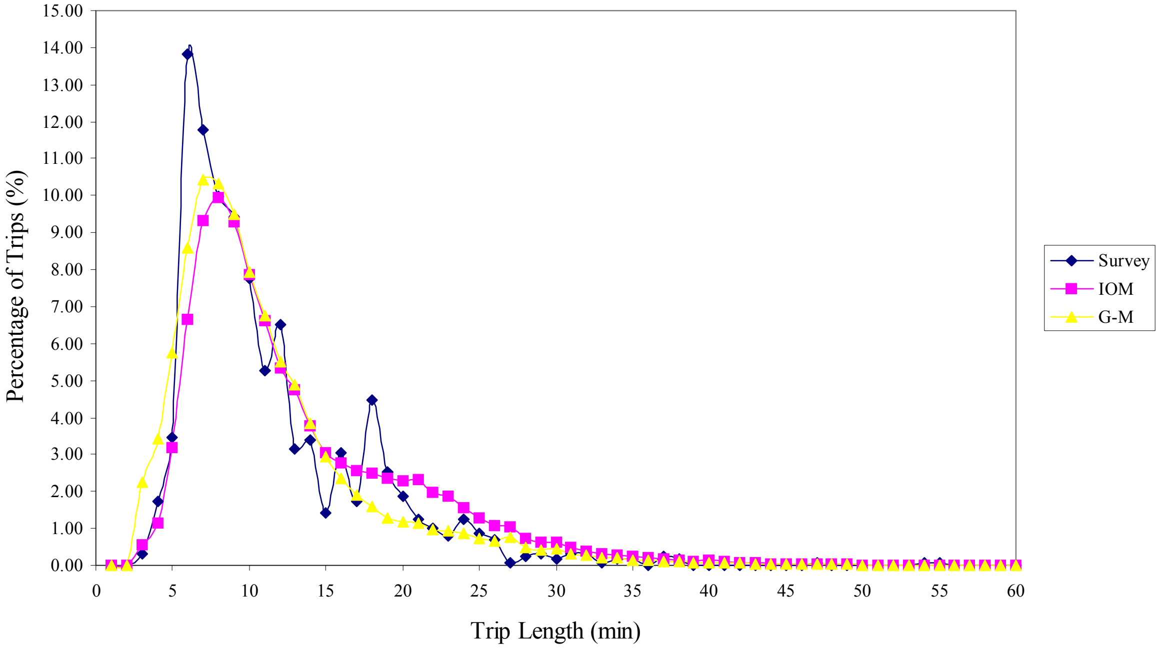

Figure 4. HBS Trip Length Distributions

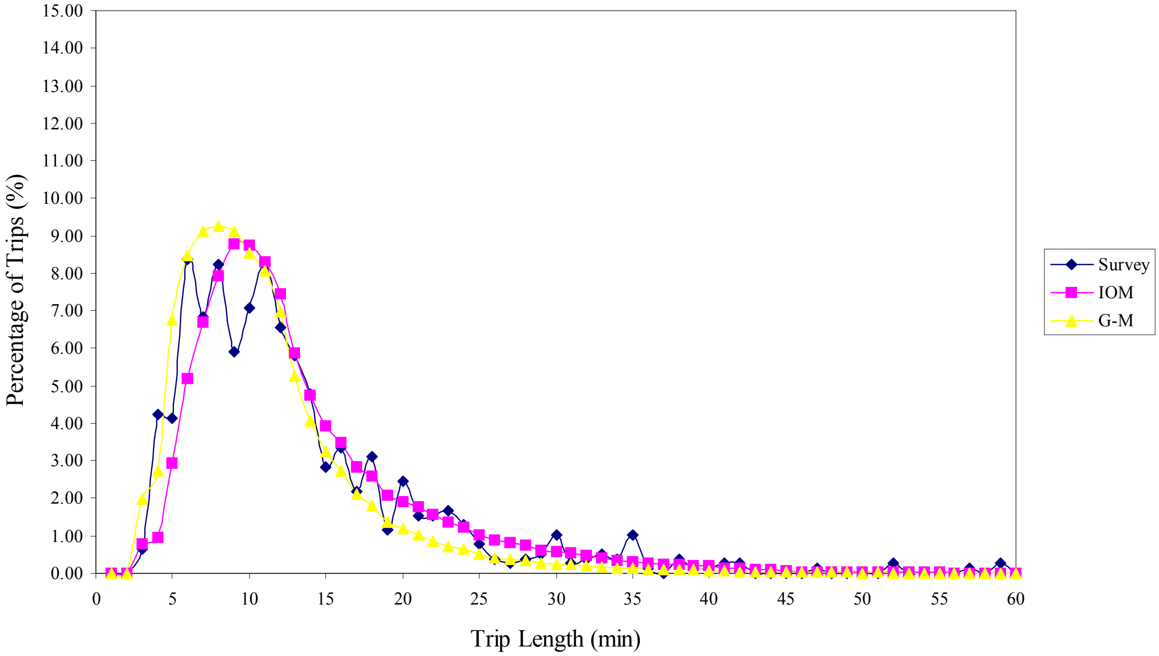

Figure 5. HBSR Trip Length Distributions

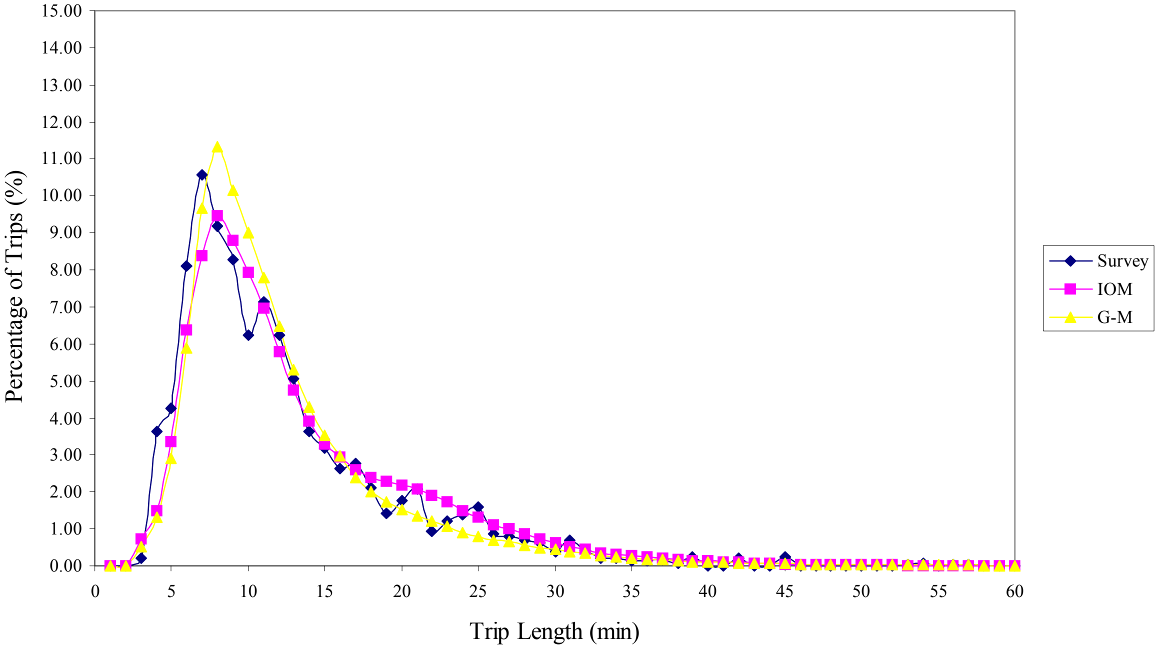

Figure 6. HBO Trip Length Distributions

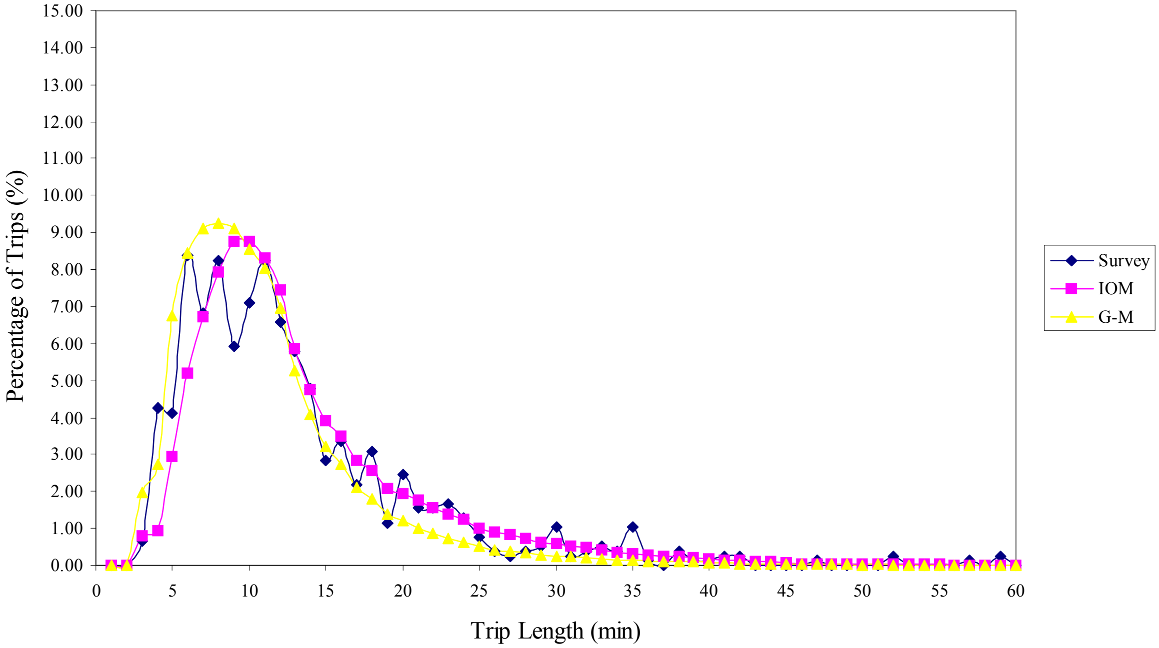

Figure 7. NHBW Trip Length Distributions

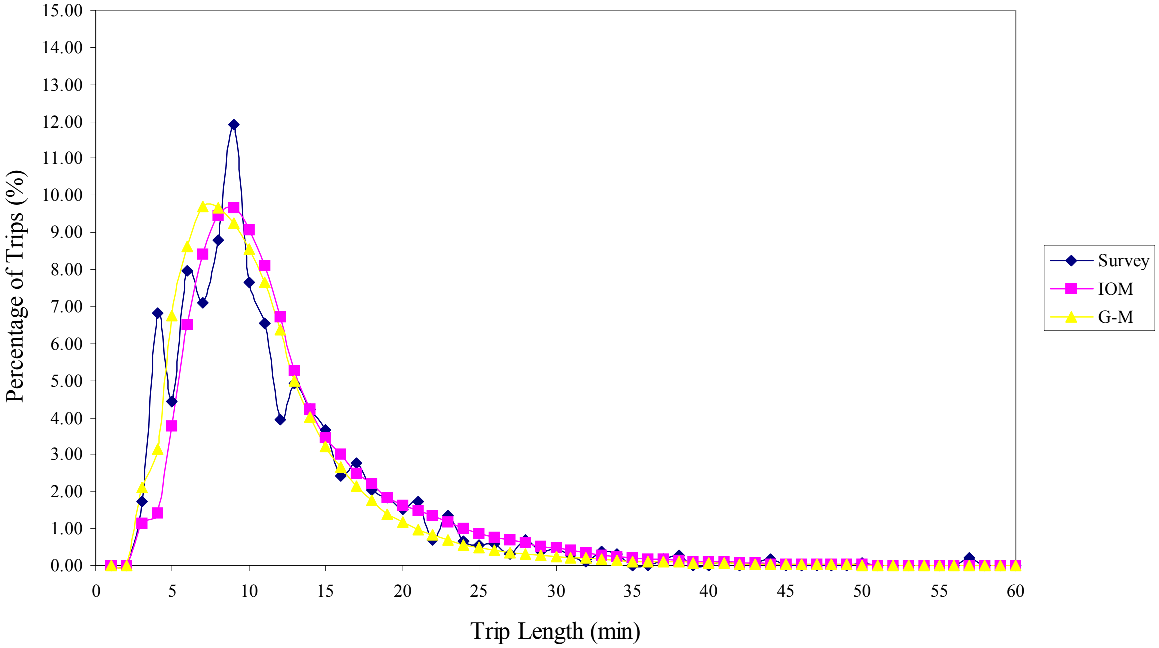

Figure 8. NHBO Trip Length Distributions

To further investigate the performance of the two models in terms of their spatial accuracy, that is whether they correctly distribute trips to the correct destinations, the trip interchanges between different areas are examined. Palm Beach County is divided into five traffic analysis districts (TADs) as shown in Figure 7. The trip interchanges between the districts are tabulated in Tables 5 through 10 for different trip purposes, in terms of percentages of the total internal trips. The texts highlighted in the tables indicate the results from the intervening opportunity model that are noticeably better than those from the gravity model. It may be seen from Table 5 that, for HBW trips, among the 25 pairs of districts, the percentages of trip interchanges between 9 district pairs have smaller errors when compared to the gravity model results. For the remaining 16 pairs of districts, the percentages predicted by the gravity model are closer to the survey data. Table 11 gives the number of district pairs for which the intervening model predicted inter-district trip interchanges closer to the survey data.

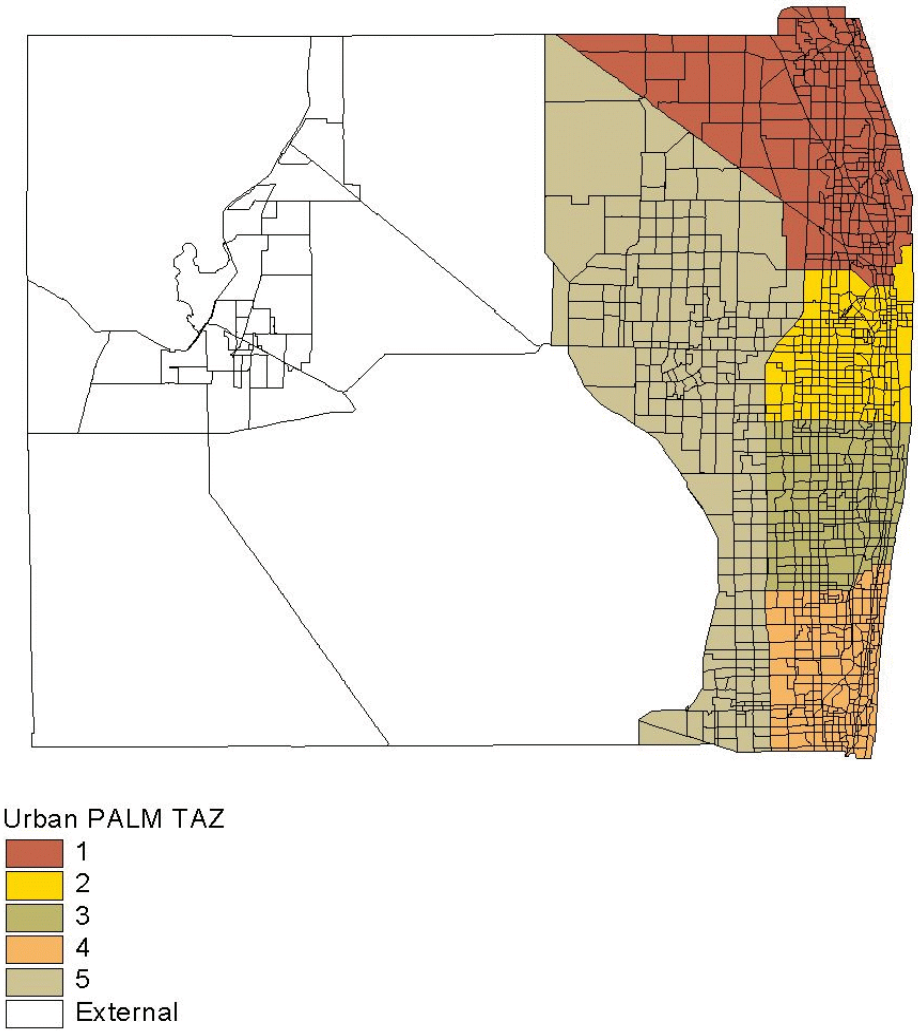

Figure 9. Palm Beach County Traffic Analysis Districts

Table 4. Comparison of Trip Interchanges Between Traffic Analysis Districts for HBW Trips (% of total trips)

District		1	2	3	4	5
1	SURV	15.67	5.58	0.48	0.70	0.91
	IOM	14.99	4.29	0.95	0.80	1.67
	GRAV	15.89	4.43	0.60	0.69	1.13
2	SURV	4.94	15.40	2.84	1.77	1.23
	IOM	4.45	11.97	3.09	1.95	1.46
	GRAV	3.76	12.91	2.99	1.71	1.24
3	SURV	2.15	3.27	6.71	6.44	0.64
	IOM	0.85	4.85	7.14	6.65	1.03
	GRAV	1.16	4.61	7.84	5.68	0.99
4	SURV	0.21	0.16	0.70	10.57	1.13
	IOM	0.12	0.69	1.20	11.79	1.02
	GRAV	0.19	0.46	1.19	12.53	0.92
5	SURV	3.27	4.94	1.29	3.65	5.36
	IOM	3.17	4.80	1.56	4.34	5.19
	GRAV	2.60	4.24	1.40	4.68	6.15

Table 5. Comparison of Trip Interchanges Between Traffic Analysis Districts for HBS Trips (% of total trips)

District		1	2	3	4	5
1	SURV	17.05	2.44	0.24	0.16	0.31
	IOM	17.81	2.66	0.68	0.09	0.29
	GRAV	19.38	1.95	0.07	0.06	0.05
2	SURV	1.96	14.06	1.89	0.00	1.26
	IOM	2.66	14.72	2.99	0.96	0.72
	GRAV	1.78	16.90	2.33	0.50	0.43
3	SURV	0.08	1.89	14.38	4.16	0.55
	IOM	0.30	3.32	11.68	5.43	0.65
	GRAV	0.22	2.77	13.99	4.01	0.40
4	SURV	0.31	0.31	0.39	15.08	1.81
	IOM	0.00	0.19	0.87	14.52	0.80
	GRAV	0.01	0.03	0.59	15.45	0.58
5	SURV	0.94	2.99	0.86	2.91	13.98
	IOM	2.40	3.91	1.48	3.33	7.51
	GRAV	2.19	3.59	0.89	3.21	8.62

Table 6. Comparison of Trip Interchanges Between Traffic Analysis Districts for HBSR Trips (% of total trips)

District		1	2	3	4	5
1	SURV	14.76	2.41	0.21	0.52	0.63
	IOM	18.21	3.54	0.89	0.07	0.51
	GRAV	20.21	2.41	0.31	0.21	0.16
2	SURV	1.47	12.25	2.09	0.00	0.73
	IOM	2.85	15.24	4.08	0.70	0.84
	GRAV	1.59	17.88	2.99	0.46	0.45
3	SURV	0.42	1.78	15.39	1.99	0.21
	IOM	0.24	3.51	11.42	4.76	0.58
	GRAV	0.24	2.91	14.01	2.91	0.32
4	SURV	0.00	0.73	1.26	19.58	1.57
	IOM	0.00	0.25	1.41	13.36	1.14
	GRAV	0.03	0.12	0.97	14.99	0.60
5	SURV	0.52	2.20	0.63	3.04	15.60
	IOM	1.46	3.65	1.37	2.54	7.37
	GRAV	1.01	2.93	0.92	2.22	9.16

Table 7. Comparison of Trip Interchanges Between Traffic Analysis Districts for HBO Trips (% of total trips)

District		1	2	3	4	5
1	SURV	17.59	3.63	0.21	0.08	0.13
	IOM	17.55	3.11	0.68	0.30	0.36
	GRAV	18.46	3.00	0.19	0.19	0.13
2	SURV	2.84	11.74	1.92	0.38	0.84
	IOM	2.40	15.26	3.00	1.12	0.68
	GRAV	2.29	15.92	3.00	0.59	0.51
3	SURV	0.29	2.13	14.20	3.13	0.42
	IOM	0.32	3.60	11.12	5.43	0.60
	GRAV	0.30	3.77	11.83	4.72	0.43
4	SURV	0.08	0.84	1.21	16.54	1.59
	IOM	0.00	0.19	0.85	13.20	0.80
	GRAV	0.02	0.08	0.92	13.57	0.79
5	SURV	1.29	2.76	0.84	3.05	12.28
	IOM	2.14	4.31	1.38	3.17	8.43
	GRAV	1.76	3.92	1.12	3.38	9.09

Table 8. Comparison of Trip Interchanges Between Traffic Analysis Districts for NHBW Trips (% of total trips)

District		1	2	3	4	5
1	SURV	17.78	5.67	0.26	0.26	1.03
	IOM	16.26	3.83	0.90	0.44	1.01
	GRAV	18.18	3.35	0.40	0.15	0.38
2	SURV	5.54	19.97	1.55	0.52	1.16
	IOM	3.79	16.55	3.51	0.91	1.68
	GRAV	2.70	18.83	3.26	0.43	1.21
3	SURV	0.52	2.32	8.63	2.45	0.64
	IOM	0.24	2.59	7.56	2.48	0.47
	GRAV	0.15	2.13	9.02	1.66	0.36
4	SURV	0.13	0.90	1.93	18.04	1.93
	IOM	0.24	0.99	2.85	21.27	2.49
	GRAV	0.09	0.34	2.40	23.20	1.79
5	SURV	1.03	1.29	0.52	1.42	4.51
	IOM	1.09	1.75	0.79	1.79	4.52
	GRAV	0.60	1.12	0.56	1.29	6.42

Table 9. Comparison of Trip Interchanges Between Traffic Analysis Districts for NHBO Trips (% of total trips)

District		1	2	3	4	5
1	SURV	17.57	2.66	0.27	0.16	0.49
	IOM	17.46	3.04	0.63	0.24	0.80
	GRAV	18.53	2.94	0.29	0.12	0.35
2	SURV	3.09	15.51	2.71	0.49	1.63
	IOM	3.58	17.38	3.28	0.67	1.59
	GRAV	2.83	18.69	3.17	0.40	1.25
3	SURV	0.43	2.93	12.42	1.57	0.60
	IOM	0.26	3.22	9.82	2.82	0.57
	GRAV	0.26	2.94	10.62	2.22	0.51
4	SURV	0.22	0.65	1.74	18.71	2.01
	IOM	0.10	0.73	2.40	18.85	1.82
	GRAV	0.11	0.35	2.26	19.71	1.52
5	SURV	0.33	1.08	0.60	2.11	10.03
	IOM	0.67	1.78	0.73	1.66	5.88
	GRAV	0.38	1.24	0.55	1.54	7.19

Table 10. Comparison of the Intervening Opportunity Model and Gravity in Prediction of Interdistrict Trips (Total 25 District Pairs)

	HBW	HBS	HBSR	HBO	NHBW	NHBO
IOM closer	9	9	9	9	11	8
GRAV closer	16	16	15	15	14	16
Tie	0	0	1	1	0	1

Two goodness-of-fit statistics were applied to evaluate the abilities of IOM and GM to replicate the set of interchanging flows between the five districts shown in Figure 7: Standardized Root Mean Square Error (SRMSE) and Information Gain (Fotheringham and O'Kelly, 1989). SRMSE ranges between zero, which indicates a completely accurate set of predictions, and one. The equation is defined as:

$$SRMSE = \frac{\sqrt{\sum_{i=1}^{5}\sum_{j=1}^{5}\frac{(p_{ij} - \hat{p}_{ij})^2}{5^2}}}{\sum_{i=1}^{5}\sum_{j=1}^{5}\frac{p_{ij}{}^2}{5^2}}$$

where

p_{ij} = estimated percentage of trips interchanging between districts *i* and *j*; and
$\hat{p}_{ij}$ = observed percentage of trips interchanging between districts *i* and *j*.

Table 12 shows the SRMSE results for the gravity model and the intervening opportunity model.

Table 11. SRMSEs for Gravity Model and IOM

	SRMSE	
	IOM	Gravity Model
HBW	0.0094	0.0091
HBS	0.0158	0.0139
HBSR	0.0258	0.0230
HBO	0.0158	0.0146
NHBW	0.0124	0.0142
NHBO	0.0112	0.0101

Information gain has a lower bound of zero, which corresponds to a perfect set of predictions, and an upper bound of infinity. It is calculated as

$$I = \sum_{i=1}^{5}\sum_{j=1}^{5} p_{ij} \ln \frac{p_{ij}}{\hat{p}_{ij}}$$

Table 13 shows the information gain results for the gravity model and IOM. Due to the restriction of natural log function, the cells with zero $\hat{p}_{ij}$ values were not included in the calculation. Except for the NHBW trip purpose, the gravity model has a smaller information gain value than the intervening opportunity model.

Table 12. Information Gain for Gravity Model and IOM

	Information Gain	
	IOM	Gravity Model
HBW	51	39
HBS	104	81
HBSR	116	77
HBO	139	116
NHBW	26	38
NHBO	53	31

It should be pointed out, however, that the comparisons presented in Tables 5 through 13 are not conclusive as the results will vary with different numbers and definitions of the districts. However, these statistics may be indicative of the performance of the two models.

5. DISCUSSIONS AND CONCLUSIONS

Based on the analyses presented in Section 4, it appears that the intervening opportunity model did reduce the assignment of short trips and produce better results for work trips. However, it tends to over-assign long trips, especially for trip purposes other than HBW purpose. There are several possible causes that may have led to this problem.

First, during the calibration of the intervening opportunity model, the selected summation file, which originally contained the interzonal skim impedance, was used to store the accumulated opportunity matrix. As mentioned in Section 3, since the skim file does not allow numbers to exceed 32,767 by default, and the number of attractions far exceeds this limit, the cumulative attractions had to be converted to a different unit in order to utilize the current calibration procedure in TRANPLAN. The maximum number of cumulative attractions for the Palm-Beach model was around 807,000 for HBW trips. Consequently, the cumulative attractions were divided by a factor of 3,000, or every 3,000 attractions was treated as one unit of impedance (impedo). The value for the upper bound of the cumulative HBW attractions was thus reduced to 269. The same factor was also applied to the other trip purposes, which produced 220, 143, 305, 129, and 270 as the maximum impedance value for HBS, HBSR, HBO, NHBW, and NHBO trips, respectively. Similarly, the new impedance unit was also applied to the "trip length" frequency data, which were the opportunities for the intervening opportunity model. After this scaling down, the survey results showed a high peak at one impedo, or the first 3,000 opportunities. The number of trips became significantly small beyond the second impedo. In other words, the first 3,000 opportunities were highly utilized. The trip lengths, however, varied greatly within the first impedo, ranging from 3 minutes to 29 minutes as shown in Figure 8. This resulted in the model becoming insensitive to the ordering of zones for this group of zones, thus affecting the model accuracy. A smaller factor that is much less than 3,000, or say 100, may produce better calibration results. However, further investigation cannot be performed under the current program configuration.

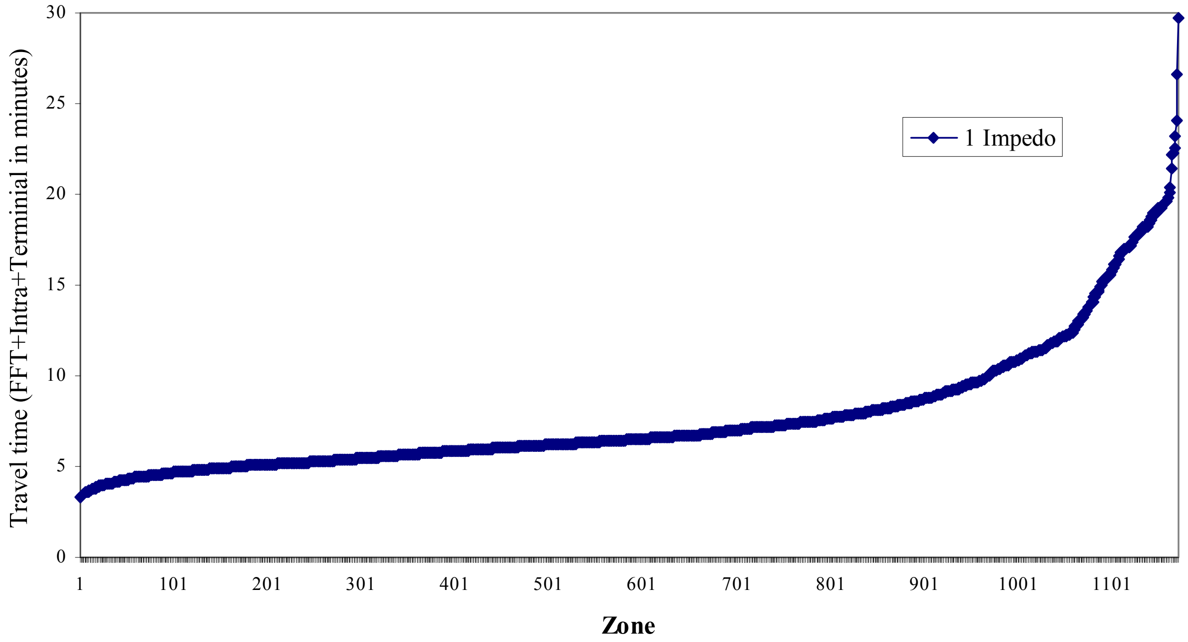

Figure 10. Distribution of Trip Lengths for One Impedo

Another problem is that if cumulative opportunities were used without cutting off at a certain value, the resulted trip length distribution curve would decrease much slowly and have a long tail, causing over-assignment of long trips. To alleviate the problem, the distribution of surveyed trip frequency versus opportunity impedance for each trip purpose was examined to locate the value where the number of observations nearly vanished. Subsequently, the observations occurred at impedance larger than the "vanishing point" were not considered in the calibration. The vanishing points for HBW, HBS, HBSR, HBO, NHBW, and NHBO trips were 200, 120, 100, 220, 100, and 200, respectively. Experiments with the use of different cutting off values during the intervening opportunity model calibration did not produce noticeable improvements.

One weakness of the intervening opportunity model is the underestimation of intra zonal trips. Compared to the gravity model and the survey data, much smaller number of intra zonal trips were obtained from the intervening opportunity model. According to Equation (1), which specifies zonal trip interchanges using the intervening opportunity model, intrazonal trips may be calculated by setting *j* to equal *i* and the accumulative opportunities to 0 (since there are no opportunities before the first zone being considered). This means that the diagonal elements of the opportunity matrix, which is stored in the summation file, should have a value of 0. This is, however, not permitted in the calibration of gravity model in TRANPLAN since zero impedance cannot be specified using the trip length frequency record (GT). As a result, during the calibration, the diagonal elements of the opportunity matrix were set to equal 1 (or impedance = 1), resulting in grouping the home zones with all other zones with an impedance of 1. Assuming a nonzero cumulative opportunity sum for intrazonal trip distribution resulted in a smaller number of intra zonal trips assigned, since based on Equation (1) intrazonal trips would be

$$T_{ij} \approx P_i \, A_j \, L \, exp(-L)$$

while theoretically it should be

$$T_{ij} = P_i \, A_j \, L \, exp(-L * 0) = P_i \, A_j \, L$$

The difference between the two is *exp(-L)*. Therefore the intrazonal trips have been underestimated by at least by *1/exp(-L)*. Since intrazonal trips, T_{ii} , increases monotonically with L, this also means that the inability to treat separately the intra zonal trips gives a smaller calibrated L value.

Some other problems include inaccuracy in the estimation of attractions, the assumption of L as a constant for all attractions, and the wide range of trip lengths for any given impedance. Attractions in terms of opportunities are much more critical for an intervening opportunity model than for a gravity model due to the fact that they are used in place of travel time as a representation of the travel patterns, which are to be duplicated by the calibrated model. In general, there is a concern about how accurate the estimates of attractions are, and information on attraction as well on their estimates is also lacking.

A problematic assumption of the intervening opportunity model is that L, the probability of an opportunity will be accepted, is a constant. This probability actually varies with different types of opportunities even when they are of the same type. Stopher and Meyburg (1975) have suggested that an L_i may be estimated for each zone *i*, or different *L*s may be estimated for different groups of trips. Estimating an L_i for each zone *i* will require an excessive amount of survey data, which is not cost feasible. The second idea of estimating different *L*s for different groups of trips has already been implemented in this model calibration effort as the trips have been segmented by trip purposes. Another possibility is to calibrate the model for groups of trips with different ranges of trip lengths. For instance, the Chicago Area Transportation Study (CATS) was reported to have calibrated separate *L*s for short trips, long residential trips, and long nonresidential trips (Stopher and Meyburg 1975). This approach may help to reduce the problem of the wide range of trip lengths for any given impedance value. Although further segmenting the trips by trip lengths will add to the program complexity, the additional complexity may be handled entirely by the program automatically without increasing the burdens on the modeler who calibrates the model.

In summary, the intervening model calibrated for the Palm Beach County using the 1999 survey, network and socioeconomic data performs slightly better than the gravity model for the HBW purpose but not better for the other trip purposes. Some of the problems that may have affected the performance of the model have been discussed. To remove or alleviate these problems require modifications of the existing TRANPLAN program, possible development of a specialized program to calibrate intervening opportunity models, and consideration of further dividing trips into different groups based on their lengths and calibrating different L parameters for each of them. Additionally, studies are needed to determine how attraction data may be improved for intervening opportunity models.

Finally, due to the aforementioned problems, it cannot be concluded whether intervening models will be beneficial or not. It is also possible that its expected advantage of better performance for elongated areas becomes more obvious if applied to the SERPM model that covers the tri-county area including Miami-Dade, Broward, and Palm Beach counties.

REFERENCES

Eash, R. (1980). "Development of a Doubly Constrained Intervening Opportunities Model for Trip Distribution," Chicago Area Transportation Study (CATS) Research News, Vol. 20, No. 2, pp. 39-44.

Eash, R. (1980). Several More Improvements in Understanding, Calibrating, and Applying the Opportunity Model, Chicago Area Transportation Study, Chicago, Illinois.

Fotheringham, A.S. and M.E. O'Kelly (1989). Spatial Interaction Models: Formulations and Applications, Kluwer Academic Publishers, Norwell, MA.

Rogerson, A.P. (1993). "A Maximum Likelihood Estimator for the Intervening Opportunities Model," Transportation Research B, Vol. 27B, No. 4, pp. 275-280.

Stopher, P.R. and A. Meyburg (1975). "Urban Transportation Modeling and Planning," Lexington Books, London.