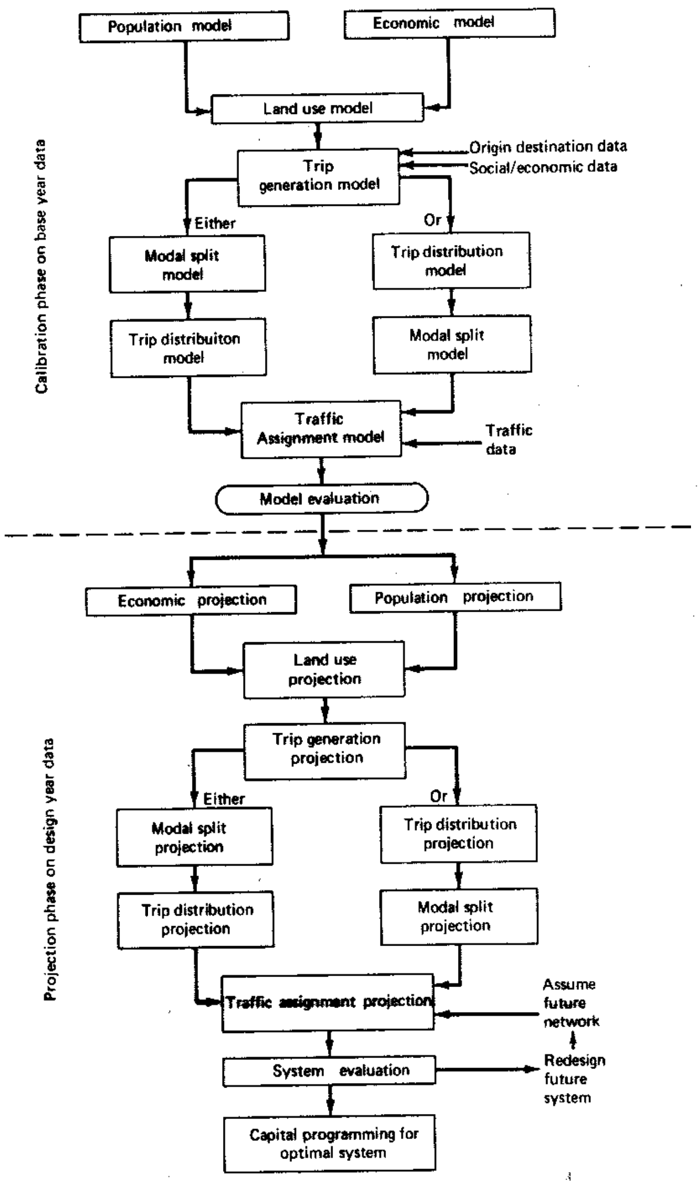


Fig 7-3. The land use transportation model.

3. Land use model.
4. Trip generation model.
5. Trip distribution model.
6. Modal split model.
7. Traffic assignment model.

Population and *economic* activity predictions generally are derived by specialist demographic and economic projections outside the scope of the transportation study. Because these areas usually would not require detailed examination by the transportation specialist in the preparation of the typical long-term transportation plan, they are omitted from this discussion.

There has been considerable debate on the third of these seven models, that for determining *land use* [4, 5]. A number of models have been developed that relate changes in land use to such independent variables as:

Accessibility to employment.
Percentage of available vacant land.
Land value.
Intensity of land use.
Measures of zone size.
Amount of land in different uses.
Net density of development in the base year.
Employment by land use type.
Time and distance to highest valued land of study area.
Degree of zoning protection expressed on a quantitative scale.
Transit accessibility.
Quality of water and sewer service.

Some of the dependent variables that have been predicted include:

Increase in residential units.
Increase in commercial land use.
Increase in industrial land use.
Increase in retail land use.

A number of models have been built [6], some of which have been extremely sophisticated and capable of calibration to remarkable accuracies [7]. These models are based on the interactive nature of the supply of development infrastructure and urban growth, as discussed in Section 7-1. There is, however, a very strong case against using land use models entirely for predicting urban growth. If used, the resultant land use plan will be self-fulfilling and the growth obtained is likely to be similar to that predicted by the model.

Usually, three variables are a limiting condition for most predictive equations. Introducing further variables, while marginally increasing the r^2 value, can result in a significant decrease in partial correlation coefficients.

Non-normality of data is a lesser problem. The analyst must examine the distribution of the variables used. Where a choice exists between a variable with a skewed distribution and one normal in character, the latter is preferable. The result of using non-normal data is to render the evaluation statistics inaccurate, but the form of relationship itself is not badly affected in most cases. In cases where the underlying distribution of an independent variable is very highly skewed, the planner is advised to avoid the use of such a variable in regression analysis.

Multiple linear regression is a process of fitting a regression plane to observed results with a minimization of the squares of the residuals. The process will force the results into the chosen linear model, whether or not the relationship is truly linear. Where the relationship is not linear, but *its form is known*, the method still can be applied by a transformation of the involved variable. For example, if the form is felt to be:

$$Y = A_0 + A_1X_1 + A_2X_2^2 \tag{9-3}$$

the variable Z_2 can be introduced, where

$$Z_2 = X_2^2 \tag{9-4}$$

and regression on the form:

$$Y = A_0 + A_1X_1 + A_2Z_2 \tag{9-5}$$

can be performed in a standard manner. Transformation of variables is useful in increasing the flexibility of the method. The difficulty lies, however, in the recognition that a nonlinear relationship exists. Its presence may be difficult to determine when mixed with the effects of other variables. In the case where the nonlinear effect is ignored, multiple regression will force the data into an incorrect linear relationship.

9-8. TRIP DISTRIBUTION MODELS

The trip generation phase of the planning process will have determined how many trips are generated from each zone and for what purpose they are made. Trip distribution models determine to what zones these trips are going by calculating trip interchanges in the base year. Most of the techniques used in the distribution process depend greatly upon the origin-destination study for *calibration* purposes, just as future trip generation was predicted from behavior patterns observed in base year generation.

9-9. THE GRAVITY MODEL

The gravity model is one of the most widely used trip distribution techniques in transportation planning. Early studies measured trip generation and attraction components in terms of zonal populations, and the resistance function was assumed to be related to an inverse function of distance. This gave similar relationship to Newton's theory of gravity, expressed in mathematical terms as:

$$I_{ij} = \frac{K \times P_i \times P_j}{D^n} \tag{9-6}$$

where

I_{ij} = the interaction between i and j
P_i = the population at i
P_j = the population at j
D = the distance betweeen i and j
K = some constant
n = some exponent

This work was followed by the development of more sophisticated models such as that by Voorhees [4] who suggested a constant exponent for the influence of distance, but recognized the need for a different exponent depending on trip purpose.

Gravity model formulations in current use are based on the hypothesis that the trips produced at an origin and attracted to a destination are directly proportional to:

- Total trip productions at the origin.
- The total attractions at the destination.
- A calibrating term.
- A socioeconomic adjustment factor.

The form of this relationship may be written:

$$T_{ij} = CP_iA_jF_{ij}K_{ij} \tag{9-7}$$

where

T_{ij} = trips produced at i and attracted at j
C = a constant
P_i = total trip production at i
A_j = total trip attraction at j
F_{ij} = a calibration term for interchange ij, (friction factor)
K_{ij} = a socioeconomic adjustment factor for interchange ij
i = an origin zone number
n = number of zones

A value for C for any origin zone i (C_i) can be established when it is specified that the sum of all T_{ij}s for origin i must be equal to P_i:

therefore

$$P_i = \sum_{j=1}^{n} T_{ij} = \sum_{j=1}^{n} (C_i P_i A_j F_{ij} K_{ij}) \quad (9\text{-}8)$$

$$= C_i P_i \sum_{j=1}^{n} (A_j F_{ij} K_{ij}) \quad (9\text{-}9)$$

therefore

$$C_i = \frac{1}{\sum_{j=1}^{n} (A_j F_{ij} K_{ij})} \quad (9\text{-}10)$$

and Eq. 9-7 becomes

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_{j=1}^{n} (A_j F_{ij} K_{ij})} \quad (9\text{-}11)$$

Equation 9-11 is the standard form of the gravity model. The term F_{ij} is the calibrating term and generally is found to be an inverse exponential function of impedance. In developing the model the output from Eq. 9-11 normally will show production (row) totals to be correct but attraction (column) totals will not necessarily match their desired values. In order to match the desired values an iterative procedure is employed.

9-10. CALIBRATING THE GRAVITY MODEL

The gravity model must be calibrated so as to establish a distribution parameter for each trip purpose, based on observed travel patterns. This distribution parameter is the travel time factor and calibration depends upon the repeated adjustment of a set of *friction factors.* Adjustment is continued until friction factors are obtained that result in a near enough approximation of base year data when the gravity model is applied to base year productions and attractions.

A procedure for calibrating the gravity model that was developed by the U.S. Department of Transportation is the computer program known as GMCAL, shown in Fig. 9-3. This calibration program can handle several trip purposes at the same time.

An example of a readjusted travel time factor curve for calibration runs

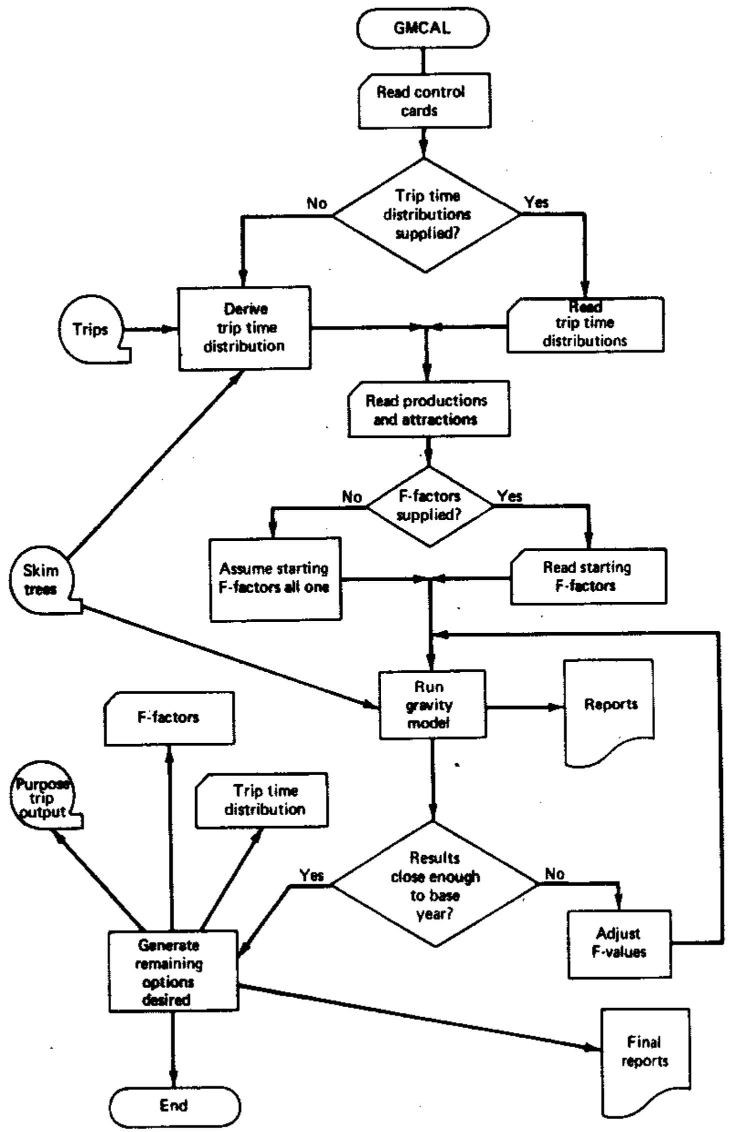


Fig 9-3. Flow diagram of the FHWA GMCAL Gravity Model Calibration Program. (Source: ***Computer Programs for Urban Transportation Planning,*** U.S. Dept. Transportation/FHWA, April 1977.)

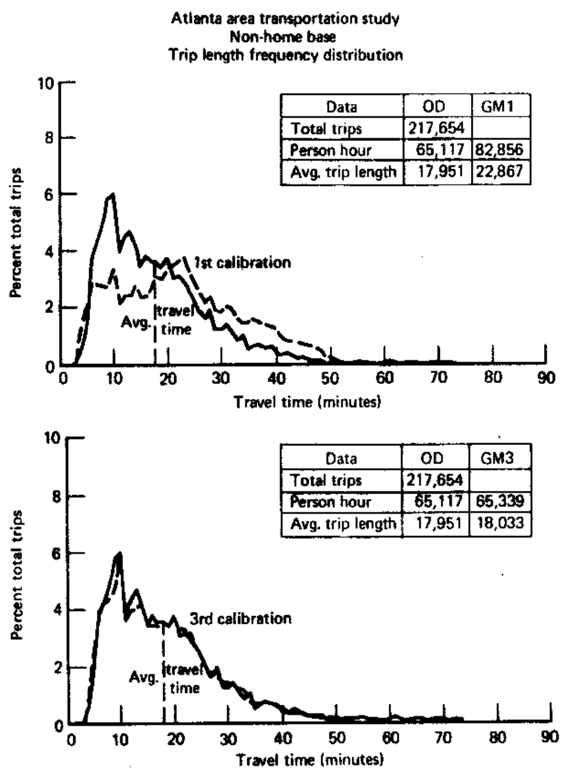


Fig 9-4. Comparison of O.D. and gravity model trip length frequency distributions. (Source: *Atlanta Area Transportation Study*, Georgia Department of Transportation.)

for non-home-based trips in the Atlanta study is shown in Fig. 9-4. These graphs show the results of the first calibration run and after the third iteration, by which time the difference between the observed and modified curve has shrunk to 0.34 percent for the person-hours of travel and 0.46 percent for the average trip length. With this degree of agreement the travel time factor curve of the last iteration is accepted as the calibrated curve. Before the gravity model can be assumed to be totally calibrated, the analyst must determine whether or not the socioeconomic adjustment factor is required to bring individual gravity model zonal interchanges into agreement with the base year zonal interchanges.

EXAMPLE 9-1

GRAVITY MODEL CALCULATION. Calculate the interzonal interchanges due to 100 productions at zone 1, with 250 attractions at zone 2,100 attractions at zone 3, and 600 attractions at zone 4. Assume that 1-2 is 5 min, 1-3 is 10 min, and 1-4 is 15 min. Assume all K_{ij} factors are unity, and that F_{ij} factors are as shown below.

Zone	A_j	F_{ij}	A_jF_{ij}	$\frac{A_jF_{ij}}{\Sigma_j A_j F_{ij}}$	P_i	T_{ij}
1	0	0	0	0	100	$0 = T_{11}$
2	250	20	5000	0.732	100	$73 = T_{12}$
3	100	5	500	0.073	100	$7 = T_{13}$
4	600	2.22	1332	0.195	100	$20 = T_{14}$
			$\Sigma A_jF_{ij} = 6832$	$\Sigma = 1.00$		$\Sigma = 100$

The reader is advised to verify that the exponent of time for the travel time factor is 2.

9-11. THE FRATAR METHOD

A technique for trip distribution utilizing *growth factors* was introduced by Thomas J. Fratar in 1954 [5]. While the technique is seldom used now as a study-wide distribution model it is considered by many to be a particularly useful way of dealing with external to external trips, that is, between external stations of the study area. The method is applied iteratively with the interchanges being computed according to the relative attractiveness of each interzonal movement from the point under consideration. The method involves the following steps:

1. Future traffic growth is estimated for each traffic zone and expressed as a "growth factor." (The growth factor is simply the ratio of expected future traffic to the existing traffic.)
2. Future traffic originating in (or destined to) a given zone is estimated by growth factors and existing traffic.
3. This traffic is distributed to other zones in proportion to existing interzonal travel and growth factors, for example,

$$(\text{Trips})_{AB} = (\text{Est. future total})_A \times \frac{(\text{present travel})_{AB}\,(\text{growth factor})_B}{\sum_{\text{All destination zones}} (\text{growth factor})\,(\text{present travel})} \qquad (9\text{-}12)$$

4. This distribution will yield two values (different) for each movement, for example, V_{AB} and V_{BA}. Average these two values.
5. The sum of these average values for a particular zone probably will be

different from the existing traffic to (or from) that zone multiplied by its growth factor (desired volume). Obtain new growth factors:

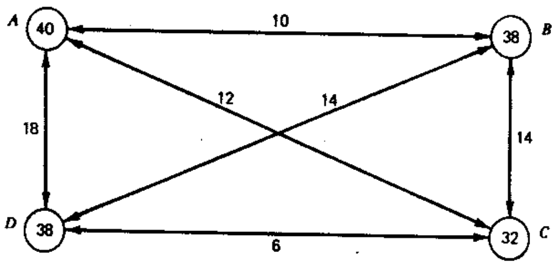
$$\text{New growth factors} = \frac{\text{(Desired volume)}}{\text{volume obtained from sum of movements}} \tag{9-13}$$

6. Make second approximation using these growth factors.
7. Repeat process until there is reasonable harmony between interzonal traffic sums and desired volume.

EXAMPLE 9-2

1. For zones *A*, *B*, *C*, and *D* the present traffic volumes and patterns and growth factors indicated below.
   Determine: Future traffic volumes and patterns by the Fratar method.
2.

	A	*B*	*C*	*D*
		Zone		
Present totals	40	38	32	38
Growth factors	2.0	3.0	1.5	1.0
Estimated future totals	80	114	48	38



3. Distribute trips:

$$V_{AB} = \frac{(10 \times 3)}{(10 \times 3) + (12 \times 1.5) + (18 \times 1)} \times 80 = 36.4$$

$$V_{AC} = \frac{(12 \times 1.5)}{(10 \times 3) + (12 \times 1.5) + (18 \times 1)} \times 80 = 21.8$$

$$V_{AD} = \frac{(18 \times 1)}{(10 \times 3) + (12 \times 1.5) + (18 \times 1)} \times 80 = 21.8$$

Total 80.0

$$V_{BA} = \frac{(10 \times 2)}{(10 \times 2) + (14 \times 1) + 14 \times 1.5)} \times 114 = 41.5$$

4. Average the two values for each movement. Note, for example, that the traffic from *A* to *B* is not equal to the traffic from *B* to *A*.

$$AB \text{ movement} = \frac{36.4 + 41.5}{2} = 39.0$$

Similarly,

AC movement =	18.9
AD movement =	18.8
New total	76.7
Desired total	80.0

5. Obtain new growth factors. For example, for zone A, new growth factor = 80.0/76.7 = 1.04.
6. Make second approximation; repeat until there is harmony between computed traffic sums and desired volumes.

First approximation results for all zones:

	A-B	*A-C*	*A-D*	*B-C*	*B-D*	*C-D*
	36.4	21.8	21.8	43.5	29.0	3.9
	41.5	16.0	15.8	28.0	18.3	4.0
	77.9	37.8	37.6	71.5	47.3	7.9
First approximations	39.0	18.9	18.8	35.7	23.6	4.0

	A	*B*	*C*	*D*
	39.0	39.0	18.9	18.8
	18.9	35.7	35.7	23.6
	18.8	23.6	4.0	4.0
New totals	76.7	98.3	58.6	46.4
Desired totals	80.0	114.0	48.0	38.0
New growth factors	1.04	1.16	0.82	0.82