Urban Transportation Planning

Definitions:

Planning: The process of working out, beforehand, scheme, program, or method for the accomplishment of an objective.

Urban Transportation Planning

1. Understand how decisions to build transportation facilities are made
2. Understand basic elements of the transportation planning process.
3. Understand basic elements of travel forecasting

Common Types of Urban Land Uses

Urban land uses classified as:

1. Residential.
2. Commercial. ex. Shopping centers (change with times)
3. Industrial.
4. Institutional. ex. Educational, governmental
5. Recreational.
6. Agricultural.

A set of alternative transport plan is then generated for that horizon year. These plans incorporate varying nature and amount of transport facilities. The operating characteristics of each alternative in the horizon year are then estimated in the form of flows on each link of the horizon-year networks.

The usual criterion for choice among the alternatives is that the difference between the collective benefits to users (in the form of reduced travel impedance) and the money costs of constructing and maintaining these facilities should be a maximum.
**Basic Elements of Transportation Planning**

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<tr>
<th>Step</th>
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<tr>
<td>Situation definition</td>
<td>Inventory transportation facilities, Measure travel patterns,</td>
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<td>Review prior studies.</td>
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<td>Problem definition</td>
<td>Define objectives (e.g., Reduce travel time), Establish criteria (e.g., Average delay time), Define constraints, Establish design standards</td>
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<td>Search for solutions</td>
<td>Consider options (e.g., locations and types, structure needs, environmental considerations)</td>
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<td>Analysis of performance</td>
<td>For each option, determine cost, traffic flow, impacts</td>
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<td>Determine values for the criteria set for evaluation (e.g., benefits vs. cost, cost-effectiveness, etc)</td>
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<td>Choice of project</td>
<td>Consider factors involved (e.g., goal attainability, political judgment, environmental impact, etc.)</td>
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<td>Specification and construction</td>
<td>Once an alternative is chosen, design necessary elements of the facility and create construction plans</td>
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Example 1: Planning the relocation of a rural road (simple, yet good enough to explain the steps…)

Step 1: Situation definition:

- to understand the situation that gave rise to the perceived need for a transportation improvement

Step 2: Problem definition

Purpose of the step: Describe the problem in terms of the objectives to be accomplished and translate those objectives into criteria.

Example:

- Objective = Statements of purpose: Reduce traffic congestion, Improve safety, Maximize net highway-user benefits, etc.

- Criteria = Measures of effectiveness: Travel time, accident rate, delays (interested in reductions in these MOEs).
Step 3: Search for solutions

- Alternative Routes for Highway Relocation

Step 4: Analysis of performance

Estimate how each of the proposed alternatives would perform under present and future conditions.
Step 4: Ranking of alternatives (in terms of MOE)

<table>
<thead>
<tr>
<th>Criteria/Alternative</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td>Travel time</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Accident factor(^a)</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Cost ($ millions)</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Residences displaced</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Air quality (\text{(\mu g/m^3)} CO)</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Noise (^a)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Tax loss</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Trees removed (acres)</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Increased runoff</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: 1 = highest; 5 = lowest.

\(^{a}\) Relative to statewide average for this type of facility.
Step 5: Evaluation of alternatives

Determine how well each alternative will achieve the objectives of the project as defined by Criteria.
**Step 6: Choice of project**

- Based on the alternative evaluation in Step 5, we will choose the best alternative for design and eventual construction. The best choice may not be built because of opposition by the people of the community that is affected.

**Step 7: Specification and construction**

- Once the project has been chosen, a detailed design phase is begun, in which each of the components of the facility is specified.
System and environment

A system may be defined as a set of components that is organized in such a manner as to direct the action of the system under inputs toward specific goals and objectives.

An environment may be defined as to set of all components outside a system, which both influences the behavior of the system and which intern is influenced by the behavior of the system.

System → all modes for urban transportation

- Bus
- Transit
- Taxi
- Passenger car.
- Etc.

We can classified them as follows:

1. Urban passenger transportation system.
2. Urban public transportation system.
3. Urban goods transport system.
4. Urban intermediate public transport system.
5. Urban personal transport system.

The urban transportation system may be thought as responding to the social and economic forces that exit in urban areas. This urban socioeconomic environment is in turn influenced by the characteristics of the transport system.

The role of the system planner may be conceived, in general way, as the direction of her efforts to design a system that achieves maximum integration, or degree of fit between the system and its environment.

Example (1)

Goal: Maximize mobility of people and goods

Related objectives:

1. Minimize travel time.
2. Minimize travel cost.
3. Provide adequate frequency of service.
4. Provide adequate system capacity.
5. Provide adequate system safety.
6. Provide adequate system reliability.

**Related Standards:**

1. The travel time by public transport between major activity centers not exceed 30 minutes.
2. The travel time cost by public transport not to exceed 15% of travel cost of private transport.
3. The frequency of public transport service on any route to be not less than 3 per hour.
4. The peak hour occupancy of public transport vehicles not exceed the permissible limits.
5. Fatal accidents involving public transport vehicles to be less than 1% of the total.
6. At least 95% of public transport operation to be as per the published time schedule.
**Definition of Study Area**

**Urban area**

1. Population not less than 5,000.
2. Non-agricultural workers not less than 75% of the total workers.
3. Population density not less than 400 per sq. km.

Towns with population of 0.1 million and above are termed as cities.
Transportation Survey

The first stage in the formulation of a transportation plan is to collect data on all factors likely to influence travel pattern. The work involves a number of surveys so as to have:

1. An inventory of existing travel pattern.
2. An inventory of existing transport facilities.
3. An inventory of existing land use and economic activities.

Definition of the Study Area

The study area for which transportation facilities are being planned is first of all defined. Transportation planning can be at the national level, the regional level or at the urban area level.

For planning at the urban level, the study area should embrace the whole contribution containing the existing and potential continuously built up areas of the city. The imaginary line representing the boundary of the study area is termed as the external cordon line. The area inside the external cordon line determines the travel pattern to a large extent and as such, it is surveyed great detail. The land use pattern and the economic activities are studied intensively and detailed survey (such as the home-interview) are conducted in this area to determine the travel characteristics. On the other hand, the area outside the cordon line is not studied in such details.

Selection of External Cordon Line

The selection of the external cordon line for urban transportation planning should be done carefully with due consideration to the following factors:

1. The external cordon line should circumscribe all areas, which are already built up, and those areas, which are considered likely to be developed during the planning period.
2. The external cordon line should contain all areas of systematic daily life of the people oriented towards the city center and should in effect be the commuter shed.
3. The external cordon line should be continuous and uniform in its courses so that movements cross it only once. The line should intersect roads where it is safe and convenient for carrying out traffic survey.
4. The external cordon line should be compatible with the previous studies of the areas studies planned for the future.
Zoning

The defined study area is sub-divided into smaller areas called zones or traffic zones.

- The purpose of such a subdivision is to facilitate the spatial quantification of land use and economic factors, which influence travel pattern. Subdivision into zones further helps in geographically associating the origins and destinations of travel.

- Zones within the study area are called internal zones and those outside the study area are called external zones.

- In large study projects, it is convenient to divide the study area into sectors, which are sub divided into zones. Zones can themselves be sub divided into sub-zones depending upon the type of land use.

- A convenient system of coding of the zones will be useful for the study. One such system is to divide the study area into 9 sectors.

The central sector CBD is designated 0, and the remaining eight are designated from 1 to 8 in clockwise manner. The prefix 9 is reserved for the external zones.

Each sector is subdivided into 10 zones bearing numbers from 0 to 9.
For ex.
It would be helpful, if the following points are kept in view when dividing the area into zones:

1. The zones should have a homogenous land use so as to reflect accurately the associated trip making behavior.
2. Anticipated change in land use should be considered when subdividing the study area into zones.
3. It would be advantageous, if the subdivision follows closely that adopted by other bodies (e.g. census department) for data collection. This will facilitate correlation of data.
4. The zones should not too large to cause considerable errors in data. At the sometime, they should not be too small either to cause difficulty in handling and analyzing the data.
   As a general guide, a population of 1000-3000 may be the optimum for a small area, and a population of 5000-10000 may be the optimum for large urban areas. In residential areas, the zones may accommodate roughly 1000 households.
5. The zones should preferably have regular geometric form for easily determining the centroid, which represent the origin and destination of travel.
6. The sectors should represent the catchment of trips generated on a primary route.
7. Zones should be compatible with screen lines and cordon lines.
8. Zone boundaries should preferably be watersheds of trip making.
9. Natural or physical barriers such as canals, rivers, etc. can form convenient zone boundaries.
10. In addition to the external cordon lines, there may be a number of internal cordon lines arranged as concentric rings to check the accuracy of survey data.

**Screen lines**

Running through the study area are also established to check the accuracy of data collected from home-interview survey. Screen lines can be conveniently located along physical or natural barriers having a few crossing points.

Examples of such barriers are river, railway lines, canals, etc.

**Types of Movements**

The basic movements for which survey data are required are:

1. Internal to internal.
2. External to internal.
3. Internal to external.
4. External to external.
For large urban areas, the internal to internal travel is heavy whereas for small areas having a small population (say less than 5000) the internal to internal travel is relatively less. Most details of internal to internal travel can be obtained by home interview survey.

The details of internal-external, external internal and external-external travels can be studied by cordon surveys.

**Data Collection:**

The data can be collected:

1. At home.
2. During the trip end.
3. At the destination of the trip.

When collected at home, the data can be wide ranging and can over all the trips made during a given period. The data collected during the trip is necessary of limited scope since the procedure yields data only on the particular trip intercepted.

At the destination end, the direct interview types of surveys provide data on demand for parking facilities and or the trip ends at major traffic attraction centers such as factories, offices and commercial establishments.

The following are the surveys that are usually carried out:

1. Home-interview survey.
2. Commercial vehicles surveys.
3. Intermediate public transport surveys.
4. Public transport surveys.
5. Road-side-interview surveys.
6. Post-card-questioner surveys.
7. Registration-number surveys.
8. Tag-on-vehicle surveys.

The information to be collected from home-interview survey can be broadly classified in two groups:

1. Household information.
2. Journey or trip data.
The household information needs to contain data with regard to:

- Size of household.
- Age of all the numbers of the households.
- Sex.
- Structure of households.
- Employee.
- Occupation.
- Place of work.
- No. of vehicles owned.
- Household income.

Journey data will contain information all trips made during the previous 24hr. with regard to:

- Origin and destination of trip.
- Purpose of trip.
- Modes of travel.
- Time at start of trip.
- Time at finish of trip.

**Inventory of Transport Facilities**

The inventory of existing transport facilities should be undertaken to identify the deficiencies in the present system and the extent to which they need to be improved. The inventory consists of:

- Inventory of streets forming the transport network. Link \[\text{width length, no. of lanes}\].
- Nodes \[\text{complete geometric of intersection}\].
- Traffic volume composition peak and off peak.
- Studies on travel time by different modes.
- Inventory of public transport buses.
- Inventory of rail transport facilities.
- Parking inventory
Accident data.

**Inventory of Land Use and Economic Activities**

1. **Inventory of Land Use**
   Since travel characteristics are closely related to the land use pattern, it is of utmost important that an accurate inventory of land-use be prepared.
   Data on intensity of usage of land for different purposes, such as residential, industrial, commercial, recreational, open space, etc. in each of the traffic zones are to be collected from concerned departments/organization.

2. **Inventory of Economic Activities**
   Aggregate data on demographic and socioeconomic activities should be collected from other sources to include the following:
   - Population of the planning area and various zones.
   - Age, sex, and composition of the family.
   - Employment statistics.
   - Housing statistics.
   - Income.
   - Vehicle ownership.
Transport Related Land-Use Models

Land –Use Transport Interaction

- Land development generates travel, and travel generates the need for new facilities, which in turn increases accessibility and attracts further development.
- The question of whether transportation influences land –use (development) or whether land use dictates transportation has been a matter of ongoing concern among transportation professionals.
- Thus, the connection between transportation and land use is a fundamental concept, which needs to be understood clearly, in transportation planning as transportation and land use are inexorably connected.
- Everything that happens to land use has transportation implications and every transportation action affects land use.
- Transportation’s most significant impact on land use development and more development generates additional travel.
- Increased access to land raises its potential for development and more development generates additional travel.
- One access has been provided land patterns begin to change over a period of time. The results of these changes are, for the most part, irreversible.
Selection of land use Transport Model

A variety of land – use transport models have been developed in the past 15 years. A few of them are research models having excellent capabilities for sensitive forecasting, while some are operational models. The former group of models require extensive data collected through special surveys, whereas the latter need data which are collected routinely by planning departments. The Lowery derivative models fall into the latter group and are very popular.

While selecting the model a number of consideration become important. These are:

1. **Simplicity**: the model should have a simple causal structure, which should be easy to comprehend. A simple model will generally consume less of time and resources.
2. **Modest data requirements**: data requirements must be modest; in fact, some of the good models make use of data routinely available with the planning department.
3. **Adaptability**: the model should be adaptable to any given location.
4. **Comprehensiveness**: the model should be comprehensive and should synthesis the relationship between activities, housing and transportation adequately well.
5. **Operationally and rapidity**: the model should be operational, capable of easy interpretation and should be able to test rapidly a wide range of policy options.
6. **Computer cost**: the model should be operational at relatively cheap computer cost.

1. **Lowery Derivative Model**

The Lowery derivative models have many of the above attributes. They are simple to use, require modest data, are comprehensive and economical, have good response to change in input variables and have simple causal structure.

They have therefore been used extensively and successfully in a number of studies.

The fundamental structure of the model is illustrated in Figure (1):
Figure (1): Structure of Lowery Model.

The Lowery model relates the three principle components of the urban area:

1. Population.
2. Employment.
3. Communication between population and employment.
**Model Equation System**

The Lowery model can be represented in terms of nine simultaneous equations and three inequalities; the following notation will be used:

\[ A = \text{Area of land}. \]

\[ E = \text{Employment (number of persons)}. \]

\[ N = \text{Population (number of households)}. \]

\[ T = \text{Index of trip distribution}. \]

\[ Z = \text{Constraints}. \]

The following superscripts are used in conjunction with the above notation:

\[ U = \text{Unusable land}. \]

\[ B = \text{Basic sector}. \]

\[ R = \text{Retail sector}. \]

\[ H = \text{Household sector}. \]

\[ k = \text{Class of establishments within the retail sector (groceries, clinics, primary schools, cloth shop etc.).} \]

\[ m = \text{Number of classes of retail establishment}. \]

\[ k = 1, m \]

\[ n = \text{Number of zones}(i=1,2,\ldots,n) \]

\[ j = 1, 2, \ldots, n) \]
**Land Use**: the total land available in each zone and the land therein not useable by any of the three activities are given. Thus:

\[ A_j = A^U_j + A^B_j + A^R_j + A^H_j \]

**Basic sector**: for each zone, the land by basic establishments \( A^B_j \) and the employment opportunities provided by these establishments \( E^B_j \) are exogenously specified.

**Retail sector**: retail sectors are divided into groups, each having its own characteristics production function. The employment in each of the retail sector can be considered roughly to be a function of the households in the region.

\[ E^k = a^k.N \]

The distribution of this retail employment among the zones depend upon the market at each location. Assuming that the shopping trips originate either from home to from work places, the market potential of any given location can be defined as weighted index of the number of households in the surrounding areas and the number of persons employed nearby. Thus:

\[ E^k_j = b^k \left[ \sum_{i=1}^{n} c^k_i N_i T^k_{ij} + d^k E_j \right] \]

\( c^k, d^k \) are measures of the relative importance of homes and work places as origins for a particular type of shopping.

\( b^k \) is a scale factor which adjust retail employment.

\[ E^k = \sum_{j=1}^{n} E^k_j \]

**Total employment**: the above procedure determines the amount of employment in any zone for each category of retail trade. The sum of these employment figures, plus the quantity of basic employment allocated to the zone is the total employment for the zone. Thus:
\[ E_j = E_j^B \sum_{k=1}^{n} E_j^k \]

**Household Sector:** the region’s population of household is a function of total employment. Thus:

\[ N = f \sum_{i=1}^{n} E_j \]

the population living in any zone j is also a function of the employment opportunities in the different zones and the measure of accessibility from zone j to each of these zones. Thus:

\[ N = f \sum_{i=1}^{n} \frac{E_i}{T_{ij}} \]

The coefficient factor f is a scale factor.

The sum of zone population must equal to the total population of the region:

\[ N = \sum_{i=1}^{n} N_j \]

**Constraints:** in order to limit the dispersion of retail employment, a minimum size constraint \( Z^k \) is imposed, expressed in terms of employment. If the market potential of particular location does not justify an establishment above this minimum size, the customers are sent elsewhere. Thus:

\[ E_j^k \leq Z^k \text{ or else, } E_j^k = 0 \]

In order to prevent the system from generating excessive population densities in locations with high accessibility indices, a maximum density constraints is imposed. The value of this constraint (number of households per unit area of residential space) may vary from zone to zone, as would be the case under zoning ordinances.

\[ N_j \leq Z_j^H \cdot A_j^H \]
And lastly, the amount of land set aside of retail establishments must not exceed the amount available.

\[ A^R_j < A_j - A^U_j - A^P_j \]

This constraint also prevents the assignment of negative value to the residential land.

2. **Hansen’s Accessibility Model**

It is designed to predict the location of population based on the premise that employment is the predominant factor in determining location. He suggested the use of an accessibility index, \( A_{ij} \), where

\[ A_{ij} = \frac{E_j}{(d_{ij})^b} \]

Where

\( A_{ij} \) = accessibility index of zone \( i \) with respect to zone \( j \)

\( E_j \) = total employments

\( d_{ij} \) = distance between \( i \) and \( j \)

\( b \) = an exponent

The overall accessibility index for zone \( i \) is therefore:

\[ A_{ij} = \sum E_j / (d_{ij})^b \]

The amount of vacant land that is suitable and available for residential use is also an additional factor in attracting future population to the zone in question. This is
referred to as holding capacity \((H_i)\). The development potential of a zone \(D_i\) is, therefore,

\[ D_i = A_i H_i \]

And population is distributed to zones on the basis of the relative development potential

\[ A_i H_i / \sum A_i H_i \]

If the total growth factor in population in a future year is \(G_t\), the population allocated to zone \(i\) will be

\[ G_i = G_t \left( A_i H_i / \sum A_i H_i \right) = G_t \left( D_i / \sum D_i \right) \]

3. **Density-Saturation Gradient Method**

This Density-Saturation Gradient (DSG) Method was first used in Chicago Area Transportation Study (CATS), since then, many researchers have elaborated on this basic work.

Three empirical rules are used in this method:

1- The intensity of land use declines as the distance or travel time to the CBD increases.

2- The ratio of the amount of land in use to the amount of available land decreases as distance from the CBD increases.

3- The proportion of land devoted to each type of land use in an area remains stable.

Clark derived the basic equation for expressing this density-distance relationship.

The basic equation:

\[ d_x = d_0 e^{-bx} \]
Where:

\( d_x \) = population density at distance \( x \) from the city center

\( d_0 \) = central density as extrapolated into the CBD of the city

\( b \) = density gradient or slop factor

\( e \) = base of natural logarithms

Clark made another assumption that is not dealt with by the density equation. He assumed that the higher downtown densities and the lower suburban densities will tend to equalize over time in most urban areas. This is supported by the findings of the most recent census, which indicate strong trends of population decline in the CBD and increased population movement toward peripheral and suburban areas. This observation implies that the density-saturation gradient is a function of age or regional location of the city and can be determined experimentally.

Holding capacity is given by the following expression:

\[
HC_i = P_i + V_i d
\]

Where:

\( HC_i \) = holding capacity of zone \( i \)

\( P_i \) = existing residential population of zone

\( V_i \) = vacant, available, and suitable land in zone \( i \)

\( d \) = anticipated average density at which all future residential development will occur

Also, Percentage population saturation of zone \( i \) in a certain year =

\[
\left( \frac{\text{Population of zone } i \text{ in a certain year}}{\text{holding capacity of zone } i} \right) \times 100
\]
The general procedure can be described as follows:

1- Establish the relationship between residential density and the distance from the CBD.

2- Determine the percent population saturation for each zone and aggregate this percentage by ring and sector.

3- Determine the percentage area of useful available land in each zone that has been earmarked for residential use. This percentage, known as the percentage residential saturation, is plotted against distance from the CBD.

4- Obtain the total population for the forecast year for the city. This figure is determined exogenously.

5- Plot a curve representing the residential density, similar to the one plotted under step 2, such that the area under the curve is proportional to the total population obtained in step 4. This is the most critical and subjective.

6- Forecast population totals by analysis rings. These totals are determined by scaling off appropriate ordinate values from the horizon-year curve.

7- Distribute ring totals to individual zones by subjectively weighting each individual zone's attractiveness according to such factors as distance to shopping centers, distance to major street systems or bus lines, residential capacity, nearness to school, and so on.
Urban Demand Transportation Modelling

Four Step Model

Transportation Forecasting is used to estimate the number of travelers or vehicles that will use a given transportation facility in the future.

The conventional approach to transportation forecasting is based on what is commonly known as the:

**Four Step Model**

1. **Trip Generation**
   Estimates the number of trips from given origins and destinations
2. **Trip Distribution**
   Determines the destination for each trip from a given origin
3. **Mode Choice**
   Determines the mode choice for each trip
4. **Trip Assignment**
   Determines the specific route for each trip

**Population & Employment Forecast.**

**Modal Split or mode choice**

**Trip Assignment**

**Link and O-D flows, cost**
Trip Generation

Trip Generation model is used to estimate the number of person-trips that will begin or end in a given traffic analysis zone.

The objective of the trip generation step is to understand the reasons behind the trip making behavior and to produce mathematical relationships to synthesis the trip-making pattern on the basis of observed trips, land-use data and household characteristics.

Since a considerable confusion can occur in the meaning of the various terms used in trip generation, it is desirable to understand the exact meaning of the various terms.

A trip is one way person movement by a mechanized mode of transport, having two trip ends, an origin (the start of trip) and a destination (the end of the trip).

The trips are usually divided into home-based and non-home-based.

Home based trips are those having one end of the trip (either origin or destination) at the home (household) of the persons making the trip, while non-home based trips are those having neither end at home of the person making the trip.

The trip ends are classified into generations and attractions.

A generation (production) is the home end of any trip that has one end at the home (i.e. home based trip).

An attraction is the non-home end of a home-based trip.

Definition of Household: a household is usually a group of persons, who normally live together. Persons in household may be related or unrelated to one another or mix of both.

A group of unrelated persons who live in an institutions is called an institutions household.

Examples: rescue homes, orphanages, hotels, hostels etc.
W: work place.
S: shopping.
R: residential area.
a,b: home based trips.
c,d: non-home based trip.
e,f: home-based trips.
g,h: home-based trips.

A total of 8 trips are involved in this particular case.
4 trips ends are produced at zone 1.
6 trips ends are attracted to zone 2.
2 trips ends are produced at 3 and 4 trips ends are attracted to zone 3.

**Trip Purpose**

Trips are made for different purposes and the classification of trips by purpose is necessary. The following are some of the some important classes of trip purpose:

1. Work trips.
2. Educational Trips.
3. Shopping Trips.
5. Social and recreational, sports.
7. Others.

**Factors Governing Trip Generation and Attraction Rates**

1. Income: Obviously, family income which represents its ability to pay for a journey affects the number of trips generated by a household. A general trend is that the higher the income the higher is the trip generation rate.
2. Car ownership: A car represents easy mobility, and hence a car owning household will generate more trips than a non-car-owing household. By the same reasoning, the more cars there are in the household, the more the number of trips generated. Of course, number of cars owned is itself related to the income of the family, which has been listed earlier as a factor.

3. Family size and composition: the bigger the family, the more trips there are likely to be generated. Apart from the size, the composition of the family itself is important. For instance, if both the husband and wife are employed, the trips generated will be more than when only the husband is employed. If there are many school-going children, the number of school-purpose trips will be large. The age structure of the family also governs the trip rates. Old persons are not expected to generate as many trips as younger ones.

4. Land use characteristics: different land uses produce different trip rates. For example, a residential area with a high density of dwellings can produce more trips than one with a low density of dwellings. On the other hand, low density areas may represent dwellings of the well-off society, which may produce a large number of private car trips. The rateable value of the dwelling and type of dwelling units affect the trip generation rates. The most important assumption made in transportation planning is that the amount of travel is dependent on land use.

5. Distance of the zone from the town center: the distance of the zone from the town center is an important determinant of the amount of travel that people might like to make to the town center. The farther the town center, the less the number of trips are likely to be.

6. Accessibility to public transport system and its efficiency: the accessibility to a public transport system and its efficiency determine to some extent the desire of persons to make trips. An easily accessible and efficient public transport system generates more trips.

7. Employment opportunities, floor space in the industrial and shopping units and offices: the employment potentially of an industrial or shopping unit or an office establishment directly governs the trip attraction rate. Similarly, another factor to which the trip attraction rate can be related is the floor space in the premises of industries, shops and offices.

The most common analytical tool used for trip generation model are:

1. Rates based on activity units: An activity unit can be described by measures such as square feet of floor space number of employees. Trip generation rates for attraction zones can be determined by survey data or from previous studies.
2. Cross classification analysis: it’s based on determining the average value of dependent variable for certain defined categories of the independent variables. A multi-dimensional matrix defines the categories, each dimension in the matrix representing one independent variable. The independent variables themselves are classified into a definite number of discrete class intervals.

3. Regression analysis: its well-known statistical technique for fitting mathematical relationships between dependent and independent variables. In the case of trip generation equation, the dependent variable is the number of trips and the independent variables are the various variable factors that influence trip generation. These independent variable are land use and socioeconomic characteristics which discussed earlier.
Model Split

Modal split is the process of separating person-trips by the mode of travel. It is usually expressed as a fraction, ratio or percentage of the total number of trips. In general, modal split refers to the trips made by private car or public transport (road or rail).

An understanding of modal split is very important in transportation studies. Further transportation pattern can only be accurately forecast if the motivations that guide the traveler in his choice of the transportation modes can be analyzed. Though the factors that govern the individual choice of mode are complex, a study of the same is of great utility.

Person trip ends (attraction or production)

Modal Split Analysis

Factors influencing mode choice of urban travelers:

1. Characteristics of the trip.
2. Household characteristics.
3. Zonal characteristics.
4. Network characteristics.
**Characteristics of trip**

i) **Trip purpose:** the choice of mode is guided to a certain extent by the trip purpose. To give an example, home based school trips have a high rate of usage of public transport. On the other hand, home based shopping journeys can have a higher rate of private car usage, for the simple reason that it is more convenient to shop when travelling in a personalized transport.

ii) **Trip length:** the length can govern an individual’s choice of a particular mode. A measure of the trip length is also possible by the travel time and the cost of travelling.

**Household characteristics**

i) **Income:** the income of a person is a direct determinant of the expenses he is prepared to incur on a journey. Higher income groups are able to purchase and maintain private cars, and thus private car trips are more frequent as the income increase.

ii) **Car ownership:** car ownership is determined by the income and for this reason both income and car ownership are inter-related in their effect on modal choice. In general, families which own a car prefer private car trips, and in contrast families without car patronize public transport in the absence of any other alternative.

iii) **Family size and composition:** the number of persons in the family, the number of school-going children, the number of wage earns, the number of unemployed, the age-sex structure of the family, and some other factors connected with the socio-economic status of the family profoundly influence the modal choice. Some of these factors are responsible for certain captive trips in public transport, such as those due to old age pensioners, school children, crippled and infirm persons and those who do not wish to drive.

**Zonal characteristics**

i) **Residential density:**

**Earlier modal split Models:**

1. **Trip End Type Modal Split Model**

The socioeconomic characteristics of trip makers were defined on zonal basis, in terms of the average number of cars per household in a zone.

The characteristics of the transport system relative to a given zone were defined by an accessibility index calculated from the following equation:
Where:

$acci$: accessibility index for zone $i$.

$a_j$: number of trips attractions in zone $j$.

$f_{ij}$: travel time factor for travel from zone $i$ to zone $j$ for the particular mode being considered.

$n$: number of zones in the urban area.

**Example:**

Two mode by car and public transit

15 travel time by car (min.)
20 travel time by transit (min.)

**Car accessibility index:**

\[
acci = \sum_{i=1}^{n} a_{j} f_{ij}
\]

\[
= \sum_{i=1}^{n} A_{j}(t_{ij})^{-2}
\]

\[
= 200 \times 0.001 + 100 \times 0.0069 + 150 \times 0.0025 + 250 \times 0.0044 + 300 \times 0.0016
\]

\[
= 2.8828
\]

**Public transit accessibility index:**

\[
= 200 \times 0.0006 + 100 \times 0.0025 + 150 \times 0.0016 + 250 \times 0.0025 + 300 \times 0.0011
\]

\[
= 1.5733
\]

**Accessibility ratio** = private mode accessibility index / public transport accessibility index

\[
= 2.8828 / 1.5733 = 1.8322
\]

The transport service provided to a particular zone by private and public transport modes was characterized by the following accessibility ratio 1.8322.
2. Trip –Interchange Modal Split Model

The basic hypothesis underlying the trip –interchange modal split model, developed for MetropolitanToronto Canada is as follows:

- The total number of people moving between an origin and destination pair constitute a travel and the various modes compete for this travel.
- They secure a position in relation to their relative competitiveness, which are expressed in terms of relative travel time, relative travel cost, relative travel service and the economic status of the trip maker.
- The relative travel time by competing modes expressed as Travel Time Ratio (TTR) is given as:
The relative travel cost was defined by the ratio of out-of-pocket travel costs by public transport and car (private transport) as follows:

\[
CR = \frac{i}{(j + k + 0.5l)/m}
\]

where:

i: public transport fare.

j: cost of petrol.

k: cost of oil, lubricants, etc.

l: parking cost at destination, if any.

m: average car occupancy.
The relative travel service was characterized by the ratio of the travel excess travel times by public transport and car. The excess travel time was defined as the time spent outside the vehicle during a trip. Thus, the Service Ratio was defined as follows:

\[
SR = \frac{b + c + d + e}{g + h}
\]

then, using TTR, CR, and SR, modal split curves were developed for work trips.
Disaggregate or Behavioral Mode – Choice Models

The methodology of modeling mode choice by disaggregate approach is based on discrete choice theory or random utility theory of microeconomics.

The concept of utility:

The utility to a given individual traveler offered by a given choice (i.e. making a trip, or of a given destination, mode, or route, combination), may be thought of as measuring the preferences the traveler attaches to that particular choice, or combination of choices.

For instance, the utility of a given mode of transportation for a given trip might be measured by the total bundle of the modes attributes, such as speed, comfort, safety, cost, etc, translated into monetary value to the traveler.

The specific manner in which the various attributes of a given alternatives combine to define the overall, or total utility is specified by the utility function.

The utility (or disutility) function is typically expressed as the linear weighted sum of the independent variables or their transformations, as:

\[ v = a_0 + a_1 x_1 + a_2 x_2 + \cdots + a_r x_r \]

Where:

\( V \): is the utility derived from a choice defined by the magnitude of the attributes \( x \) that are present in that choice and weighted by the modal parameters \( a \) (\( a_0, a_1, a_2, \text{etc.} \)).

In the context of mode choice, \( v \) is the disutility and is negative. This is because typical independent variables include travel times and costs that are perceived as losses.

Early attempts to describe the utility associated with travel modes, calibrated a separate utility function for each mode, as illustrated by the following hypothetical three-mode case:

\[ v_1 = 6.2 + 2.4 x_1 + 3.5 x_2 \]
\[ v_2 = 3.4 + 3.1 x_1 + 2.9 x_2 \]
The three modes in this hypothetical example may be a personal vehicle (say motorized two wheeler), a city bus system and an intermediate public transport IPT system, respectively, and the independent variables or attributes may represent the travel cost and travel time associated with a mode.

This types of formulation is known as mode specific (and, in the general case, choice-specific) model because the same attributes are assigned different weights for the different modes.

Although there may be some validity in this hypothesis, it causes a problem when a new mode is introduced. In that case it would be next to impossible to estimate the utility associated with the new mode because the necessary base year data required for the calibration of its utility function would be unavailable.

As a way to solve the problem, Luncaster postulated the idea of choice-abstract (or attribute-specific) approach.

The choice theory is based on the hypothesis that when making choices, people perceive services indirectly in terms of their attributes, each of which is weighted identically across choices.

The trip makers perceive two distinct modes offering the same cost, level of service, and convenience as being identical. Continuing with the three-mode example, a mode abstract model of modal choice would use a single equation to measure utility.

\[ v_3 = 4.3 + 2.9x_1 + 3.2x_3 \]

Differences in the utilities \( v \) associated with each of the competing modes arise because of differences of the magnitudes of the attributes \( x \) of these modes.

\[ v = 3.1 + 2.8x_1 + 1.2x_3 + 0.9x_3 \]

Though the attribute-specific approach has a strong conceptual foundation, in practical applications, it is not possible to enumerate all the relevant attributes involved in the choice of mode.
The first constant term in equation above is meant to capture the effect of variables that are not explicitly included in the modal. It is unlikely that a given set of competing modes will be identical in these excluded attributes.

Hence, it is reasonable to attempt to capture these unexpressed difference by calibrating alternative specific constants.

This can be done by weighting the explicitly identified attributes equally across modes by utilizing any of the modes in the choice set as the base mode. Thus for equations below:

\[ v_1 = 6.2 + 2.4x_1 + 3.5x_2 \]
\[ v_2 = 3.4 + 3.1x_1 + 2.9x_2 \]
\[ v_3 = 4.3 + 2.9x_1 + 3.2x_3 \]

Instead of having \( a_1=6.2, a_2=3.4, a_3=4.3 \)

The model may be estimated with mode 2 as the base. Then, the alternative-specific coefficients would be \( a_1=2.8, a_2=0, a_3=0.9 \)

The calibrated utility function for the three-mode example may then become,

\[ v_k = a_k + 2.5x_1 + 1.5x_2 + 0.8x_3 \]

where:

\( v_k \) is the utility function of mode k and \( a_k \) is the calibrated mode specific constant for the same mode, which represent the fixed advantages or disadvantages of mode k vis a vis the base mode.

The need to capture the added utility of using transit for travel oriented toward CBD is one example. The effect of this attribute is usually positive for transit trips because of the limited availability and high cost of parking at the CBD destination.

A binary variable taking the value of 0 for non-CBD orientation and 1 for CBD destined trips may be included along with its coefficient in the transit utility equation.

This assumption is clearly unrealistic, as the choice of mode by individuals depends on the relative utility of the mode, as realized by her or him, which depends on the characteristics of the individual and his or her perception of the utility of the chosen mode.
Thus the utility of a given mode is not a fixed quantity but random quantity as it varies between individuals. Hence, the utility that a traveler in zone i receives when choosing alternative j can be written as:

\[ U_{ij} = V_{ij} + \epsilon_{ij} \]

where:

\( V_{ij} \) the average traveler’s utility, given by an utility function,

\( \epsilon_{ij} \) the uncertain or random part of the utility function specific to individual travelers.

The key to the estimation of the probabilities of choice is to make specific assumptions about the probability distribution function of the random term \( \epsilon_{ij} \).

If there are two alternatives ( j = 1,2) facing each individual traveler in a given zone i, then the corresponding random utilities for the two alternatives can be written as follows:

\[ U_1 = V_1 + \epsilon_1 \]
\[ U_2 = V_2 + \epsilon_2 \]

The alternative that would be chosen by the traveler will now depend on the values of \( \epsilon_j (\epsilon_1 and \epsilon_2) \) also.

The variation of the probability of choice of say alternative 2, as a function of the difference in systematic utilities (fixed part of the utility function), which is equal to \( (V_2 - V_1) \) can be represented graphically as shown in the following figure:
A mode choice situation involving two modes (1,2) wherein 40% of travelers make use of mode 1 can be mathematically represented as follows:

\[
p(1) = \frac{40}{100} = \frac{40}{40 + 60} = \frac{U_1}{U_1 + U_2}
\]

If \( m \) modes are involved:

\[
p(j) = \frac{U_j}{\sum_{k=1}^{m} U_k}
\]

\[
p(j) = \frac{e^{v_j}}{\sum_{k=1}^{m} e^{v_k}}
\]  \hspace{1cm} \text{(Logit Model Equation)}

where:

\( p(j) \) is the probability of choice of alternatives

\( m \) is the number of alternative modes including \( j \).
Trip Distribution Analysis

The purpose of the trip distribution analysis is to develop a procedure that synthesizes the trip linkages between traffic zones for both transit captive and choice trip makers.

The distribution of trips between zones can be better illustrated in the form of a matrix.

There are two types of trip distribution matrices:

1. Production- attraction PA matrix.
2. Origin destination OD matrix.

In the PA matrix the rows and columns represent production and attraction zones respectively as shown in Table (1).
Table (1): Production-Attraction Matrix.

<table>
<thead>
<tr>
<th>Production zones</th>
<th>Attraction zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( l )</td>
<td></td>
</tr>
<tr>
<td>( \ldots )</td>
<td></td>
</tr>
<tr>
<td>( i )</td>
<td></td>
</tr>
<tr>
<td>( \ldots )</td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td></td>
</tr>
<tr>
<td>sum</td>
<td></td>
</tr>
</tbody>
</table>

- The cell element \( t_{ij} \) is the number of trips produced at zone \( I \) and attracted to zone \( j \).
- Hence a PA matrix has no directional meaning and its cell element represent trip interchanges.
- The number of production zones generally equals the number of attraction zones, \( n \).
- The row sum, \( p_i \) is the total number of trips produced at zone \( I \) and the column sum \( A_j \) is the total number of trips attracted to zone \( j \).
- The sum of production equals the sum of attractions.

The OD matrix is required for directional traffic assignment. In this matrix, the rows and columns represent the origin and destination zones respectively as shown in Table (2).

Table (2): Origin – Destination Matrix.

<table>
<thead>
<tr>
<th>Origin zones</th>
<th>Destination zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( l )</td>
<td></td>
</tr>
<tr>
<td>( \ldots )</td>
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</tr>
<tr>
<td>( i )</td>
<td></td>
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<tr>
<td>( \ldots )</td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td></td>
</tr>
<tr>
<td>sum</td>
<td></td>
</tr>
</tbody>
</table>
The cell element denoted by \( t_{i-j} \) is the number of trips originating from \( i \) and destined to \( j \). Therefore, an OD matrix has directional meaning and its cell element represents trip flows.

The row sum \( O_i \) is the total number of trips originating from zone \( i \) and the column sum \( D_j \) is the total number of trips destined to zone \( j \).

**Converting a PA matrix into an OD Matrix**

For directional traffic assignment, the PA matrix must be converted to an OD matrix. Consider the trip interchange between zones 1 and 2 shown in the following Figure below:

![Trip Interchange Diagram]

Let the proportion of trips originating from the production zone, denoted by \( \lambda \), be 0.4.

Then, the general formulae for finding the cell elements of an OD matrix, from the cell elements of PA matrix, are:

\[
\begin{align*}
t_{i-j} &= \lambda t_{ij} + (1-\lambda) t_{ji} \\
t_{j-i} &= \lambda t_{ji} + (1-\lambda) t_{ij}
\end{align*}
\]

Conversion of PA matrix into OD matrix (\( \lambda = 0.4 \))
Note that the sum \( t_{ij} \) and \( t_{ji} \) equals the sum \( t_{i-j} \) and \( t_{j-i} \), also, the diagonal elements in both matrices are the same.

In practice the value of \( \lambda \) will be around 0.5 for a 24 hour matrix which will result in a symmetrical OD matrix.

Consider the previous example by taking \( \lambda = 0.5 \)
Basis of Trip Distribution

- The rational of trip distribution is as follows: all trip attracting zone j in the region are in competitions with each other to attract trips produced by each zone i.
- Everything else being equal, more trips will be attracted by zones that have higher levels of attractiveness.
- However, other intervening factors affect the choice of j as well.

Consider for example, the case of two identical shopping centers (i.e. of equal attractiveness) competing for the shopping trips produced by a given zone i.

If the distances between zone i and each of the total centers are different, shoppers riding in zone i will show a preference for the closer of the two identical centers.

Thus, the intervening difficulty of travel between the producing zone i and each of the competing zones j has a definite effect on the choice of attraction zone.

In the shopping center example, distance is cited as a measure of this difficulty of travel, but other measures of this effect be used, such as travel time or some generalized cost that includes travel time, out-of-pocket cost and the like.

The notation $w_{ij}$ is used to denote this generalized cost, which is also known as travel time impedance.

Gravity Model

The gravity model gets its name from the fact that it is conceptually based on Newton’s Law of gravitations, which state that force of attraction between two bodies is directly proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between them, that is:

$$F = K \frac{M_1 M_2}{r^2}$$  \hspace{1cm} (1)

Variations of this formula have been applied to many situations having human interactions.

The application of this concept to trip distribution takes the form,
- Trip productions and attractions of the zones replacing the masses of the bodies and the travel impedance between zones taking the place of \( r \).
- The concept of the impedance term in the denominator, however, does not need to be exactly equal to two but may replace by a model parameter \( c \).
- Equation (2) implies that the interchange volume between a trip producing zone \( i \) and trip attracting zone \( j \) is directly proportional to the magnitude of trip productions of zone \( i \) and the trip attractiveness of zone \( j \) and inversely proportional to a function of impedance \( W_{ij} \) between the two zones.
- Using the usual mathematical modeling terminology, it can be said that the interzonal volume is dependent variable, the productions, attractions and the travel impedance are the independent variables, and the constants \( K \) and \( c \) are the parameters of the model that must be estimated through calibration using data base.
- The parameter \( K \) can be eliminated from equation (2) by applying trip production-balance constraint, which states that the sum over all trip attracting zones \( j \) of the interchange volumes that share \( i \) as the trip producing zone, must equal the total trip productions of zone \( i \) or,

\[
P_i = \sum_{j=1}^{n} T_{ij} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (3)
\]

Substituting the value of \( T_{ij} \) from equ. (2) in equ. (3) we get:

\[
P_i = \sum_{j=1}^{n} \frac{KP_i A_j}{W_{ij}^c} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (4)
\]

\[
P_i = KP_i \sum_{j=1}^{n} \frac{A_j}{W_{ij}^c}
\]

\[
1 = K \sum_{j=1}^{n} \frac{A_j}{W_{ij}^c}
\]

From equ. (4) \( K \) be written as:
The expression of $K$ ensures that the trip balance equation is satisfied.

Substitution of the value of $K$, from equation (5) in equation (2) leads to the classical form of the gravity model.

$$T_{ij} = \left[ \frac{1}{\sum_{j=1}^{n} \frac{A_j}{W_{ij}^c}} \right] P_i A_j \ldots \ldots \ldots \ldots \ldots (6)$$

Writing $F_{ij} = \frac{1}{W_{ij}^c}$

Note: the calibration constant $c$ is now implicit in the friction factor $F_{ij}$

Equation (6) can be written as,

$$T_{ij} = \frac{P_i A_j F_{ij}}{\sum_{j=1}^{n} A_j F_{ij}} \ldots \ldots \ldots \ldots \ldots (7)$$

Gravity model for trip distribution:

$$T_{ij} = \frac{P_i A_j F_{ij}}{\sum_{j=1}^{n} A_j F_{ij}}$$

Finally, a set inter-zonal socioeconomic adjustment factors $K_{ij}$ are introduced during calibration to incorporate the effects that are not captured by the limited number of independent variables included in the model.

Then, the resulting gravity model formula becomes,
The general formulation of the gravity model:

\[ T_{ij} = \frac{P_i F_{ij} K_{ij}}{\sum_{j=1}^{n} A_j F_{ij} K_{ij}} \]  \( \ldots \ldots \ldots \ldots \) (8)

Where:
- \( T_{ij} \): trip produced in zone \( i \) and attracted to zone \( j \) by mode \( m \) in the \( K^{th} \) iteration.
- \( P_i \): empirically derived travel time factor for mode \( m \) which expresses the average area-wide effect of spatial separation on trip interchange between zone \( i \) and zone \( j \).
- \( K \): iteration number,
- \( p \): trip purpose.

**Frater Growth – Factor Method**

This method was introduced by T.J Fratar (1954). According to this method, the total trips of each zone are distributed to the inter-zonal movements, as a first approximation, according to the relative attractiveness of each movement.

Thus, the future trips estimated for any zone, would be distributed to the movements involving that zone, in proportion to the existing trips between it and each other zone and to the expected growth of each zone.

This may be expressed mathematically:

\[ T_{ij} = t_{ij} + \frac{Q_i}{q_i} \times \frac{Q_j}{q_j} \times \frac{\sum_{i=1}^{n} t_{ij}}{\sum_{j=1}^{n} q_j t_{ij}} \]

Where:
Specific Situations under Which Growth Factor may be used

1. Growth factor may be used to estimate trip interchanges involving traffic zones outside the study area (external trips).
2. Applied for short-term forecasting of trip distribution in urban areas, where the zonal growth rates are expected to be more uniform.
Trip Assignment (Route assignment)

Trip or traffic assignment is the last phase of the four-step transportation planning process which concerns with trip maker’s choice of path between pairs of zones by travel mode and with the resulting vehicular flows on the multimodal transportation networks.

- The question of interest, given the estimate of inter-zonal demand by mode, to determine the trip maker’s likely choice of paths between all zones along the network of each mode and predict the resulting flows on the individual links that make up the network of that mode. The number of available paths between any pairs of zones depends on the mode of travel.

- In the case of private transportation modes, a relatively large set of possible paths will be available and also a good deal of freedom in selection between them. On the other hand, typical mass transit modes offer a limited number of path (or choice).

- Three preliminary questions must be dealt with prior to the performance of network assignment:

  1. The first is related to the difference between intra-zonal person-trips and intra-zonal vehicle trips.
  2. The second is related to the difference between daily trips (i.e. the estimate of the 24-hr demand versus the diurnal (time of the day) distribution of this demand.
  3. The third is concerned with the direction of travel of the trip to be assigned on the transportation network.

Person – Trip and vehicle Trip

- The forecast of the person – trip and vehicle – trip flows that are expected to use the transportation system are both relevant to the assessment of its performance.
- The estimate of person-trips that desire to use a highway, for example, provides an indication of the passenger throughput that will be accommodate.
- On the other hand, the LOS that the trip makers experience when traveling on a highway is related to the vehicular flow (e.g., veh/hr) that desires to use the highway.
- For this reason the estimated inter-zonal person-trips must be translated into vehicular trip to perform the highway trip assignment.
- Mass transit (or transit assignment) must address another issue as well, it consists of fixed facilities that constitute the modal network and the scheduling of the transit service.

- This means that analysis of a particular transit alternative must address the question of whether a proposed fleet size and operating schedule and the relating flow provide sufficient capacity to meet the anticipated inter-zonal person-trip demand.

**Diurnal (Time of day)**

- The road—network flows that are used to calculate the prevailing level of service are expressed in veh/hr or pcu/hr.

- On the other hand, the estimates of inter-zonal flows that are obtained by the trip-generation distribution, mode choice sequence are often based on 24 hr period.

- But the demand for transportation exhibits a highly peaked pattern with sharp peak period in the morning and generally longer but less pronounced peak period in the evening. It is appropriate to investigate the performance of the transportation system under peak demand conditions when capacity limitation become critical.

- The time variation of demand is most relevant to mass transit planning because scheduling of service is typically tailored to the variation of demand over 24 hr period.

- The diurnal distribution of demand may be estimated through the use of factors taken from observation during base year.

**Trip Direction**

It is desirable that the assignment of trips (especially by the time of day) retains the direction of these trips. The predominant direction of travel during the morning peak period is toward major activity centers (i.e. CBD, schools, etc.) and the reverse is true during the evening peak period.

**Route Choice Behavior**

The key to assigning users on the network is the underlying behavior assumption of route choice, in 1952 Wardrop established two principles of route choices:

1. According to the first principle, users choose the route that minimize their own travel time. (shortest path) (user equilibrium).
2. Users distribute themselves on the network in such way that the average travel time for all users is equal. (system equilibrium, total cost of using the system is minimized), (fuel consumption)

3. Stochastic equilibrium: each user assign himself /herself on path that he or she think is the shortest.

**Route Assignment Technique**

1) **All–or–nothing assignment**

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Find the shortest route between the TAZs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>Assign all trips to links comprising the shortest route</td>
</tr>
<tr>
<td>Step 3</td>
<td>Continue until trips between all TAZs pairs have been assigned</td>
</tr>
</tbody>
</table>

This is simple, inexpensive and fast method, with absence of capacity and congestion effects.

2) **Multipath Assignment:**

In essence, the all–or- nothing assignment assumes that all trips- maker’s traveling between a specific pair of zones actually select the same path. In reality, however, interchange volumes are divided among a number of paths.

Algorithms that are capable of determining several paths between each pair of zones in order of increasing impedance are available. Irwin and Von Cube formula:

\[ p(r) = \frac{W_{ijr}^{-1}}{\sum x W_{ijx}^{-1}} \]

Where:

\( W_{ijr}^{-1} \): is the impedance of route r from i to j.
3) **Use of Multinomial Logit Model**

Use of multinomial model based on path impedances is:

\[ p(j) = \frac{e^{\beta v_j}}{\sum_{k=1}^{m} e^{\beta v_k}} \]

Where:
- \( P(j) \): probability of choice of alternative j.
- \( \beta \): is the parameter to be estimated.
- \( m \): number of alternative modes including j.

4) **Capacity – Restrained Traffic Assignment**

As the road traffic flow increased toward capacity, the average stream speed decreases from the free flow speed to the speed at maximum flow. Beyond this point the internal friction between vehicles in the stream becomes sever, (LOS E and F).

As a result, the minimum paths computed prior to trip assignment may not be the minimum paths after the trips are assigned. Several iterative assignment address the convergence between the link impedance assumed prior to assignment and the link impedance that are implied by the resulting link volume. (these known capacity-restrained technique).

The relationship between link flow and link impedance is described as the link – capacity function: (BPR Bureau public road):

\[ W = \bar{W} \left[ 1 + \alpha \left( \frac{q}{q_{max}} \right)^\beta \right] \]

Where:
- \( W \): impedance of a given link.
- \( \bar{W} \): free flow impedance of the link.
- \( q \): flow of the link.
- \( q_{max} \): link capacity.
Economic Evaluation of Transportation plans

Need for Economic Evaluation

For a given a given set of goals and polices, it is possible to formulate a number of alternative plans. The cost of these plans may vary, and so also the benefits that are likely to accrue from among them.

What is the criterion for selecting a particular plan from among the alternatives?

Are there any accepted principles and procedures to achieve a desired purpose?

Economic analysis has been found for application in problems concerned with the evaluation of transport plans. In fact, most of the countries now follow economic evaluation before any development plan is taken up for implementation.

Cost and Benefits of Transport Project

The basic principle behind any method of economic evaluation is to measure the costs of the project, determine benefits that are likely to accrue and compare the two.

Cost

- Capital cost of initial construction.
- Costs of delays to vehicles during the period of construction.
- Maintenance cost.

Benefits

- benefits to the existing traffic by way of reduce operating costs, savings in travel time and reduction in accidents.
- benefits to the generated traffic.
- benefits to traffic diverted from other routes.
- benefits to the traffic operating of other roads and railways.

Time horizon in economic assessment

An economic assessment is usually carried out for specific time horizon. For road schemes, the evaluation period commonly selected is 20 to 30 years.
Methods of Economic Evaluation

Discounting Cash Flow

1. Net present Value Method

Net present value method is based on the discounted technique. In this method, the costs/benefits associated with the project over an extended period of the time is calculated and is discounted at selected discount rate to give the present value.

Benefits are treated as positive and costs as negative and the net present value is fund.

The net present worth value is algebraically expressed as:

\[ NPW = \sum_{n=1}^{N} \frac{R_n}{(1+i)^n} + \frac{S}{(1+i)^n} - \sum_{n=0}^{N} \frac{M_n + O_n + U_n}{(1+i)^n} - C_0 \]

Where:

- \( C_0 \): initial construction cost.
- \( n \): specific year.
- \( M_n \): maintenance cost in year n.
- \( O_n \): operating cost in year n.
- \( U_n \): user cost in year n.
- \( S \): salvage value.
- \( R_n \): revenues in year n.
- \( N \): service life, years.

2. Benefit Cost Ratio Method

The benefit –cost ratio method is one of the widely used for evaluation of highway projects and the basis of AASHTO road users analysis.

In this method, the ratio of the annual benefits to the net annual costs is determined.

\[ \frac{\text{Benefits in the reference year}}{\text{annual costs}} = \frac{\text{(Road user cost for the existing road } - \text{ road user cost for the improved road )in}}{\text{the reference year}} \]

\[ = \frac{\text{equivalent annual highway costs for the improved road } - \text{equivalent annual highway}}{\text{costs for the existing road}} \]
The numerator of the B/C ratio represents the benefits, which are really the reduction in user costs. The denominator represents the difference in annual highway costs between the new facility and the existing facility, including maintenance. A ratio greater than 1.0 indicates that the extra cost involved in the improvement is less than the benefits that are likely to accrue and the project is economically justified.

3. **The internal Rate of return**

Determines the interest rate at which the PW of reductions in user and operation costs equal the PW of increases in facility costs. If the internal rate of return exceeds the internal rate, the higher cost project is retained. If the internal rate of return is less than the interest rate, the higher period project is eliminated.
Sustainable Transportation

Definition of Sustainable Transportation

**Sustainable transportation** – Transportation that promotes sustainable development.

**Sustainable development** – Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

**Sustainability** – A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of natural, economic and social resources.

Sustainable transport is about finding ways to move people, goods and information in ways that reduce its impact on the environment, economy and society.
Some options include:

(1) using transport modes that use energy more efficiently, such as walking or cycling, and public transport;

(2) improving transport choice by increasing the quality of public transport, cycling and walking facilities, services and environments;

(3) improving the efficiency of our car use, such as using more fuel efficient vehicles, driving more efficiently;

(4) using cleaner fuels and technologies;

(5) using telecommunications to reduce or replace physical travel, such as teleworking or telex-shopping;

(6) planning the layout of cities to bring people and their needs closer together, and to make cities more vibrant and walkable; and

(7) developing policies that allow and promote these options.

Environmentally sustainable transportation is transportation that does not endanger public health and that meets needs for access consistent with:

Sustainable transport is not just about encouraging people to use public transport. It is about reducing carbon emissions on all transport modes across the entire transport system and designing the transport system and our cities so there is less need to travel.

The climate change is one of the greatest environmental, economic and social challenges of our time.

The way we travel has a major impact on our environment - most of our air pollution and about 16.5 per cent of our greenhouse gas emissions come from transport.

A sustainable urban transport and land use system:

(1) Provides access to goods and services in an efficient way for all inhabitants in the urban area;

(2) protects the environment, cultural heritage and ecosystems for the present generation, and

(3) does not endanger opportunities of future generations to reach at least
the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.
Transit Concept Introduction

Transit Characteristics

Several characteristics differentiate transit from the automobile in terms of availability and capacity. Although the automobile has widespread access to roadway facilities, transit service is available only in certain locations during certain times.

Roadway capacity is available 24 hr/day once constructed, but transit capacity is limited by the number of transit vehicles operated at a given time. Transit passengers rely on other modes to gain access to transit. Transit use is greatest where population densities are highest and pedestrian access is good. A typical transit user does not have transit service available at the door and must walk, bike or derive to a transit stop and then must walk or bike from transit discharge point to the destination, transit is not an option.

Transit goals is to move large numbers of people rather than large numbers of vehicles. transit modes include buses, streetcars, and light rail. Streetcars can share a lane with other traffic; light rail trains are almost always separated from other traffic, even when running on street. light rail provides higher speeds and somewhat higher capacity than streetcars.

General Transit Capacity Concept

Vehicle capacity: reflects the number of transit units (buses or trains) that can be served by a loading area, transit stop, or route during a specified period of time.

Transit vehicle is commonly determined for three locations:

- loading areas

- berths

- bus lanes and transit routes

Each location directly influences the next. the vehicle capacity of a bus atop or rail station is controlled by the vehicle capacities of the loading areas, and the vehicle capacity of a bus lane or transit route is controlled by the vehicle capacity of the critical stops along the lane or more.

The two greatest influences on loading area vehicle capacity are the dwell time and the ratio of the green time to the cycle length (g/c ratio) for the street on which the transit operates. Dwell time and g/c ratio also have major influences on the vehicle capacity of transit stops and routes. Dwell time (the time required to serve passengers at the busiest door plus the
time required to open and close the doors) has the greater influence on loading area vehicle capacity. The amount of green time provided to a street controls the number of transit vehicles that theoretically can arrive at a loading area during an hour. In addition, the length of red in relation to a vehicle’s dwell time also affects vehicle capacity: if passenger movement have finished, but the vehicle must wait for a traffic signal to run green, vehicle capacity will be less than if the vehicle can leave immediately, so that another vehicle can use the loading area.

**Person capacity:** reflects the number of people that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction and with reasonable certainty.

Person capacity typically is calculated for transit stops and stations and for the maximum load point of a transit route or bus lane; its calculated for three locations:

- Transit stops and stations
- Transit routes at their maximum load point.
- Bus lanes at their maximum load points.

**Operator Policy:** A transit operator directly controls the maximum passenger load allowed on transit vehicles and the service frequency. An operator with a policy requiring all passengers to be seated will have a lower potential person capacity for a given number of vehicles than an operator with a policy allowing standees. However, passengers experience a higher quality of service with the first operator.

The service frequency determines how many passengers actually can be carried, even though a transit stop, transit route, or bus lane can serve more vehicles than actually are scheduled.

**Passenger Demand Characteristics**

How passenger demand is distributed spatially along a route and how it is distributed over time during the analysis period affects the number of boarding passengers that can be carried. Because of the spatial aspect of passenger demand, person capacity must be stated for a location (typically the maximum load point), not for a route or a street as a whole.

Passenger demand fluctuates during the peak hour. the peak-hour factor (PHF) reflects peak demand volumes typically over a 15-min. period during the hour. A transit system should provide sufficient capacity to accommodate peak passenger demand.
However, since peak demand is not sustained over the entire hour, and since every transit vehicle will not experience the same peak loadings, actual person capacity during the hour will not less than the peak 15 min. demand volumes.

The average passengers trip length affects how many passengers can board a transit vehicle as it travels its route. If trips tend to be long with passengers boarding near the start of the route and alighting near the end, vehicles will not board as many passengers as when passengers board and alight at many locations. However, the total number of passengers onboard at the maximum load points may similar for each route.

The distribution of boarding passengers among transit stops affects the dwell time of vehicles at each stop. If passenger boarding’s are concentrated at each stop, the vehicle capacity of a transit route or bus lane will be lower, since the dwell time at the stop will control the vehicle capacity (and, in turn, the person capacity) of the entire route or lane. Vehicle capacity (and person capacity at the maximum load point) is greater when passenger boarding volumes (and dwell times) are evenly distributed among stops. The relationship between vehicle capacity of transit facilities and the elements of person capacity is illustrated in Figure below;

**Dwell Time**

There are six main influences on dwell time. Two relate to passenger demand and the others relate to passenger service time:

1. Passenger demand and loading: the number of people boarding and alighting through the highest -volume door determines how long it will take to serve all passengers. If standees are present on a transit vehicle as it arrives at a stop, or if all seats are filled as passengers board, service times will be higher than normal because of congestion in the vehicle.

2. Stop and station spacing: the fewer the stops along a route, the greater the number of passengers boarding at each stop. A balance must be found between few stops and too many. Too few stops increase both the distance riders must walk to gain access to transit and the amount of time a vehicle occupies a loading area. Too many stops reduce overall travel speeds due to the time lost in accelerating and decelerating as well as waiting at traffic signals because stops were made.

3. Fare payment procedures: the amount of time passengers spend paying fares is a major factor in the total time for passenger boarding. This time can reduced by minimizing the number of bills and coins required to pay a fare; encouraging the use of prepaid tickets, tokens, passes or smart cards; using a proof-of-payment fare collection system; or collecting
fares before boarding. Besides eliminating the time required for each passenger to pay a fare onboard, proof-of-payment and paid-fare waiting area collection systems allow an even distribution of boarding passengers among the vehicle doors, rather than concentrating them at a single door.

4. Vehicle types: low-floors buses decrease passenger service time by eliminating the need to ascend and descend steps. This particularly applies to routes frequently used by the elderly, persons with facilities, or persons with strollers or bulky carry-on items. Wide doors also allow more passengers to board and alight simultaneously.

5. On-Board circulation: Encouraging people to exit via the rear doors of buses with more than one door decrease passenger congestion at the front door and reduces passenger service times.

6. Wheelchair and bicycle boarding: Dwell time also can be affected by the time to board and disembark passengers in wheelchairs and for bicyclists to load and unload bicycles onto a bus-mounted bicycle rack.