Al-Mustansiriyah University

College of Engineering

HWY and Transportation Department

TRANSPORTATION PLANNING

تخطيط النقل

Fourth Stage

Dr. Noor Moutaz Asmael

2018

References:

1. Nicholas J. Garber, Lester A. Hoel, **TRAFFIC AND HIGHWAY ENGINEERING**, Fourth Edition
2. Khisty, C. Jotin and Lall, B. Kent, **Introduction to Transportation Engineering**, 2002.
3. Banks, James. **Introduction to Transportation Engineering**, 2nd ed., 2001.

Urban transportation planning is the process that leads to decisions on transportation policies and programs. In this process, planners develop information about the impacts of implementing alternative courses of action involving transportation services, such as new highways, bus route changes, or parking restrictions. This information is used to help decision-makers (elected officials or their representatives) in their selection of transportation policies and programs.

Transportation planning is a process that involves:

- The analysis of current travel patterns,
- The forecasting of future travel patterns (Transportation Demand Analysis),
- The proposal of transportation infrastructure and services, and
- The evaluation of proposed alternative projects to be considered by decision makers for implementation

The transportation planning process relies on travel demand forecasting, which involves predicting the impacts that various policies and programs will have on travel in the urban area. The forecasting process also provides detailed information, such as traffic volumes, bus patronage, and turning movements, to be used by engineers and planners in their designs. A travel demand forecast might include the number of cars on a future freeway or the number of passengers on a new express bus service. It might also predict the amount of reduction in auto use that would occur in response to a new policy imposing taxes on central-area parking.

Transportation planning should answer these questions

- What is the total number of trips generated in specific urban zones?
- What is the number of trips between all urban pair zones?
- What is the traffic load at specific links in the urban transportation network?
- What is the number of passenger kilometers that can be achieved?

Common urban transportation problems:

- Congestion
- Safety
- Efficiency
- Mobility
- Noise and air pollution

Planning can be defined as the activity or process that examines the potential of future actions to guide a situation or system toward a desired direction. The most important aspect of planning is that it is oriented toward the future. Transportation planners rely on historical data, model predictions, comparable studies, and many assumptions to make estimates about future conditions and predictions about future transportation needs.

Modeling: a process in which a model is built to represent a base year data i.e. “Calibration” is done to the model using this data.

Purpose of Modeling: Using the model to forecast a future data for a design year (after 20 to 30 years).

Modelling is the core of the planning process.

Model is a mathematical equation

Models are built for:

1. Population forecast
2. Economic activities: e.g. size and type of industry to be created
3. Land use: to figure out
    - Increase in residential density
    - increase in commercial land use
    - increase in industrial land use
    - increase in retail land use
4. Trip activities

Outcome: trip rates (volume)

Types of Planning & Characteristics

1- **Long Range Planning**:

This is done by “long range planning”.

Its Characteristics:

1) Long period 20 to 30 years
2) Requires huge financial expenditures
3) Requires extensive construction programs
4) Multi-level administrative involvement
5) Very complex in scope: involves analysis of impacts on

a) society

b) economy

c) environment

2- **Short and medium-term Planning** (***Transportation System Management TSM***)

Programs designed to reduce demand for transportation through various means, such as the use of public transit and of alternative work hours. Solve problems through expenditures of limited resources to obtain optimum operation such as

1) Improving street operation

2) Car pooling

3) High-occupancy lanes, etc.

Its Characteristics:

1) 5 to 10 year period
2) Resources are limited
3) No major construction
4) Scope is usually limited

The key word here is management. The TSM Element is concerned with making existing systems as efficient as possible and with making provisions for an area's short-range transportation needs. Automobiles, taxis, trucks, terminals, public transit, pedestrians, and bicycles are all parts of the urban transportation system.

There are four basic categories of actions to increase the efficiency of the different parts of the system.

1. Actions to ensure the efficient use of existing road space. These actions include measures to manage and control the flow of motor vehicles. Installing reversible lanes to accommodate rush-hour traffic and improving intersection capacities are examples.

2. Actions to reduce vehicle use in congested areas. Encouraging carpooling and other forms of ride-sharing are examples.

3. Actions to improve transit service. People can be encouraged to use transit by such actions as providing park-and-ride services from fringe areas to the central business district.

4. Actions to improve internal transit management efficiency — for example, developing management tools, such as information systems, or marketing campaigns.

To decide which actions to implement, you need a clear understanding of how each would affect the transportation system and the region as a whole. That is, what are the results of selecting a particular course of action? "Planning tools" are developed so that you can predict impacts and provide the information necessary for decision-makers to evaluate alternatives and select the best courses of action.

Travel demand forecasting tools provide input to this process by predicting travel impacts on transportation systems and their users. These predictions are one part of the planning process where travel demand forecasting plays an important role.

Land use and transportation system:

Piece of land with a particular type of land use produces a certain number of trips. Theses trips indicate the need for transportation facilities in order to serve the trip making demand. In turn the new or improved transportation facilities provide better accessibility. Naturally, the demand to develop this land increases because of its improved accessibility, causing its land value to increase. So Travel patterns are influenced by land use.

Land use models are used to forecast future development patterns as well as the potential for proposed transportation improvement to induce new or accelerated land development in a particular area. The output of land use models typically provides the input to the trip generation step of the travel forecasting model.

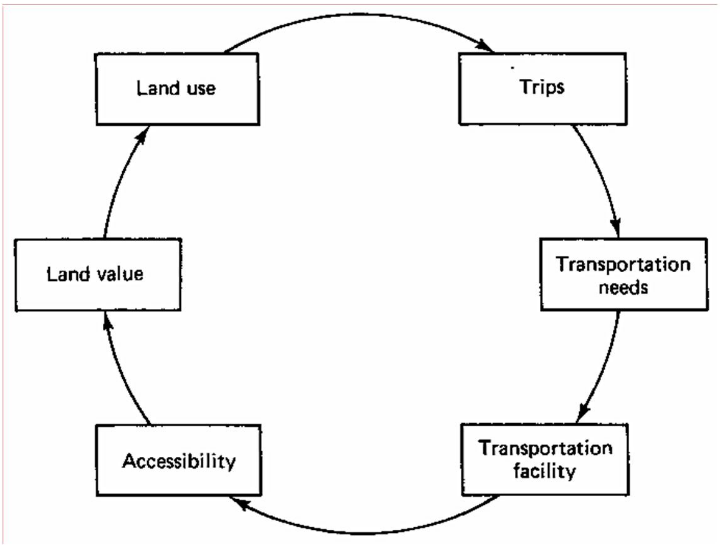


Figure: Land use and Transportation Cycle

Land Use Types

Common land use types include:

• Port and terminal: land uses, including waterports, airports, transit stations, etc.

• Industrial: land uses, including general light and heavy industrial, manufacturing, warehousing, etc.

• Residential: land uses, including single-family homes, various types of apartments, senior living, etc.

• Lodging: land uses, including hotels, motels, resorts, etc.

• Recreational: land uses, including various parks, fitness facilities, movie theaters, racetracks, etc.

• Institutional: land uses, including schools, churches, military facilities, museums, libraries, etc.

• Medical: land uses—hospital, nursing home, clinic. Office: land uses, including general office, medical offices, government offices, post office, etc.

• Retail: land uses, including various supply stores, convenience stores, supermarkets, sporting goods stores, apparel stores, pet stores, etc.

• Services: land uses, including restaurants, fast food, coffee shops, gas stations, banks, etc.

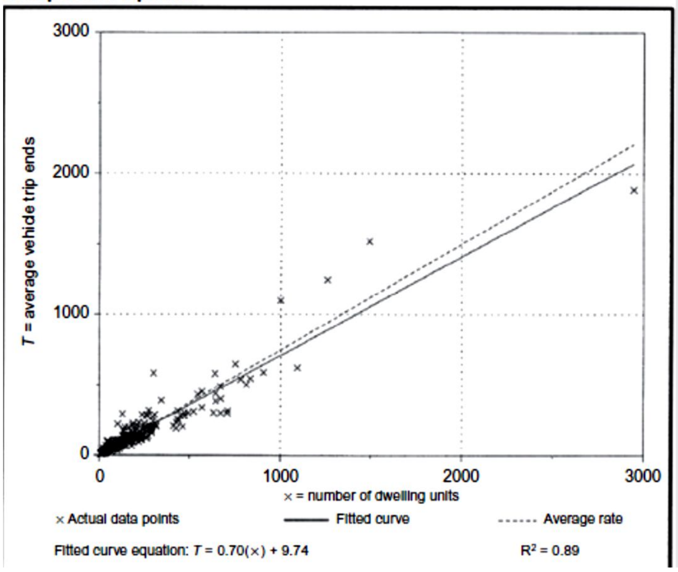
Example: A 500-acre site is being developed to support 400 single-family detached houses and a swimming pool with a clubhouse. Estimate the number of trips (T) exiting the subdivision during a typical am peak hour.

Number of studies: 286
Avg. number of dwelling units: 194
Directional distribution: 25% entering, 75% exiting

Trip generation per dwelling unit

Average rate	Range of rates	Standard deviation
0.75	0.33–2.27	0.90

Data plot and equation



Solution:

T =0.70* (X) +9.74, where X is the number of dwelling units.

T=0.70 *(400)+ 9.74 T=290 total trips

Now, T_{exit} = 0.75* (290)= 218 trips exiting during the Am peak hour.

The 0.75 comes from the chart in that 75% are exiting and 25% are entering during the Am peak hour.

Accessibility

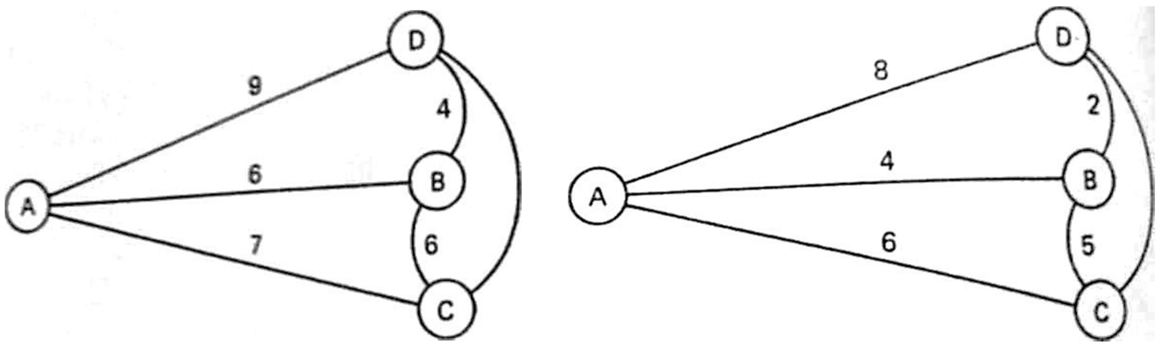
The basic concept underlying the relationship between land use and transportation is accessibility. In its broadest context, accessibility refers to the ease of movement between places, it provide the ability for people and goods to be able to move efficiently and effectively from point to point. Accessibility increases in either in terms of time or money when movement becomes less costly. Also, the propensity for interaction increases as the cost of movement decreases.

Example 1

To / From	Node				$\sum$	Change
	A	*B*	*C*	*D*		
A	**0(0)**	**6(4)**	**7(6)**	**9(8)**	**22(18)**	**-18%**
B	**6(4)**	**0(0)**	**6(5)**	**4(2)**	**16(11)**	**-31%**
C	**7(6)**	**6(5)**	**0(0)**	**7(5)**	**20(16)**	**-20%**
D	**9(8)**	**4(2)**	**7(5)**	**0(0)**	**20(15)**	**-25%**

Note: **Figures outside parentheses refer to original travel time; figures within parentheses refer to travel times after improvements.**

Each node (A, B,C,D) represents an activity center, and each link (e.g., AB, BC) represents travel times in minutes. Transportation improvements are implemented on each link such that travel times are reduced. How do improvements affect the activity centers (land use)? (Revised travel times are indicated parentheses.)



Network for example 1

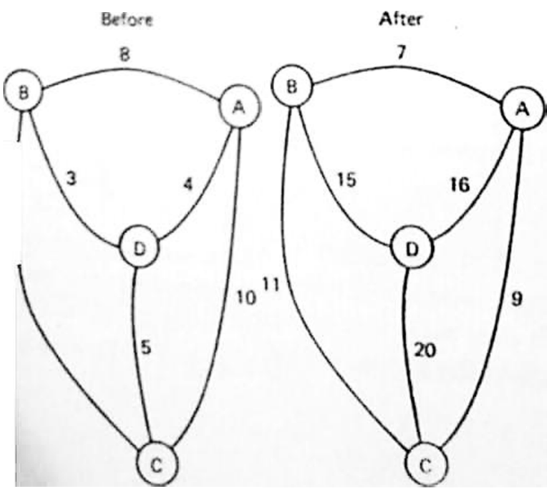
Solution:

The matrix shows the existing and revised times of travel. The row sums are the accessibility measure for each node. Naturally, lower travel times mean greater accessibility. In cases, there is a reduction in travel time: A, -18%;B, -31% C -20%; and D), 25%, it is apparent that activity center B has benefited the most, followed by D, C, and A.

Example 2

A downtown (D) is connected by arterials to activity/residential centers By A, B and C and to one another with travel times shown on the links. The arterials become more and congested, with the result that travel times (in minutes) increase to new levels as shown in Figure below and most of the commercial and business centers located downtown establish branch centers in A, B, and C. Which activity center is likely to prosper most? What possible actions on the part of the city would improve the downtown?

To From	Activities Center			Downtown ***D***	∑	Change
	A	***B***	C			
A	0(0)	8(7)	10(9)	4(16)	22(32)	45%
B	8(7)	0(0)	12(11)	3(15)	23(33)	43%
C	10(9)	12(11)	0(0)	5(20)	27(40)	48%
D	4(16)	3(15)	5(20)	0(0)	12(51)	325%



Solution:

Activity centers A, B, and C are all likely to be equally benefited, as the difference between 43,45, and 48 seems hardly significant. The downtown is certainly going to deteriorate rapidly. The possible ways by which it could be saved would be to reduce the travel time by improving the traffic flow on the arterials or to implement a bus system that would compete with the travel time to activity centers.

Personal accessibility is usually measured by counting the number of activity sites (also called opportunities) available at a given distance from the person's home and factoring that number by the intervening distance. Accessibility measures can be calculated for specific types of opportunities, such as shopping or working. One such measure is given by

$$A_i = \sum_j O_j d_{ij}^{-b}$$

where

A_i = accessibility of person i

O_j = number of opportunities at distance d from person i home

d_{ij}= some measure of separation between i and j (such as travel time, travel cost, or just simply distance)

b = a constant

Such an accessibility index is a measure of the number of potential destinations available to a person and how easily he or she can reach them. The accessibility of a place with respect to other places in the city can be measured in a similar way, in which case A_i is the accessibility of zone i.

The Transportation System

It consist of two main components: demand and supply.

Travel demand derives from the need to access urban functions and services in different places and is determined by the distribution of households and activities in the area. Household members make long-term “mobility choices” (holding a driving license, owning a car, etc.) and short-term “travel choices” (trip frequency, time, destination, mode, path,1 etc.), and use the transportation network and services so that they can undertake different activities (work, study, shopping, etc.) in different locations.

The transportation supply component is made up of the facilities (roads, parking spaces, railway lines, etc.), services (transit lines and timetables), regulations (road circulation and parking regulations), and prices (transit fares, parking prices, road tolls, etc.) that produce travel opportunities. Travel from one location to another frequently involves the successive use of several connected facilities or services.

Transportation facilities generally have a finite capacity, that is, a maximum number of units that may use them in a given time interval. Transportation facilities also generally exhibit congestion; that is, the number of their users in a time unit affects their performance.

the performance of the transportation system influences the relative accessibility of different zones of the urban area by determining, for each zone, the generalized cost (disutility) of reaching other zones (active accessibility), or of being reached from other zones (passive accessibility). As has been noted, both these types of accessibilities influence the location of households and economic activities and ultimately the real estate market

Travel demand: is expressed as the number of persons or vehicles per unit time that can be expected to travel on a given segment of a transportation system under a set of given land-use, socioeconomic, and environmental conditions.

Forecasts of travel demand: are used to establish the vehicular volume on future or modified transportation system alternatives.

Factors Influencing Travel Demand: three factors that influence the demand for urban travel are:

(1) The location and intensity of land use;

Is a primary determinant of travel demand. The amount of traffic generated by a parcel of land depends on how the land is used. For example, shopping centers, residential complexes, and office buildings produce different traffic generation patterns.

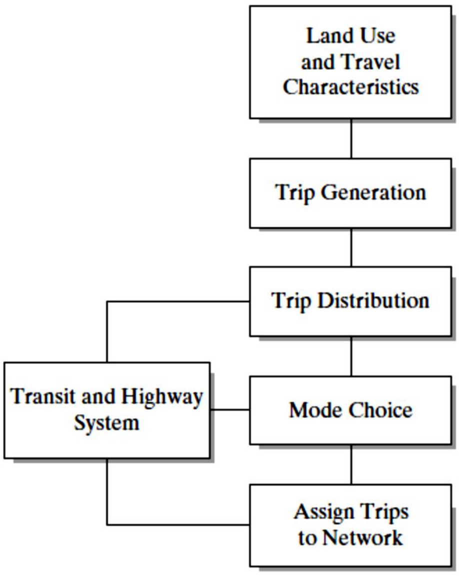
(2) The socioeconomic characteristics of people living in the area;

Socioeconomic characteristics of the people living within the city also influence the demand for transportation. Lifestyles and values affect how people decide to use their resources for transportation. For example, a residential area consisting primarily of high-income workers will generate more trips by automobile per person than a residential area populated primarily by retirees.

(3) The extent, cost, and quality of available transportation services.

The availability of transportation facilities and services, referred to as the supply, also affects the demand for travel. Travelers are sensitive to the level of service provided by alternative transportation modes. When deciding whether to travel at all or which mode to use, they consider attributes such as travel time, cost, convenience, comfort, and safety.

The most approach used to forecast travel demand is based on land use and travel characteristics that provide the basis for the "four-step process" of trip generation, trip distribution, modal choice, and traffic assignment as illustrated in Figure below.



Travel Forecasting Process

Information on how, when, and where people are currently traveling is of obvious importance in the forecasting process. This information is studied to determine the underlying factors causing people to make certain travel decisions so that models can be calibrated and used to forecast how people will travel in the future or in response to changing conditions now.

Study Area

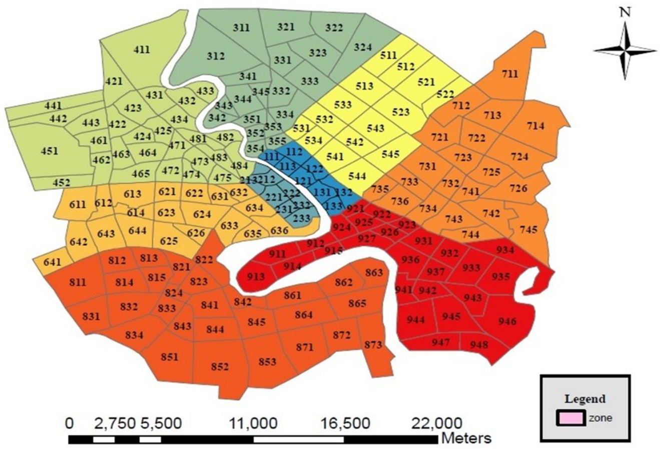
To forecast travel demand, the study area must be delineated into a set of **traffic analysis zones** (**TAZ**) that form the basis for analysis of travel movements within, into, and out of the urban area. The set of zones can be aggregated into larger units, called districts.

Zone definition. The urban area is divided into small spatial analytical areas, similar in concept to census tracts.

Generally, transportation analysis zones (TAZs) are defined by:

- Homogeneous land uses, such as residential neighborhoods, central business districts, and industrial areas.
- Major "traffic generators" such as universities, hospitals, shopping centers, and airports.
- Natural or human-made geographic boundaries, such as rivers or railroads.

Trips between two different traffic zones are known as interzonal trips, whereas intrazonal trips are those that start and end within the same zone.



TAZ of Baghdad City

Orign – Destination Marix (O-D)

To be able to analyze trip-making, the planner needs information on where trips come from, where they go, by what mode, for what purpose, and characteristics about the trip maker and activities at the origin and destination of the trip. This information is termed origin-destination data. Origin-destination survey data are generally available in sufficient detail and of proper statistical stability to allow accurate estimates of the model parameters. The home interview survey provides the most complete and accurate information for computing the parameters. However, since home interviews have been done in all large cities and are extremely expensive, they are no longer done for large samples. Small-sample surveys are now done to update past surveys.

The O/D matrix is a large table or spreadsheet that lists all origins as rows and all destinations as columns. The table entries then refer to the number of trips estimated between each zonal pair. It is important to emphasize that trip distribution makes no assignment of how traffic is expected to get from one zone to the other (i.e., which roads do people choose to get from A to B), but rather estimates the total expected flow between A and B, independent of travel path.

O/D studies are very time consuming and labor intensive, O/D surveys are therefore often limited to key origin destination pairs or used as a tool to calibrate an estimated O/D table.

Types of Surveys

The objective of the survey is primarily to collect the origin and destination trip zones and for this many suitable methods can be adopted.

1- **Household surveys**

Trips made by all household members by all modes of transport both within the study area and leaving/arriving to the area during the survey period; this survey should include socioeconomic information (income, car ownership, family size and structure, etc.). This information is very efficient at generating data that permits the estimation of trip generation and mode split models; furthermore, data on household travel provides good information on the distribution of trip lengths in the city, an important element in the estimation of trip distribution models.

2- **O-D survey**

The Origin-Destination matrix (O-D matrix) contains information about traffic flow values between all pairs of centroids

3- **Roadside interviews**

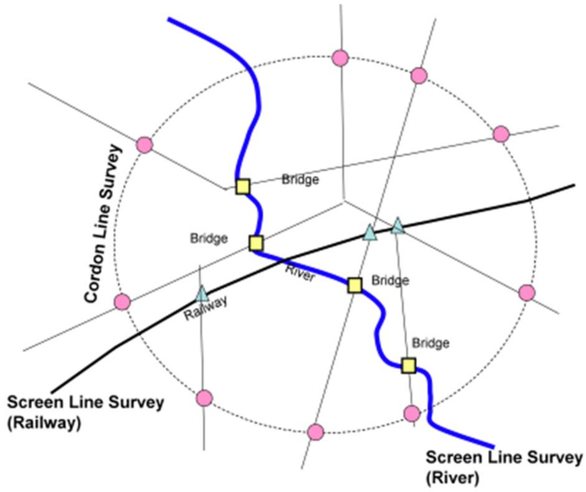
These provide trips not registered in a household survey, especially external-internal trips. This involves asking questions to a sample of drivers and passengers of vehicles crossing a particular location. But it should be noted that at road-side, drivers will not be willing to spend much time for a survey.

4- **Cordon and screen-line survey**

These provide useful information about external–external and external–internal trips. Their objective is to determine the number of trips that enter, leave and/or cross the cordoned area, thus helping to complete the information coming from the household O–D survey data on people crossing the study area border, particularly nonresidents of the study area. This provides useful information about trips from and to external zones. For large study area, internal cordon line surveying can be conducted. It could be either recording the license plate number at all the external cordon points or by post-card method.

Screen lines divide the study area into large natural zones, like either sides of a river, with few crossing points between them. The procedure for both cordon-line and screen-line survey are similar to road-side interview.

However, these counts are primarily used for calibration and validation of the models.

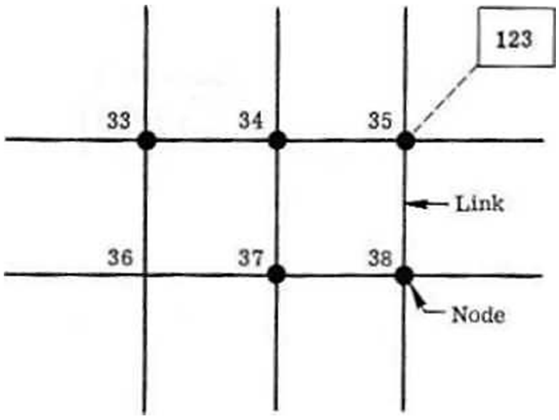


Four Step Modelling

Network Geometry

The transportation system consists of networks that represent the available modes (auto, bus, etc.). The network description is an abstraction of what is actually on the ground, and as such does not include every local street or collector street in the area. A network description is developed to describe auto and truck travel, with a separate description for transit, if transit is a consideration. These descriptions could include the geometry of the transportation system.

Network geometry includes numbering the intersections (called nodes for assignment purposes). Numbering the nodes allows us to identify the segments between them (called links). In transit networks we also identify groups of links over which specific routes pass (called lines). This geometric description of the transportation network shows all possible ways that travel can take place between points in the area.



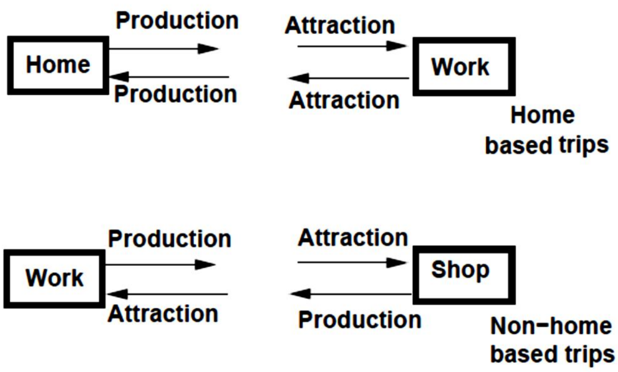
In the network description, zone centroids (centers of activity) are identified; they are connected to nodes by imaginary links called centroid connectors. Centroids are used as the points at which trips are "loaded" onto the network.

TRIP GENERATION

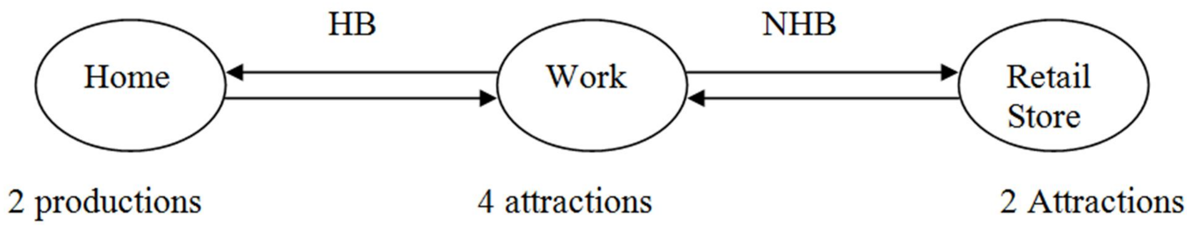
Trip generation is the process of determining the number of trips that will begin or end in each traffic analysis zone within a study area. Since the trips are determined without regard to destination, they are referred to as trip ends. Each trip has two ends, and is produced by a traffic zone and attracted to another traffic zone.

For example, a home-to-work trip

would be considered to have a trip end produced in the home zone and attracted to the work zone.



- Trips are classified as Home-based and Non-Home based trips



Types of trips:

Journey is an out way movement from a point of origin to a point of destination, whereas the word \trip" denotes an outward and return journey. If either origin or destination of a trip is the home of the trip maker, then such trips are called home based trips and the rest of the trips are called non home based trips.

The trips can be classified based on the purpose of the journey as trips for work, trips for education, trips for shopping, trips for recreation and other trips. Among these the work and education trips are often referred as mandatory trips and the rest as discretionary trips. All the daily trips are normally home based trips and constitute about 80 to 85 percent of trips.

The trip purpose breakdown in most widespread use is as follows,

1. **Home-based work** — trips between a person's home and place of employment for the purpose of working.

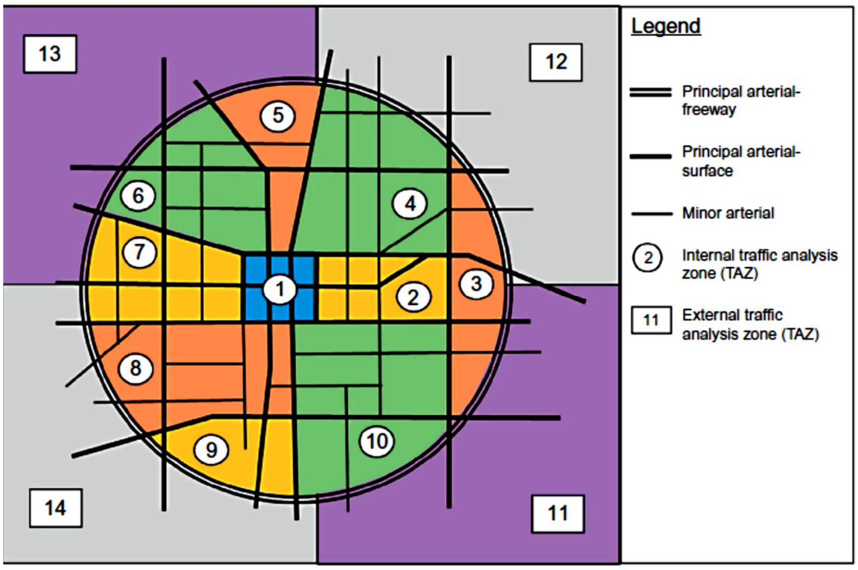
2. **Home-based other** — trips between a person's home and any other destination for any other purpose.

3. **Non-home-based** « trips that have neither end at home, regardless of purpose. These may include truck and taxi trips.

4. **Internal-external trips** — trips with one end inside the study area and one outside the study area.

5. **Through trips** —trips that have neither end in the study area, but pass through it.

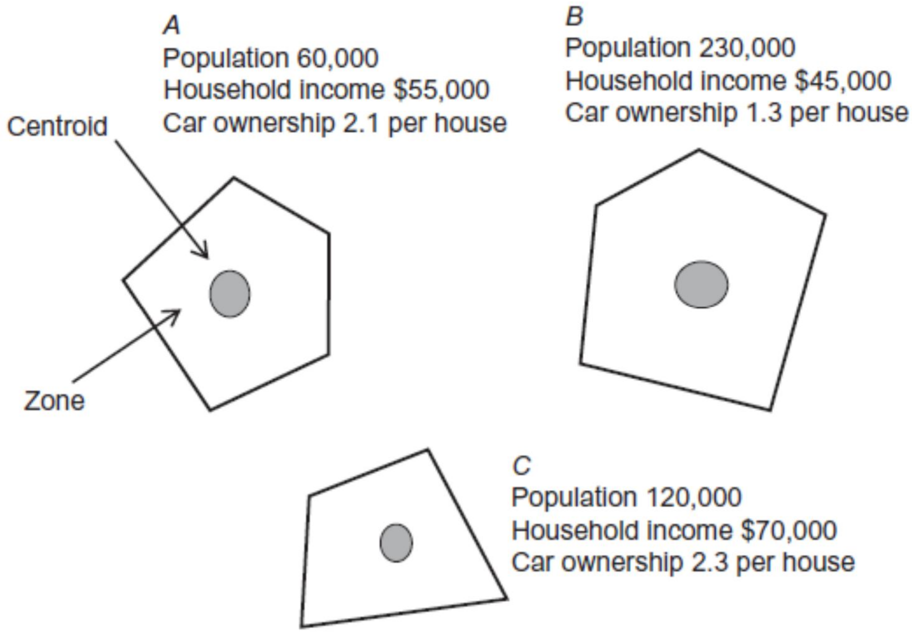
The second way of classification is based on the time of the day when the trips are made as peak trips and off peak trips.



The external area is usually subdivided into larger traffic zones. External zones represent trips that use the study area's transportation system, but start or end outside of the study area itself. External zones are also represented by zone centroids sometimes called stations.

Trip generation models are found to be accurate if separate models are used based on trip purpose. The rest of the trips, namely non home based trips, being treated separately.

Trip production is defined as all the trips of a home based or as the origin of the non home based trips.



Trip generation analysis has two functions:

1- To develop a relationship between trip end production or attraction and land use

2- To use the relationship to estimate the number of trips generated on a near future date under a new set of land use conditions.

Factors influencing trip generation:

1- **Land use** is one of the major attributes of trip generation activities, different uses of land produce different trip generation rates. For example, land developed for shopping or office could be expected to generate more trips than that developed for residential use.
2- **Family size**: there is a relationship between the number frequencies of trips made from home as against the varying family size, average trip frequency

increases with the increasing persons per household at the rate approximately 0.8 trips per day for each additional person.

3- **Auto ownerships**: increased auto ownership generates more trips per household
4- **Family income**: families with high income generally perform more trips than the low income household.

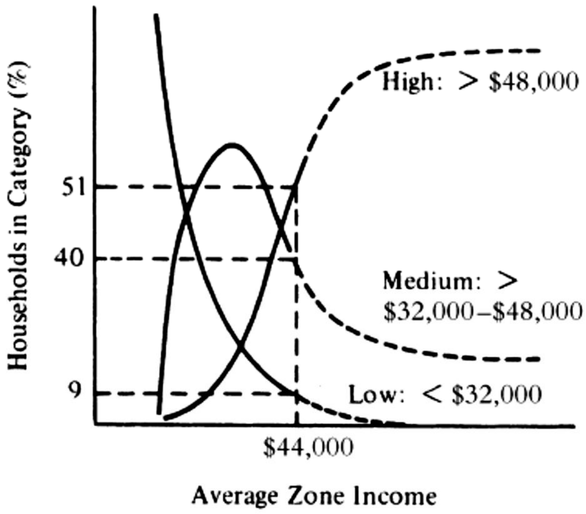
To illustrate the trip generation process, three methods are considered:

1- Cross-classification (category analysis)
2- Regression analysis, which has been applied to estimate both trip productions and attractions.
3- Method of trip rate

Trip generation methods use a ***disaggregated analysis***, based on individual sample units such as persons, households.

Cross-Classification method

Cross-classification is a technique developed by the Federal Highway Administration (FHWA) to determine the number of trips that begin or end at the home. The first step is to develop a relationship between socioeconomic measures and trip production. The two variables most commonly used are average income and auto ownership. The figure below illustrates the variation in average income within a zone. Other variables that could be considered are household size; the relationships are developed based on income data and the results of O-D surveys. It is a disaggregate Models rely on behavioral information for various classes within the area.



Average Zonal Income versus Households in Income Category

Example 1: Developing Trip Generation Curves from Household Data

A travel survey produced the data shown in Table, Twenty households were interviewed. The table shows the number of trips produced per day for each of the households (numbered 1 through 20), as well as the corresponding annual household income and the number of automobiles owned. Based on the data provided, develop a set of curves showing the number of trips per household versus income and auto ownership.

Household Number	*Trips Produced per Household*	*Household Income ($1000s)*	*Autos per Household*
1	2	16	0
2	4	24	0
3	10	68	2
4	5	44	0
5	5	18	1
6	15	68	3
7	7	38	1
8	4	36	0
9	6	28	1
10	13	76	3
11	8	72	1
12	6	32	1
13	9	28	2
14	11	44	2
15	10	44	2
16	11	52	2
17	12	60	2
18	8	44	1
19	8	52	1
20	6	28	1

Solution:

Table 12.2 Number and Percent of Household in Each Income Category versus Car Ownership

Income ($1000s)	*Autos Owned* 0	1	2+	*Total*
24	2(67)	1(33)	0(0)	3(100)
24–36	1(25)	3(50)	1(25)	5(100)
36–48	1(20)	2(40)	2(40)	5(100)
48–60	—	1(33)	2(67)	3(100)
>60	—	1(25)	3(75)	4(100)
Total	4	8	8	20

Note: Values in parentheses are percent of automobiles owned at each income range.

Table 12.3 Average Trips per Household versus Income and Car Ownership

Income ($1000s)	*Autos Owned* 0	1	2+
≤24	3	5	—
24–36	4	6	9
36–48	5	7.5	10.5
48–60	—	8.5	11.5
>60	—	8.5	12.7

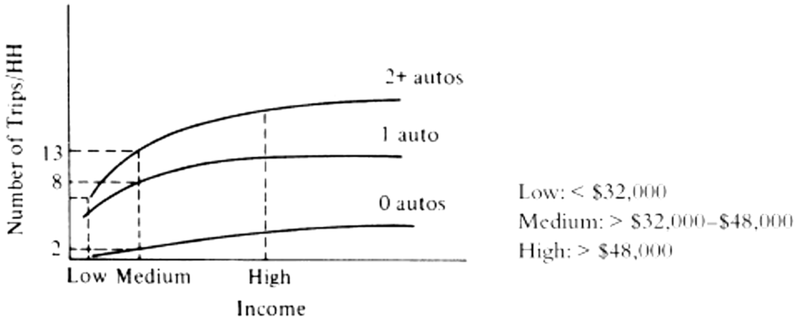


Figure 12.4 Trips per Household per Day by Auto Ownership and Income Category

SOURCE: Modified from *Computer Programs for Urban Transportation Planning,* U.S. Department of Transportation, Washington, D.C., April 1977.

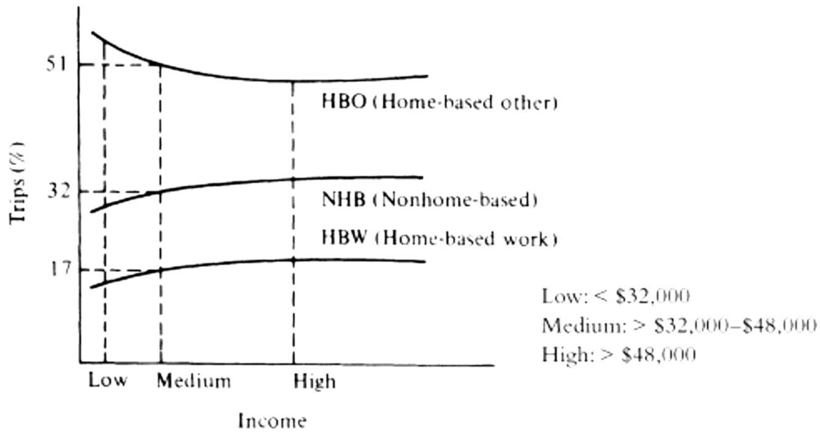


Figure 12.5 Trips by Purpose and Income Category

The trip generation model that has been developed based on survey data can now be used to estimate the number of home- and non-home-based trips for each trip purpose.

H.W: Develop Trip Generation Curves from the following Household Data

Houshold	Trip	Income	Auto
1	2	4,000	0
2	4	6,000	0
3	10	17,000	2
4	5	11,000	0

5	5	4,500	1
6	15	17,000	3
7	7	9, 500	1
8	4	9,000	0
9	6	7, 000	1
10	13	19,000	3
11	8	18,000	1
12	9	21,000	1
13	9	7, 000	2
14	11	11,000	2
15	10	11,000	2
16	11	13,000	2
17	12	15,000	2
18	8	11,000	1
19	8	13,000	1
20	9	15,000	1

Example 2: Computing Trips Generated in a Suburban Zone

Consider a zone that is located in a suburban area of a city. The population and income data for the zone are as follows.

Number of dwelling units: 60

Average income per dwelling unit: $44,000

Determine the number of trips per day generated in this zone for each trip purpose, assuming that the characteristics depicted in Figures 12.2 through 12.5 apply in this situation.

Solution:

The problem is solved in four basic steps.

Step 1. Determine the percentage of households in each economic category. These results can be obtained by analysis of census data for the area. A typical plot of average zonal income versus income distribution is shown in Figure 12.2. For an average zonal income of $44,000, the following distribution is observed.

Income ($)	*Households (%)*
Low (under 32,000)	9
Medium (32,000–48,000)	40
High (over 48,000)	51

Step 2. Determine the distribution of auto ownership per household for each income category. A typical curve showing percent of households, at each income level, that own 0, 1, or 2+ autos is shown in Figure 12.3, and the results are listed in Table 12.4.

Table 12.4 shows that 58% of medium-income families own one auto per household. Also, from the previous step, we know that a zone, with an average income of $44,000, contains 40% of households in the medium-income category. Thus, we can calculate that of the 60 households in that zone, there will be $60 \times 0.40 \times 0.58 = 14$ medium-income households that own one auto.

Step 3. Determine the number of trips per household per day for each income–auto ownership category. A typical curve showing the relationship between trips per household, household income, and auto ownership is shown in Figure 12.4. The results are listed in Table 12.5.

Table 12.4 Percentage of Households in Each Income Category versus Auto Ownership

	Autos/Household		
Income	*0*	*1*	*2+*
Low	54	42	4
Medium	4	58	38
High	2	30	68

Table 12.5 Number of Trips per Household per Day

	Autos/Household		
Income	*0*	*1*	*2+*
Low	1	6	7
Medium	2	8	13
High	3	11	15

Table 12.6 Number of Trips per Day Generated by Sixty Households

	Income, Auto Ownership	*Total Trips by Income Group*
$60 \times 0.09 \times 0.54 \times 1 =$ 3 trips	L, 0+	
$60 \times 0.09 \times 0.42 \times 6 =$ 14 trips	L, 1+	
$60 \times 0.09 \times 0.04 \times 7 =$ 2 trips	L, 2+	19
$60 \times 0.40 \times 0.04 \times 2 =$ 2 trips	M, 0+	
$60 \times 0.40 \times 0.58 \times 8 =$ 111 trips	M, 1+	
$60 \times 0.40 \times 0.38 \times 13 =$ 119 trips	M, 2+	232
$60 \times 0.51 \times 0.02 \times 3 =$ 2 trips	H, 0+	
$60 \times 0.51 \times 0.30 \times 11 =$ 101 trips	H, 1+	
$60 \times 0.51 \times 0.68 \times 15 =$ 312 trips	H, 2+	415
Total = 666 trips		666

The table shows that a medium-income household owning one auto will generate eight trips per day.

Step 4. Calculate the total number of trips per day generated in the zone. This is done by computing the number of households in each income–auto ownership category, multiplying this result by the number of trips per household, as determined in Step 3, and summing the result. Thus,

$$P_{gh} = HH \times I_g \times A_{gh} \times (P_H)_{gh} \tag{12.1}$$

$$P_T = \sum_{g}^{3} \sum_{h}^{3} P_{gh} \tag{12.2}$$

where

HH = number of households in the zone
I_g = percentage of households (decimal) in zone with income level g (low, medium, or high)
A_{gh} = percentage of households (decimal) in income level g with h autos per household ($h = 0, 1,$ or $2+$)
P_{gh} = number of trips per day generated in the zone by householders with income level g and auto ownership h
$(P_H)_{gh}$ = number of trips per day produced in a household at income level g and auto ownership h
P_T = total number of trips generated in the zone

The calculations are shown in Table 12.6. For a zone with 60 households and an average income of $44,000, the number of trips generated is 666 auto trips/day.

Step 5. Determine the percentage of trips by trip purpose. As a final step, we can calculate the number of trips that are HBW, HBO, and NHB. If these percentages are 17, 51, and 32, respectively (see Figure 12.5), for the medium-income category, then the number of trips from the zone for the three trip purposes are 232 * 0.17 = 40, HBW, 232 * 0.51 =118, HBO, and 232 * 0.32 = 74 NHB. (Similar calculations would be made for other income groups.) The final result, which is left for the reader to verify, is obtained by using the following percentages: low income at 15, 55, and 30, and high income at 18, 48, and 34. These yield 118 HBW, 327 HBO, and 221 NHB trips.

2- Regression Analysis

For each of a number of zones a certain number of trip ends - the dependent variable - are observed and each zone has certain measurable characteristics to which this trip generation rate may be related. These characteristics XI. X2, etc. are referred to as the independent variables and are the land-use and socioeconomic factors which have been previously referred to.

The equation obtained by least squares analysis is of the general form:

$Y= b_o +b_1*X_1 +b_2*X_2+ \dots b_n X_n$

where b_O is the intercept term or constant.

B_O, b_1, b_2 .... bn are obtained by regression analysis.

X_1 , X_2 ..... X_n are the independent variables.

In developing regression equations it is assumed that:

(1) All the independent variables are independent of each other.

(2) All the independent variables are normally distributed; if the variable has a skew distribution often a log transformation is used.

(3) The independent variables are continuous.

A typical equation obtained as follows:

$Ys = 0.0649X1 - 0.0034X3 + 0.0066X4 + 0.9489X5$

where Ys = total trips per household

XI = family size,

X3 = residential density,

X4 = total family income,

X5 = cars /household.

It is ***Aggregate Models*** and characteristics of area are "aggregated" on an average basis and resulting trips will, in turn, be on an average basis.

3- Method of Trip Rates

Trips generated at the household end are referred to as productions, and they are attracted to zones for purposes such as work, shopping, visiting friends, and medical trips. Thus, an activity unit can be described by measures such as square feet of floor space or number of employees. Trip generation rates for attraction zones can be determined from survey data or are tabulated in some of the reference sources listed at the end of this chapter. Trip attraction rates are illustrated in Table

Table 12.7 Trip Generation Rates by Trip Purpose and Employee Category

	Attractions per Household	*Attractions per Nonretail Employee*	*Attractions per Downtown Retail Employee*	*Attractions per Other Retail Employee*
HBW	—	1.7	1.7	1.7
HBO	1.0	2.0	5.0	10.0
NHB	1.0	1.0	3.0	5.0

Example: Computing Trips Generated in an Activity Zone

A commercial center in the downtown contains several retail establishments and light industries. Employed at the center are 220 retail and 650 non-retail workers.Determine the number of trips per day attracted to this zone.

Solution: Use the trip generation rates listed in Table 12.7

HBW: (220 * 1.7)+ (650* 1.7)= 1479

HBO: (220 * 5.0) + (650 * 2.0) = 2400

NHB: (220* 3.0)+ (650 * 1.0)= 1310

Total = 5189 trips/day

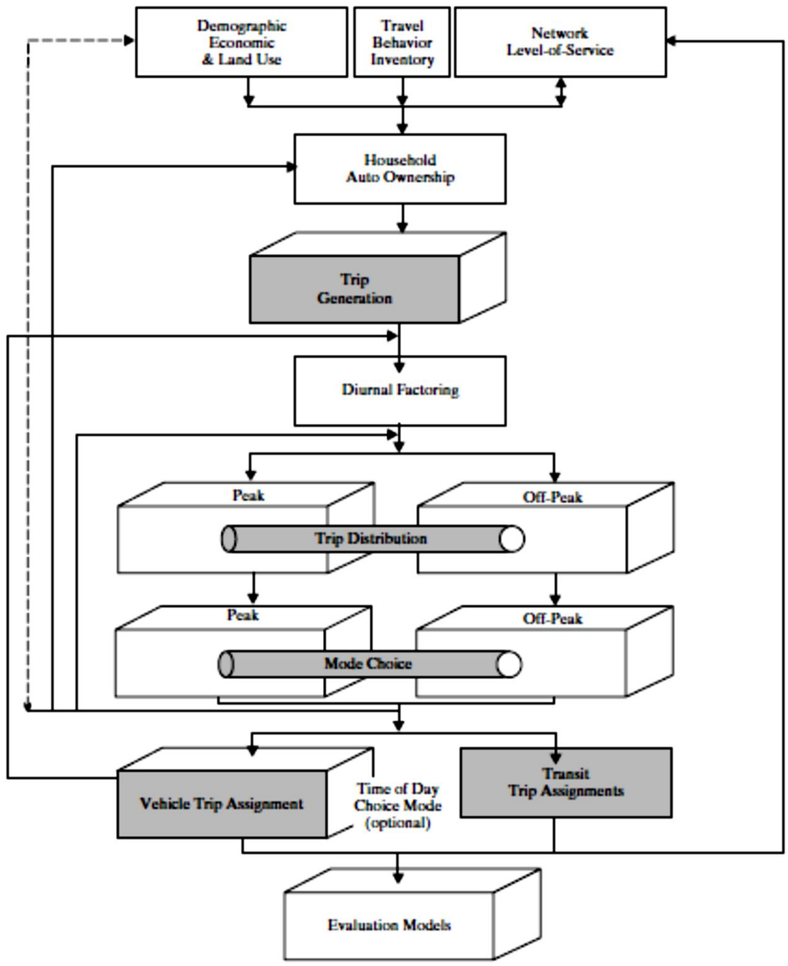
Balancing Trip Productions and Attractions

The result of the trip generation process is the number of trip productions and these values may not be equal to the number of trip attractions. Trip productions, which are based on census data, are considered to be more accurate than trip attractions. Accordingly, trip attractions are usually modified so that they are equal to trip productions.

Table 12.8a illustrates how adjustments are made. The trip generation process has produced 600 home-based work productions for zones 1 through 3. However, the same process has produced 800 home-based work attractions. To rectify this imbalance, each attraction value for zones 1 through 3 is reduced by a factor equal to 600/800, or 0.75. The result is shown in Table 12.8a in the column "Balanced HBW Trips" Now both productions and attractions are equal. A similar procedure is used for HBO trips.

Table 12.8a Balancing Home-Based Work Trips

	Unbalanced HBW Trips		*Balanced HBW Trips*	
Zone	*Productions*	*Attractions*	*Productions*	*Attractions*
1	100	240	100	180
2	200	400	200	300
3	300	160	300	120
Total	600	800	600	600



TRIP DISTRIBUTION

Trip distribution is a process of distributing the estimated trips to traffic analysis zones (TAZs) by which the trips generated in one zone are allocated to other zones in the study area. These trips may be within the study area (internal-internal) or between the study area and areas outside the study area (internal external).

Several basic methods are used for trip distribution. Among these:

- The gravity model,
- Growth factor models,

The gravity model is preferred because it uses the attributes of the transportation system and land-use characteristics and has been calibrated extensively for many urban areas.

Growth factor models, which were used more widely in the 1950s and 1960s, require that the origin-destination matrix be known for the base (or current) year, as well as an estimate of the number of future trip ends in each zone.

Gravity Model

The gravity model is an analytical methodology to estimate the productions and attractions between each zonal pair in the trip distribution step. It is most applicable for larger studies and networks, and can be quite data intensive to complete. The underlying concept for the gravity model mirrors principles in physics, where two masses attract one another, and where the magnitude of that attraction is proportional to the size of the mass. In other words, larger zones (or more precisely, zones with more activity or higher development density) attract more trips than smaller zones (less activity and a lower development density). That physics-based gravity model is further calibrated by the relative travel time between zones and socioeconomic characteristics. Specifically, the gravity model estimates the number of trips between each origin zone, i, and each destination zone, j, and states that the number of trips between the two zones is directly proportional to the number of trip attractions generated by the zone of destination and inversely proportional to a function of time of travel between the two zones. And is a function of the following characteristics:

• The number of trips produced in each zone, Pi

• The number of trips attracted to each zone, Aj

• A friction factor for each ij zonal pair that is a function of the travel time between those zones, Fij, since F values decrease as travel time increases.

• A socioeconomic factor for each ij zonal pair that can be used to calibrate the desire of travelers to travel between those zones, Kij

The general form of the gravity model is shown in the following equation, followed by an example.

$$Q_{ij} = (P_i)\frac{A_j \times F_{ij} \times K_{ij}}{\sum_{1}^{j}(A_j \times F_{ij} \times K_{ij})}$$

where

Qij= trips from zone i to zone j

Pi =trips produced

Aj =trips attracted

Fij =friction factor (typically the inverse of distance or travel time)

Kij=socioeconomic factor (calibrated)

The gravity model has to be applied in an iterative fashion for both the total attractions and productions for each zone to match with the entered data. In the first iteration, the productions for each zone will be balanced, but the attractions will likely differ from the entered trip generation data. In repeated iterations, the results of one iteration are fed as input to the next iteration, until a desirable match is obtained.

Example 1:

A study area consisting of three zones. The number of productions and attractions has been computed for each zone and the average travel times between each zone have been determined. Both are shown in Tables 12.9 and 12.10. Assume Kij is the same unit value for all zones. Finally, the F values have been calibrated as shown in Table 12.11 for each travel time increment. Determine the number of zone-to-zone trips through two iterations.

Table 12.9 Trip Productions and Attractions for a Three-Zone Study Area

Zone	*1*	*2*	*3*	*Total*
Trip productions	140	330	280	750
Trip attractions	300	270	180	750

Table 12.10 Travel Time between Zones (min)

Zone	*1*	*2*	*3*
1	5	2	3
2	2	6	6
3	3	6	5

Table 12.11 Travel Time versus Friction Factor

Time (min)	*F*
1	82
2	52
3	50
4	41
5	39
6	26
7	20
8	13

Note: *F* values were obtained from the calibration process.

Solution:

From Table 12.10 select travel time and selecting the correct F value from Table 12.11. For example, travel time is 2 min between zones 1 and 2. The corresponding F value is 52.)

$$T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum_{j=1}^{n} A_j F_{ij} K_{ij}} \right] \qquad K_{ij} = 1 \text{ for all zones}$$

$$T_{1-1} = 140 \times \frac{300 \times 39}{(300 \times 39) + (270 \times 52) + (180 \times 50)} = 47$$

$$T_{1-2} = 140 \times \frac{270 \times 52}{(300 \times 39) + (270 \times 52) + (180 \times 50)} = 57$$

$$T_{1-3} = 140 \times \frac{180 \times 50}{(300 \times 39) + (270 \times 52) + (180 \times 50)} = 36$$

$$P_1 = 140$$

Make similar calculations for zones 2 and 3.

$$T_{2-1} = 188 \quad T_{2-2} = 85 \quad T_{2-3} = 57 \quad P_2 = 330$$
$$T_{3-1} = 144 \quad T_{3-2} = 68 \quad T_{3-3} = 68 \quad P_3 = 280$$

The results summarized in Table 12.12 represent a singly constrained gravity model. This constraint is that the sum of the productions in each zone is equal to the number of productions given in the problem statement. However, the number of attractions estimated in the trip distribution phase differs from the number of attractions given. For zone 1, the correct number is 300, whereas the computed value is 379. Values for zone 2 are 270 versus 210, and for zone 3, they are 180 versus 161.

Table 12.12 Zone-to-Zone Trips: First Iteration, Singly Constrained

Zone	*1*	*2*	*3*	*Computed P*	*Given P*
1	47	57	36	140	140
2	188	85	57	330	330
3	144	68	68	280	280
Computed *A*	379	210	161	750	750
Given *A*	300	270	180	750	

To create a doubly constrained gravity model where the computed attractions equal the given attractions, calculate the adjusted attraction factors according to the formula

$$A_{jk} = \frac{A_j}{C_{j(k-1)}} A_{j(k-1)} \qquad (12.4)$$

where

A_{jk} = adjusted attraction factor for attraction zone (column) j, iteration k
$A_{jk} = A_j$ when $k = 1$
C_{jk} = actual attraction (column) total for zone j, iteration k
A_j = desired attraction total for attraction zone (column) j
j = attraction zone number, $j = 1, 2, \ldots, n$
n = number of zones
k = iteration number, $k = 1, 2, \ldots, m$
m = number of iterations

To produce a doubly constrained gravity model, repeat the trip distribution computations using modified attraction values so that the numbers attracted will be increased or reduced as required. For zone 1, for example, the estimated attractions were too great. Therefore, the new attraction factors are adjusted downward by multiplying the original attraction value by the ratio of the original to estimated attraction values.

$$\text{Zone 1:} A_{12} = 300 \times \frac{300}{379} = 237$$

$$\text{Zone 2:} A_{22} = 270 \times \frac{270}{210} = 347$$

$$\text{Zone 3:} A_{32} = 180 \times \frac{180}{161} = 201$$

Table 12.13 Zone-to-Zone Trips: Second Iteration, Doubly Constrained

Zone	*1*	*2*	*3*	*Computed P*	*Given P*
1	34	68	38	140	140
2	153	112	65	330	330
3	116	88	76	280	280
Computed *A*	303	268	179	750	750
Given *A*	300	270	180	750	

Apply the gravity model (Eq. 12.3) for all iterations to calculate zonal trip interchanges using the adjusted attraction factors obtained from the preceding iteration. In practice, the gravity model becomes

$$T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}} \right]$$

where T_{ijk} is the trip interchange between i and j for iteration k, and A_{jk} = Aj when k = 1. Subscript j goes through one complete cycle every time k changes, and i goes through one complete cycle every time j changes. This formula is enclosed in parentheses and subscripted to indicate that the complete process is performed for each trip purpose. Perform a second iteration using the adjusted attraction values.

$$T_{1-1} = 140 \times \frac{237 \times 39}{(237 \times 39) + (347 \times 52) + (201 \times 50)} = 34$$

$$T_{1-2} = 140 \times \frac{347 \times 52}{(237 \times 39) + (347 \times 52) + (201 \times 50)} = 68$$

$$T_{1-3} = 140 \times \frac{201 \times 50}{(237 \times 39) + (347 \times 52) + (201 \times 50)} = 37$$

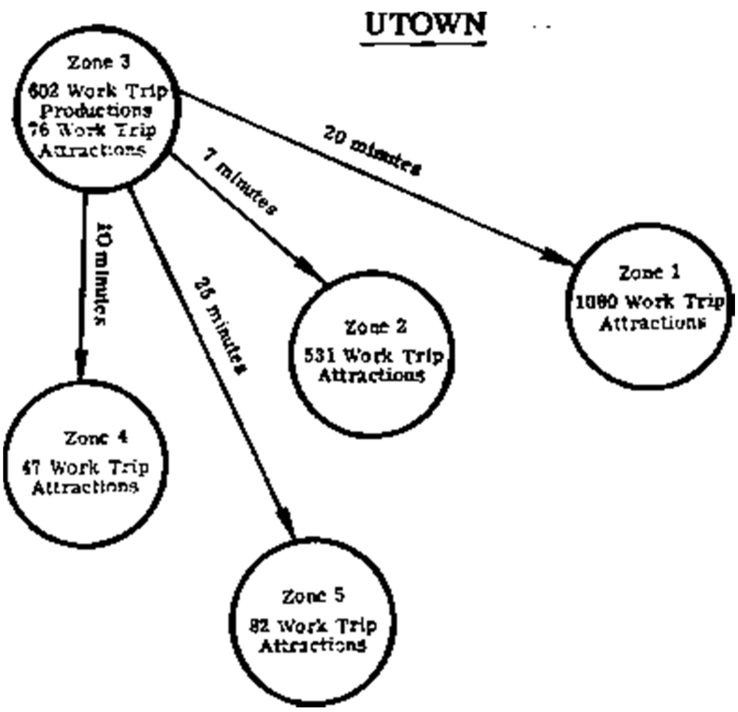
$$P_1 = 140$$

Make similar calculations for zones 2 and 3.

$$T_{2-1} = 153 \qquad T_{2-2} = 112 \qquad T_{2-3} = 65 \qquad P_2 = 330$$
$$T_{3-1} = 116 \qquad T_{3-2} = 88 \qquad T_{3-3} = 76 \qquad P_3 = 280$$

The results are summarized in Table 12.13. Note that, in each case, the sum of the attractions is now much closer to the given value. The process will be continued until there is a reasonable agreement (within 5%) between the A that is estimated using the gravity model and the values that are furnished in the trip generation phase.

H.W:



From Zone	To Zone	Attractions Aj	Impedance (minutes)	F(t)ij
3	1	1080	20	6
3	2	531	7	29
3	3	76	5*	45
3	4	47	10	18
3	5	82	25	4

Example 2: A new office park is expected to generate 1500 homebound trips in the pm peak hour. Analysts expect the trips to terminate in four residential zones. Using a gravity model, estimate the number of trips to go from the office park to zone 3 during the pm peak hour.

Zone number	Travel time from office park (min)	Number of trips attracted during a typical pm peak hour	Socioeconomic factor from office park to zone *i*
1	10	3000	1.2
2	15	2000	0.8
3	25	1800	1.0
4	30	4000	1.5

Solution

This problem is best solved by setting up a table to calculate the trips from the office park to each zone. In this example, Pi is equal to 1500 for all rows in the table. The table shows, attractions for each destination zone, estimates friction factors as the inverse of travel time, and gives the socioeconomic factor. Those three terms are used to estimate the A*F*K product for each destination zone, which are then used to get the estimate of the number of trips for each zonal pair.

Zone j	A_j	F_{ij}	K_{ij}	$A \times F \times K$	$\frac{A \times F \times K}{\sum(A \times F \times K)}$	Q_{ij}
1	3000	$1/10 = 0.100$	1.2	360	0.4885	733
2	2000	$1/15 = 0.067$	0.8	107	0.1452	218
3	1800	$1/25 = 0.040$	1.0	72	0.0977	146
4	4000	$1/30 = 0.033$	1.5	198	0.2686	403
Σ	—	—	—	737	1.0000	1500

The total number of trips estimated from the office park to zone 3 is 146 trips.

Growth Factor Models

Trip distribution can also be computed when the only data available are the origins and destinations between each zone for the current or base year and the trip generation values for each zone for the future year. This method was widely used when O-D data were available but the gravity model and calibrations for F factors had not yet become operational. Growth factor models are used primarily to distribute trips between zones in the study area and zones in cities external to the study area. Since they rely upon an existing O-D matrix, they cannot be used to forecast traffic between zones where no traffic currently exists. Further, the only measure of travel friction is the amount of current travel. Thus, the growth factor method cannot reflect changes in travel time between zones, as does the gravity model.

The most popular growth factor model is the Fratar method, which is a mathematical formula that proportions future trip generation estimates to each zone as a function of the product of the current trips between the two zones T_{ij} and the growth factor of the attracting zone G_j. Thus,

$$T_{ij} = (t_i G_i) \frac{t_{ij} G_j}{\sum_x t_{ix} G_x}$$

where

T_{ij} = number of trips estimated from zone i to zone j
t_i = present trip generation in zone i
G_x = growth factor of zone x
$T_i = t_i G_i$ = future trip generation in zone i
t_{ix} = number of trips between zone i and other zones x
t_{ij} = present trips between zone i and zone j
G_j = growth factor of zone j

Example Forecasting Trips Using the Fratar Model A study area consists of four zones (A, B, C, and D). An O-D survey indicates that the number of trips between each zone is as shown in Table 12.17. Planning estimates for the area indicate that in five years the number of trips in each zone will increase by the growth factor shown in Table 12.18 and that trip generation will be increased to the amounts shown in the last column of the table. Determine the number of trips between each zone for future conditions.

Table 12.17 Present Trips between Zones

Zone	*A*	*B*	*C*	*D*
A	—	400	100	100
B	400	—	300	—
C	100	300	—	300
D	100	—	300	—
Total	600	700	700	400

Table 12.18 Present Trip Generation and Growth Factors

Zone	*Present Trip Generation (trips/day)*	*Growth Factor*	*Trip Generation in Five Years*
A	600	1.2	720
B	700	1.1	770
C	700	1.4	980
D	400	1.3	520

Solution:

Using the Fratar formula, calculate the number of trips between zones A and B, A and C, A and D, and so forth. Note that two values are obtained for each zone pair (that is, T_{AB} and T_{BA}). These values are averaged, yielding a value for $T_{AB}= (T_{AB}+ T_{BA}) /2$. The calculations are as follows.

$$T_{ij} = (t_i G_i) \frac{t_{ij} G_j}{\sum_x t_{ix} G_x}$$

$$T_{AB} = 600 \times 1.2 \frac{400 \times 1.1}{(400 \times 1.1) + (100 \times 1.4) + (100 \times 1.3)} = 446$$

$$T_{BA} = 700 \times 1.1 \frac{400 \times 1.2}{(400 \times 1.2) + (300 \times 1.4)} = 411$$

$$\overline{T}_{AB} = \frac{T_{AB} + T_{BA}}{2} = \frac{446 + 411}{2} = 428$$

Similar calculations yield

$T_{AC} = 141$ $T_{AD} = 124$ $T_{BC} = 372$ $T_{CD} = 430$

The results of the preceding calculations have produced the first estimate (or iteration) of future trip distribution and are shown in Table 12.19. The totals for each zone do not equal the values of future trip generation. For example, the trip generation in zone A is estimated as 693 trips, whereas the actual value is 720 trips. Similarly, the estimate for zone B is 800 trips, whereas the actual value is 770 trips. Proceed with a second iteration in which the input data are the numbers of trips between zones as previously calculated. Also, new growth factors are computed as the ratio of the trip generation expected to occur in five years and the trip generation estimated in the preceding calculation. The values are given in Table 12.20. The calculations for the second iteration are left to the reader to complete and the process can be repeated as many times as needed until the estimate and actual trip generation values are close in agreement.

Table 12.19 First Estimate of Trips between Zones

Zone	*A*	*B*	*C*	*D*	*Estimated Total Trip Generation*	*Actual Trip Generation*
A	—	428	141	124	693	720
B	428	—	372	—	800	770
C	141	372	—	430	943	980
D	124	—	430	—	554	520
Totals	693	800	943	554		

Table 12.20 Growth Factors for Second Iteration

Zone	*Estimated Trip Generation*	*Actual Trip Generation*	*Growth Factor*
A	693	720	1.04
B	800	770	0.96
C	943	980	1.04
D	554	520	0.94

3.Mode choice

is the process by which the analyst determines the amount of travel that will be made by using each avail¬able mode of transportation in the urban area. Determining the preference of people within zones to make a trip by personal vehicle, public transportation, bicycling, walking, etc., and dividing the total trips among those modes. It determines the number (or percentage) of trips between zones that are made by automobile and by transit. The selection of one mode or another is a complex process that depends on factors such as the traveler's income, the availability of transit service or auto ownership, and the relative advantages of each mode in terms of travel time, cost, comfort, convenience, and safety. Mode choice models attempt to replicate the relevant characteristics of the traveler, the transportation system, and the trip itself, such that a realistic estimate of the number of trips by each mode for each zonal pair is obtained.

Depending on the level of detail required, three types of transit estimating procedures are used:

- Direct generation of transit trips,
- Use of trip end models,
- Trip interchange modal split models.

FACTORS THAT AFFECT MODE USAGE

- characteristics of the traveler — the trip maker;
- characteristics of the trip; and
- characteristics of the transportation system.

Direct Generation Models

Transit trips can be generated directly, by estimating either total person trips or auto driver trips. Figure 12.8 is a graph that illustrates the relationship between transit trips per day per 1000 population and persons per acre versus auto ownership. As density of population increases, it can be expected that transit riding will also increase for a given level of auto ownership.

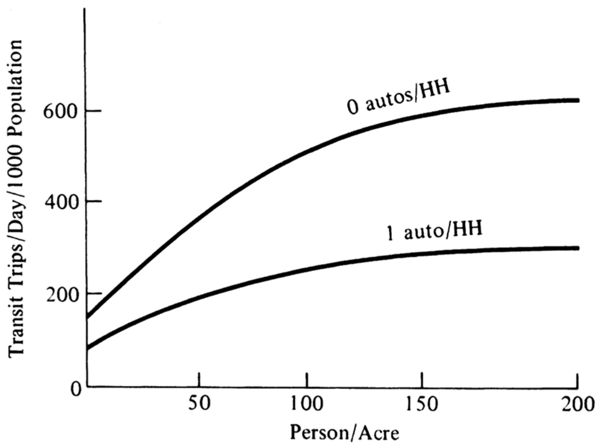


Figure 12.8 Number of Transit Trips by Population Density and Automobile Ownership per Household

Example: Determine the number of transit trips per day in a zone using Figure 12.8 which has 5000 people living on 50 acres. The auto ownership is 40% of zero autos per household and 60% of one auto per household.

Solution: Calculate the number of persons per acre: 5000 / 50= 100. Then determine the number of transit trips per day per 1000 persons (from Figure 12.8) to calculate the total of all transit trips per day for the zone.

Zero autos /HH: 510 trips /day/1000 population

One auto /HH: 250 trips /day/1000 population

Total Transit Trips: (0.40)(510)(5) + (0.60)(250)(5) =

1020+ 750 = 1770 transit trips per day

This method assumes that the attributes of the system are not relevant. Factors such as travel time, cost, and convenience are not considered. These so-called “pre trip” distribution models apply when transit service is poor and riders are “captive,” or when transit service is excellent and “choice” clearly favors transit. When highway and transit modes “compete” for auto riders, then system factors are considered.

Trip End Models

To determine the percentage of total person or auto trips that will use transit, estimates are made prior to the trip distribution phase based on land-use or socioeconomic characteristics of the zone.

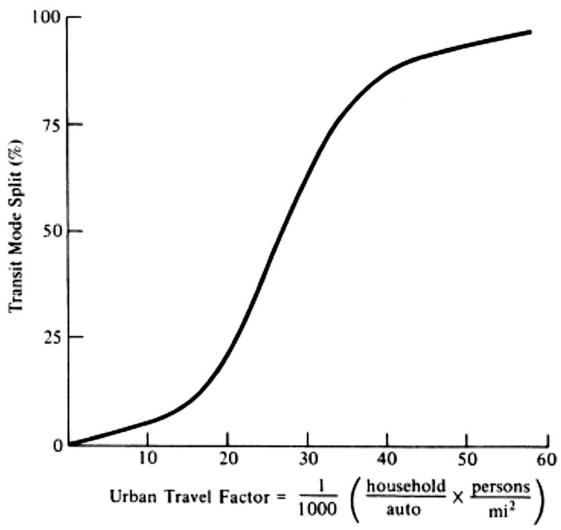


Figure 12.9 Transit Mode Split versus Urban Travel Factor

This method does not incorporate the quality of service. The procedure follows:

1. Generate total person trip productions and attractions by trip purpose.

2. Compute the urban travel factor.

3. Determine the percentage of these trips by transit using a mode choice curve.

4. Apply auto occupancy factors.

5. Distribute transit and auto trips separately.

The mode choice model shown in Figure 12.9 is based on two factors: households per auto and persons per square mile. The product of these variables is called the urban travel factor (UTF). Percentage of travel by transit will increase in an S curve fashion as the UTF increases.

Example:

The total number of productions in a zone is 10,000 trips/day. The number of households per auto is 1.80, and residential density is 15,000 persons/square mile. Determine the percent of residents who can be expected to use transit.

Solution: Compute the urban travel factor.

$$\begin{aligned} UTF &= \frac{1}{1000}\left(\frac{\text{household}}{\text{auto}}\right)\left(\frac{\text{persons}}{\text{mi}^2}\right) \\ &= \frac{1}{1000} \times 1.80 \times 15{,}000 = 27.0 \end{aligned}$$

Enter Figure 12.9. Transit mode split = 45%.

Trip Interchange Models

In this method, system level-of-service variables are considered, including relative travel time, relative travel cost, economic status of the trip maker, and relative travel service. An example of this procedure is illustrated using the QRS method which takes account of service parameters in estimating mode choice. The QRS method is based on the following relationship

$$MS_a = \frac{I_{ijt}^{-b}}{I_{ija}^{-b} + I_{ija}^{-b}} \times 100 \text{ or } \frac{I_{ija}^{b}}{I_{ijt}^{b} + I_{ija}^{b}} \times 100 \tag{12.6}$$

$$MS_t = (1 - MS_a) \times 100 \tag{12.7}$$

where

MS_t = proportion of trips between zone *i* and *j* using transit
MS_a = proportion of trips between zone *i* and *j* using auto
I_{ijm} = a value referred to as the *impedance* of travel of mode *m*, between *i* and *j*, which is a measure of the total cost of the trip. [*Impedance* = (in-vehicle time min) + (2.5 × excess time min) + (3 × trip cost, $/income earned/min).]
b = an exponent, which depends on trip purpose
m = *t* for transit mode; *a* for auto mode

In-vehicle time is time spent traveling in the vehicle, and excess time is time spent traveling but not in the vehicle, including waiting for the train or bus and walking to the station. The impedance value is determined for each zone pair and represents a measure of the expenditure required to make the trip by either auto or transit.

The data required for estimating mode choice include

(1) distance between zones by auto and transit,

(2) transit fare,

(3) out-of-pocket auto cost,

(4) parking cost,

(5) highway and transit speed,

(6) exponent values, b,

(7) median income, and

(8) excess time,

which includes the time required to walk to a transit vehicle and time waiting or transferring. Assume that the time worked per year is 120,000 min.

Travel time is usually divided into two groups:

- Riding time is the amount of time spent in the vehicle; and
- Excess time is the amount of time spent outside the vehicle (walking, parking, waiting, transferring, etc.).

Example 12.9 Computing Mode Choice Using the QRS Model

To illustrate the application of the QRS method, assume that the data shown in Table 12.21 have been developed for travel between a suburban zone *S* and a downtown zone *D*. Determine the percent of work trips by auto and transit. An exponent value of 2.0 is used for work travel. Median income is \$24,000 per year.

Table 12.21 Travel Data Between Two Zones, *S* and *D*

	Auto	*Transit*
Distance	10 mi	8 mi
Cost per mile	\$0.15	\$0.10
Excess time	5 min	8 min
Parking cost	\$1.50 (or 0.75/trip)	—
Speed	30 mi/h	20 mi/h

Solution: Use Eq. 12.6.

$$MS_a = \frac{I_{ija}^b}{I_{ijt}^b + I_{ija}^b}$$

$$I_{SDa} = \left(\frac{10}{30} \times 60\right) + (2.5 \times 5) + \left\{\frac{3 \times [(1.50/2) + 0.15 \times 10]}{24{,}000/120{,}000}\right\}$$

$$= 20 + 12.5 + 33.75$$

$$= 66.25 \text{ equivalent min}$$

$$I_{SDt} = \left(\frac{8}{20} \times 60\right) + (2.5 \times 8) + \left[\frac{3 \times (8 \times 0.10)}{24{,}000/120{,}000}\right] = 24 + 20 + 12$$

$$= 56 \text{ equivalent min}$$

$$MS_a = \frac{(56)^2}{(56)^2 + (66.25)^2} \times 100 = 41.6\%$$

$$MS_t = (1 - 0.416) \times 100 = 58.4\%$$

Thus, the mode choice of travel by transit between zones S and D is 68.4%, and by highway the value is 41.6%. These percentages are applied to the estimated trip distribution values to determine the number of trips by each mode. If for example, the number of work trips between zones S and D was computed to be 500, then the number by auto would be 500 *0.416 =208, and by transit, the number of trips would be 500 * 0.584 = 292.

Logit Models

An alternative approach used in transportation demand analysis is to consider the relative utility of each mode as a summation of each modal attribute. Then the choice of a mode is expressed as a probability distribution. For example, assume that the utility of each mode is

$$U_x = \sum_{i=1}^{n} a_i X_i \tag{12.8}$$

where

U_x = utility of mode x
n = number of attributes
X_i = attribute value (time, cost, and so forth)
a_i = coefficient value for attributes i (negative, since the values are disutilities)

If two modes, auto (A) and transit (T), are being considered, the probability of selecting the auto mode A can be written as

$$P(A) = \frac{e^{U_A}}{e^{U_A} + e^{U_T}}$$

This form is called the logit model, as illustrated in Figure 12.10 and provides a convenient way to compute mode choice. Choice models are utilized within the urban transportation planning process, in transit marketing studies, and to directly estimate travel demand.

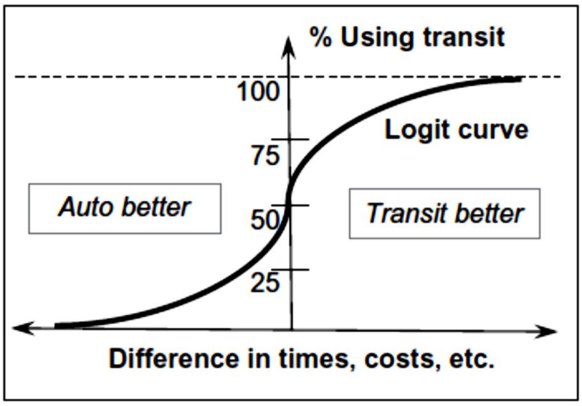


Figure 12-10

Example: Use of Logit Model to Compute Mode Choice, The utility functions for auto and transit are as follows:

$$\text{Auto: } U_A = -0.46 - 0.35T_1 - 0.08T_2 - 0.005C$$
$$\text{Transit: } U_T = -0.07 - 0.05T_1 - 0.15T_2 - 0.005C$$

where

T1 = total travel time (minutes)

T2= waiting time (minutes)

C = cost (cents)

The travel characteristics between two zones are as follows:

	Auto	*Transit*
T_1	20	30
T_2	8	6
C	320	100

Solution: Use the logit model to determine the percent of travel in the zone by auto and transit.

$$U_x = \sum_{i=1}^{n} a_i x_i$$

$$U_A = -0.46 - (0.35 \times 20) - (0.08 \times 8) - (0.005 \times 320) = -9.70$$

$$U_B = -0.07 - (0.35 \times 30) - (0.08 \times 6) - (0.005 \times 100) = -11.55$$

$$P_A = \frac{e^{U_A}}{e^{U_A} + e^{U_T}} = \frac{e^{-9.70}}{e^{-9.7} + e^{-11.55}} = 0.86$$

$$P_T = \frac{e^{U_T}}{e^{U_A} + e^{U_T}} = \frac{e^{-11.55}}{e^{-9.7} + e^{-11.55}} = 0.14$$

Occupancy rate

After we figure out trips by auto and those by transit, we use, occupancy rate to find the number of vehicles.

e.g. $$\frac{\text{30,000 persons use cars per day}}{\text{1.2 persons per car}} = 25000 \; cars/day$$

$$\frac{\text{15000 person use transit per day}}{\text{30 persons per bus}} = 500 \; \text{bus/day}$$

$\therefore$ Total no. of vehicles per day or

"Volume" = 25500 veh/day

4. Trip assignment:

The final step in the transportation forecasting process is to determine the actual street and highway routes that will be used and the number of automobiles and buses that can be expected on each highway segment. The procedure used to determine the expected traffic volumes is known as traffic assignment. Since the numbers of trips by transit and auto that will travel between zones are known from the previous steps in the process, each trip O-D can be assigned to a highway or transit route. The sum of the results for each segment of the system results in a forecast of the average daily or peak hour traffic volumes that will occur on the urban transportation system that serves the study area.

Assigning all the trips to the transportation system to identify actual routes taken, consider capacity constraints on the network, and to ultimately determine the impact to the transportation network.

To carry out a trip assignment, the following data are required:

(1) number of trips that will be made from one zone to another (this information was determined in the trip distribution phase),

(2) available highway or transit routes between zones,

(3) how long it will take to travel on each route,

(4) a decision rule (or algorithm) that explains how motorists or transit users select a route, and

(5) external trips that were not considered in the previous trip generation and distribution steps.

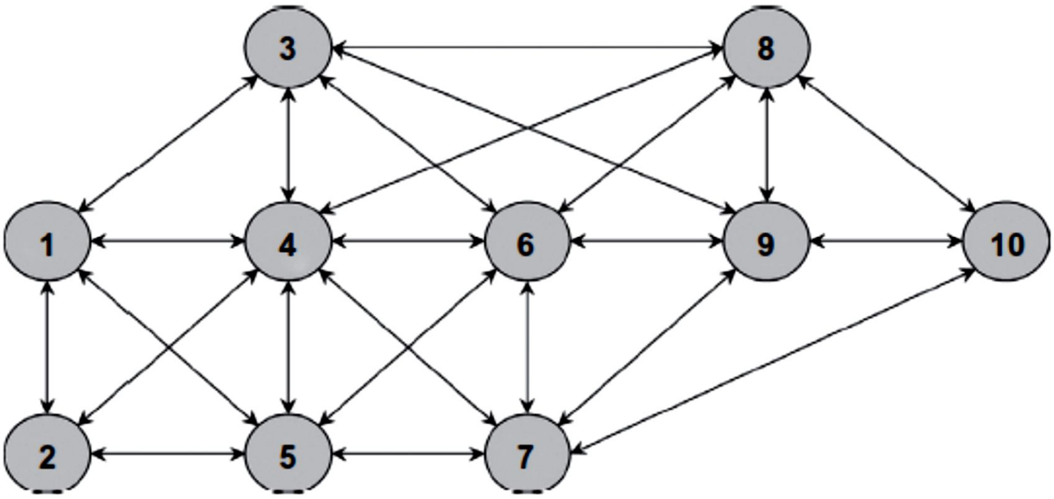


Figure 2-13 Simple network for assignment illustration

for example, the simplified 10-zone network in Figure 2.13. If evaluating a trip with origin in zone 1 and destination in zone 4, the path is represented by link 1-4 that connects the two zones. All attributes of link 1-4 are translated to the path for analysis. But while link 1-4 has a clear direct path, other zonal pairs have multiple paths. For example, take the O/D pair for links 1 and 7. In this case, one potential path is "1-4-4-7." But several alternate paths exist in this case, including "1-5-5-7," "1-2-2-5-5-7," or "1-4-4-6-6-7." Therefore, the decision of which path drivers will take becomes a function of the attributes of each path, which, in turn, are estimated from the aggregated attributes of each link sequence.

For the second zonal pair example, the path travel times are 5 min for "1-4-4-7," 4 min for "1-5-5-7," 7 min for "1-2-2-5-5-7," and 6 min for "1-4-4-6-6-7." So in this case, path "1-5-5-7" produces the lowest travel time at 4 min.

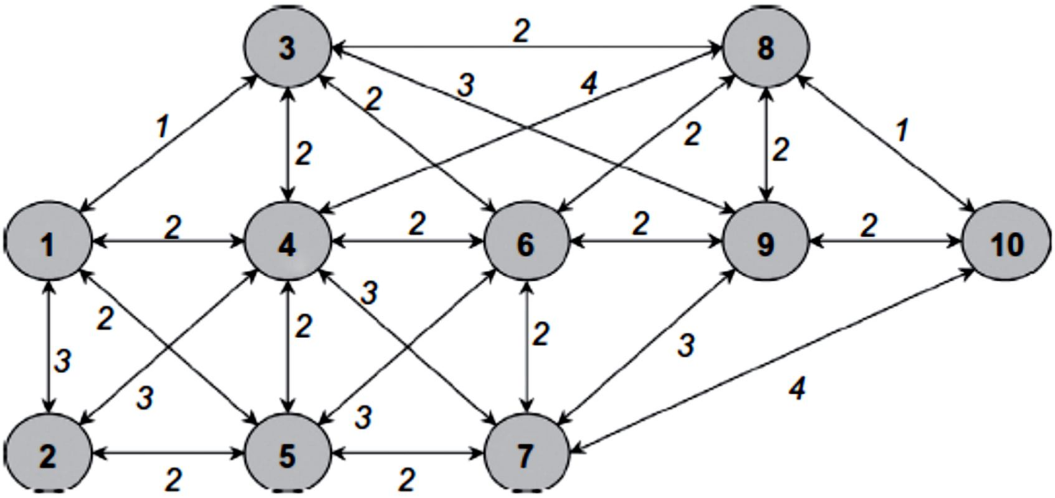
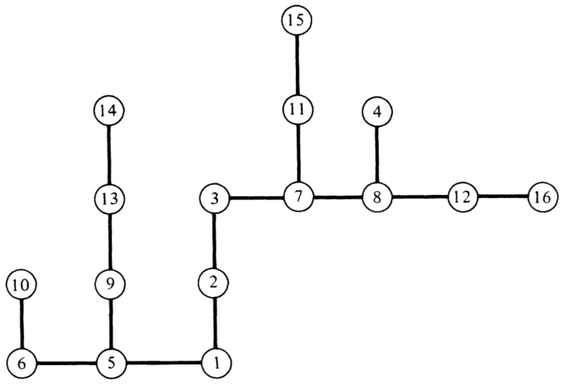


Figure 2.14 Simple assignment network with link travel times.

H.W1: the following 16-node network with travel times on each link shown for each node (zone) pair. The link and node network is representative of the road and street system. Determine the shortest travel path from node 1 (home node) to all other zones.



Example1: The links that are on the minimum path for each of the nodes connecting node 1 are shown in Table 12.23. Also shown are the number of auto trips between zone 1 and all other zones. From these results, the number of trips on each link is determined.

Table 12.23 Links on Minimum Path for Trips from Node 1

From	*To*	*Trips*	*Links on the Minimum Path*
1	2	50	1–2
	3	75	1–2, 2–3
	4	80	1–2, 2–3, 3–7, 7–8, 4–8
	5	100	1–5
	6	125	1–5, 5–6
	7	60	1–2, 2–3, 3–7
	8	30	1–2, 2–3, 3–7, 7–8
	9	90	1–5, 5–9
	10	40	1–5, 5–6, 6–10
	11	80	1–2, 2–3, 3–7, 7–11
	12	25	1–2, 2–3, 3–7, 7–8, 8–12
	13	70	1–5, 5–9, 9–13
	14	60	1–5, 5–9, 9–13, 13–14
	15	20	1–2, 2–3, 3–7, 7–11, 11–15
	16	85	1–2, 2–3, 3–7, 7–8, 8–12, 12–16

Table 12.24 Assignment of Trips from Node 1 to Links on Highway Network

Link	*Trips on Link*	
1–2	50, 75, 80, 60, 30, 80, 25, 20, 85 =	505
2–3	75, 80, 60, 30, 80, 25, 20, 85 =	455
3–7	80, 60, 30, 80, 25, 20, 85 =	380
1–5	100, 125, 90, 40, 70, 60 =	485
5–6	125, 40 =	165
7–8	80, 30, 25, 85 =	220
4–8	80 =	80
5–9	90, 70, 60 =	220
6–10	40 =	40
7–11	80, 20 =	100
8–12	25, 85 =	110
9–13	70, 60 =	130
11–15	20 =	20
12–16	85 =	85
13–14	60 =	60

To illustrate, link 1 to 2 is used by trips from node 1 to nodes 2, 3, 4, 7, 8, 11, l2, 15, and 16. Thus, the trips between these node pairs are assigned to link 1 to 2 as illustrated in Table 12.23. The volumes are 50, 75, 80, 60, 30, 80, 25, 20, and 85 for a total of 505 trips on link 1 to 2 from node 1.

Solution: Calculate the number of trips that should be assigned to each link of those that have been generated in node 1 and distributed to nodes 2 through 16 (Table 12.24). A similar process of network loading would be completed for all other zone pairs.

Capacity-Constrained Assignment

There are several problems with the shortest path and all-or-nothing assignment. For example, the assignment doesn't take into account that the total traffic demand assigned to a particular link may result in increases in travel time on that link, thereby increasing link travel time and decreasing its desirability in the assignment. In extreme cases, of course, the demand may actually exceed the capacity of a link, making it impossible to process the full demand from all zones. A capacity constrained assignment takes these travel time increases and link capacity constraints into consideration. A capacity constrained assignment applies a relationship between the volume-to-capacity ratio (v/c) on a link and the resulting travel time to each link. The higher the v/c ratio estimated, the higher is the resulting effect on link travel time. The most commonly used relationship was developed by the U.S. Bureau of Public Roads and is referred to as the BPR function. The BPR formula for estimating link travel time under capacity constraint is as follows:

$$t_{CR,i} = t_{0,i} \times \left[1 + 0.15 \times \left(\frac{v_i}{c_i}\right)^4\right]$$

where

$t_{CR,i}$ = capacity restrained travel time of link i (min)
$t_{0,i}$ = free-flow travel time of link i (min)
v_i = demand volume forecast for link i (veh/h)
c_i = capacity of time of link i (veh/h)

The form of the equation results in an increase in the estimated link travel time as a function of link capacity and v/c ratio. The link travel time is equal to 1.15 times the free-flow travel time at capacity (v/c=1) and increases exponentially past the capacity. The application of the capacity-constrained assignment is iterative. After an initial (shortest path) assignment, the link travel times are updated based on the BPR function or another impedance curve. The assignment is then repeated with the updated link travel times until an equilibrium is reached. Equilibrium in this case means that the assigned flows and link sequences no longer change, and travel times on all links are thus stable between successive assignments.

Example 12.17 Computing Capacity Restrained Travel Times

In Example 12.16, the volume on link 1 to 5 was 485, and the travel time was 2 minutes. If the capacity of the link is 500, determine the link travel time that should be used for the next traffic assignment iteration.

Solution:

$$t_1 = t_0\left[1 + 0.15\left(\frac{V}{C}\right)^4\right]$$

$$t_{1-5} = 2\left[1 + 0.15\left(\frac{485}{500}\right)^4\right]$$

$$= 2.27 \text{ min}$$