Module -1

Urban transport planning: Urbanization, urban class groups, transportation problems and identification, impacts of transportation, urban transport system planning process, modeling techniques in planning. Urban mass transportation systems: urban transit problems, travel demand, types of transit systems, public private, para-transit transport, mass and rapid transit systems, BRTS and Metro rails, capacity, merits and comparison of systems, coordination, types of coordination.

Scope of Urban Transport Planning: Transport planning is a science that seeks to study the problems that arise in proving transportation facilities in an urban, regional or national setting and to prepare a systematic basis for planning.

- Since the developed countries where this science has evolved are mainly urban-oriented the emphasis is more on urban transport planning.
- The principles of urban transport planning can be applied to regional or national transport planning as well with due changes.
- Town and country planning is a science that deals with the study of the urban or country “system” covering the interacting activities using adopted spaces linked by communications through channels.
- Transport planning is an important part of overall town and country planning, since it deals with the transport network which is an important channel of a communications.

Through motor vehicles have revolutionised our life and brought comfort, pleasure and convenience, they have created problems of congestion, lack of safety and degeneration of the environment

1. Urbanization

Urbanization is a process whereby populations move from rural to urban area, enabling cities and towns to grow. It can also be termed as the progressive increase of the number of people living in towns and cities. It is highly influenced by the notion that cities and towns have achieved better economic, political, and social mileages compared to the rural areas.

Majority of people move to cities and towns because they view rural areas as places with hardship and backward/primitive lifestyle. Therefore, as populations move to more developed areas (towns and cities) the immediate outcome is urbanization. This normally contributes to the development of land for use in commercial properties, social and economic support institutions,
transportation, and residential buildings. Eventually, these activities raise several urbanization issues.

**Causes of Urbanization**

1. **Industrialization**

Industrialization is a trend representing a shift from the old agricultural economics to novel non-agricultural economy, which creates a modernized society. Through industrial revolution, more people have been attracted to move from rural to urban areas on the account of improved employment opportunities. Industrialization has increased employment opportunities by giving people the chance to work in modern sectors in job categories that aids to stir economic developments.

2. **Commercialization**

Commerce and trade play a major role in urbanization. The distribution of goods and services and commercial transactions in the modern era has developed modern marketing institutions and exchange methods that have tremendously given rise to the growth of towns and cities. Commercialization and trade comes with the general perception that the towns and cities offer better commercial opportunities and returns compared to the rural areas.

3. **Social benefits and services**

There are numerous social benefits attributed to life in the cities and towns. Examples include better educational facilities, better living standards, better sanitation and housing, better health care, better recreation facilities, and better social life in general. On this account, more and more people are prompted to migrate into cities and towns to obtain the wide variety of social benefits and services which are unavailable in the rural areas.

4. **Employment opportunities**

In cities and towns, there are ample job opportunities that continually draw people from the rural areas to seek better livelihood. Therefore, the majority of people frequently migrate into urban areas to access well paying jobs as urban areas have countless employment opportunities in all developmental sectors such as public health, education, transport, sports and recreation, industries, and business enterprises. Services and industries generate and increase higher value-added jobs, and this leads to more employment opportunities.
5. Modernization and changes in the mode of living

Modernization plays a very important role in the process of urbanization. As urban areas become more technology savvy together with highly sophisticated communication, infrastructure, medical facilities, dressing code, enlightenment, liberalization, and other social amenities availability, people believe they can lead a happy life in cities. In urban areas, people also embrace changes in the modes of living namely residential habits, attitudes, dressing, food, and beliefs. As a result, people migrate to cities and the cities grow by absorbing the growing number of people day after day.

6. Rural urban transformation

As localities become more fruitful and prosperous due to the discovery of minerals, resource exploitation, or agricultural activities, cities start emerging as the rural areas transform to urbanism. The increase in productivity leads to economic growth and higher value-added employment opportunities.

This brings about the need to develop better infrastructure, better education institutions, better health facilities, better transportation networks, establishment of banking institutions, better governance, and better housing. As this takes place, rural communities start to adopt the urban culture and ultimately become urban centers that continue to grow as more people move to such locations in search of a better life.

2. Effects of Urbanization

1. Positive effects of urbanization

Urbanization yields several positive effects if it happens within the appropriate limits. Some of the positive implications of urbanization therefore include creation of employment opportunities, technological and infrastructural advancements, improved transportation and communication, quality educational and medical facilities, and improved standards of living. However, extensive urbanization mostly results in adverse effects. Below listed points are few of them.

2. Housing problems

Urbanization attracts people to cities and towns which lead to high population increase. With the increase in the number of people living in urban centers, there is continued scarcity of houses. This is due to insufficient expansion space for housing and public utilities, poverty, unemployment, and costly building materials which can only be afforded by few individuals.
3. Overcrowding

Overcrowding is a situation whereby a huge number of people live in a small space. This form of congestion in urban areas is consistent because of overpopulation and it is an aspect that increases day by day as more people and immigrants move into cities and towns in search of better life. Most people from rural or undeveloped areas always have the urge of migrating into the city that normally leads to congestion of people within a small area.

4. Unemployment

The problem of joblessness is highest in urban areas and it is even higher among the educated people. It is estimated that more than half of unemployed youths around the globe live in metropolitan cities. And, as much as income in urban areas is high, the costs of living make the incomes to seem horribly low. The increasing relocation of people from rural or developing areas to urban areas is the leading cause of urban unemployment.

5. Development of slums

The cost of living in urban areas is very high. When this is combined with random and unexpected growth as well as unemployment, there is the spread of unlawful resident settlements represented by slums and squatters. The growth of slums and squatters in urban areas is even further exacerbated by fast-paced industrialization, lack of developed land for housing, large influx of rural immigrants to the cities in search of better life, and the elevated prices of land beyond the reach of the urban poor.

6. Water and sanitation problems

Because of overpopulation and rapid population increase in most urban centers, it is common to find there are inadequate sewage facilities. Municipalities and local governments are faced with serious resource crisis in the management of sewage facilities. As a result, sanitation becomes poor and sewages flow chaotically, and they are drained into neighboring streams, rivers, lakes, or seas. Eventually, communicable diseases such as typhoid, dysentery, plague, and diarrhea spread very fast leading to suffering and even deaths. Overcrowding also highly contributes to water scarcity as supply falls short of demand.
7. Poor health and spread of diseases

The social, economic and living conditions in congested urban areas affects access and utilization of public health care services. Slum areas in particular experience poor sanitation and insufficient water supply which generally make slum populations susceptible to communicable diseases. The environmental problems such as urban pollution also cause many health problems namely allergies, asthma, infertility, food poisoning, cancer and even premature deaths.

8. Traffic congestion

When more people move to towns and cities, one of the major challenges posed is in the transport system. More people means increased number of vehicles which leads to traffic congestion and vehicular pollution. Many people in urban areas drive to work and this creates a severe traffic problem, especially during the rush hours. Also as the cities grow in dimension, people will move to shop and access other social needs/wants which often cause traffic congestion and blockage.

9. Urban crime

Issues of lack of resources, overcrowding, unemployment, poverty, and lack of social services and education habitually leads to many social problems including violence, drug abuse, and crime. Most of the crimes such as murder, rape, kidnapping, riots, assault, theft, robbery, and hijacking are reported to be more prominent in the urban vicinities. Besides, poverty related crimes are the highest in fast-growing urban regions. These acts of urban crime normally upset the peace and tranquility of cities/towns.
3. **URBAN CLASS GROUP**

According to the Census definition of India, an urban area consists of (Census of India, 2011).

1) All Statutory Towns: All places with a Municipality, Corporation, Cantonment Board or Notified Town Area Committee, etc. so declared by State law; and

2) Census Towns: which places and satisfy following criteria:
   - a minimum population of 5000;
   - at least 75% of male working population engaged in non agricultural pursuits;
   - and a density of population of at least 400 persons per sq km.

Furthermore, Population Census in India classifies urban settlement into six size classes as per the limits indicated below (Kundu, 2001):

- Population Size Category 100,000 and more Class I
- 50,000 to 100,000 Class II
- 20,000 to 50,000 Class III
- 10,000 to 20,000 Class IV
- 5,000 to 10,000 Class V
- Less than 5,000 class VI

4. **COMMON TYPES OF URBAN LAND USES**

Urban land uses classified as:

1. Residential.
2. Commercial. ex. Shopping centers
3. Industrial.
4. Institutional. ex. Educational, governmental
5. Recreational.
6. Agricultural.
5. URBAN TRANSPORT PROBLEMS

1. Road congestion

As populations increase, the average travel distances as well as intensity are expected to increase as there is a direct correlation between the two indicators (See Figure 3). Average trips lengths for metro cities including Bengaluru are over 8 km, while it is 6 km or less for all other metro cities. This trend in trip length and frequency is only expected to increase with increasing income levels, migration, participation of women and a service-oriented economy. As more people travel over longer distances on regular basis for employment and education purposes, will inevitably lead to road congestion.

2. Parking problems

The acute shortage of parking spaces both on and off the streets in Indian cities increases the time spent searching for a parking spot and induces traffic congestion. Available data shows that a high proportion of Indian streets are faced with on-street parking issue. This problem is especially acute in smaller, compact Indian cities. On-street parking is perversely incentivized because it is either free or priced lower than off-street parking. Even if cities invest in multilevel car parks in prime areas, the parking rates are not expected to recover the costs.

3. Air pollution

The severity of air pollution in Indian cities is judged based on CPCB’s (Central Pollution Control Board) air quality classification. According to available air quality data of 180 Indian cities, there is a wide variation in the pollution concentration and severity across cities. Cities are considered critically polluted if the levels of criteria pollutants are more than 1.5 times the standard. Results show that half of the residential areas in cities monitored by CPCB are at critical levels of air pollution. The danger is especially pronounced when diesel vehicles are operating, as diesel emissions are known to trigger adverse respiratory health effects.

Metro cities that have initiated pollution control action have witnessed either stabilization or dip in the pollution levels, however, in other cities, the situation has been observed to be getting worse. Toxic air and its effects on health are seriously compromising the ‘livability’ of Indian cities.

4. Deteriorating road safety

The high dependence of migrants on non-motorised transport modes such as walking and cycling causes traffic mix in common roads where fast-moving motorised traffic shares the roads with slow-moving modes leading to an increasing number of fatalities and road accidents. In
most Indian cities, non-motorised modes like cycling and walking presently share the same right of way as cars and two-wheelers leading to unsafe conditions for all.

The number of fatalities is also increasing in relation to the increasing motorisation and higher slow-moving vehicles in the traffic stream. While progress has been made towards protecting people in cars, the needs of vulnerable groups of road users, primarily cyclists and pedestrians, are not being met. Pedestrian fatalities constitute a significant share of total fatalities and the magnitude is in fact much higher in cities that lack adequate pedestrian facilities. The percentage of streets with pedestrian pathways is hardly 30 per cent in most Indian cities. The main reason behind this is inequitable distribution of road space and the fact that streets in India are not designed with the intention of accommodating all the functions of a street. Furthermore, only a part of the right of way is developed leading to un-organised and unregulated traffic, which is unsafe for pedestrians and cyclists.

6. BASIC ELEMENTS OF TRANSPORTATION PLANNING
- **Situation definition:** Inventory transportation facilities, Measure travel patterns, Review prior studies.
- **Problem definition:** Define objectives (e.g., Reduce travel time), Establish criteria (e.g., Average delay time), Define constraints, Establish design standards
- **Search for solutions:** Consider options (e.g., locations and types, structure needs, environmental considerations)
- **Analysis of performance:** For each option, determine cost, traffic flow, impacts
- **Evaluation of alternatives:** Determine values for the criteria set for evaluation (e.g., benefits vs. cost, cost-effectiveness, etc)
- **Choice of project:** Consider factors involved (e.g., goal attainability, political judgment, environmental impact, etc.
- **Specification and construction:** Once an alternative is chosen, design necessary elements of the facility and create construction plans
7. **URBAN MASS TRANSPORTATION SYSTEMS**

“Mass Transit, also referred to as public transit, is a passenger transportation service, usually local in scope that is available to any person who pays a prescribed fare “

Mass Transit System is designed to move large numbers of people at one time.

7.1 **NEED FOR MASS TRANSIT SYSTEM**

- Generates low travel times and travel costs for people and goods
- Permits equal access to urban life opportunities (social services, education, Health, recreation)
- Provides adequate support to desired form, size, and density of the city-region
- contributes to the improvement of air quality and urban environment

**Classification of mass transit system**

The classification of modes can be done for transit are based on three characteristics

i. Right of way
ii. Technology
iii. Type of service

### i. **RIGHT OF WAY**

Right of way is the strip of land on which the transit vehicle operates. There three basic right of way categories, distinguished by three degree separation from other traffic.

a. **Category A**: “grade separated or exclusive” It is a fully controlled right of way without grade crossing or any legal access by other vehicles. In some way it resembles a free way system.

b. **Category B**: Includes right of way types that are longitudinally physically separated from other traffic, but with grade crossing for vehicles and pedestrians, including regular intersections. A light rail transit system that crosses a few streets at the surface falls into this category.
c. **Category C**: surface streets with mixed traffic. Most bus system and streetcar system fall into this category.

### ii. TECHNOLOGY

The technology of transit concerned with the mechanical features of the vehicle and riding surface there are at least four important characteristics of transit modes

- a. The support between the vehicle and riding surface – rubber tires on bituminous roads, steel tires on steel rails.
- b. The steering or guidance of vehicle.
- c. The method of propulsion
- d. The means of regulating or controlling the vehicles longitudinally

### iii. TYPE OF SERVICE

Type of service can be classified into three groups by the types of routes and trips served

- a. Short haul is low speed service within small areas with high travel density, such as central business districts
- b. City transit, which is the most common type, serves people needing transport in the city.
- c. Regional transit serves long trips, makes few stops, and generally has high speeds. Rapid rail and express bus system fall into this category.

### 8. TYPES OF TRANSIT SYSTEMS

1. **Heavy Rail Transit (HRT)**

   - Trains of high performance, electrically powered rail cars operating in exclusive rights-of-way
   - Metro is the most common international term for Heavy Rail Transit.
   - Maximum service speeds range from 50 to 70 kmph
   - Conventional two rail "railroad" tracks, plus a slightly raised third rail
   - Full grade separation ensures safety

2. **Automated Guide Way Transit**

   Guided transit mode with fully automated operation
   The Automated Guide way Transit would include
   - a. Personal Rapid Transit (PRT)
2-6 passengers per vehicle  
- Maximum Speed of +/- 30 mph  
- Short trips - local circulators/shuttles  
- Lighter passenger loads.

b. People Movers

- 30-100 Passengers/Vehicle,  
- +/-30 mph maximum speed,  
- Short trips - local circulators/shuttles, medium passenger loads.

c. Advanced Rapid Transit (ART)

- 75-135 P/V, +/-  
- 50 mph maximum operating speed,  
- 4-6 cars per train,  
- medium trips - regional trunk routes,  
- heavier passenger loads

3. Monorail

These are guided transit mode with vehicles riding on or suspended from a single rail, beam, or tube.

- Vehicles may employ steel wheel or rubber tire support. Supported or suspended  
- Won’t run on a single rail, runs on the surface of a rather large beam, or inside an enclosed box structure.  
- Grade separated guide ways to accommodate rubber-tire mono-beams  
- Trains are articulated, 4-car units about 42 m long by 2.6 m wide, with about 60 seats. Seat & standing capacity of 215 passengers  
- Ultimate capacity of 20,000 PHPD passengers

4. Light Rail Transit

Commonly referred as “streetcars” or “trolleys.”

- Most systems are powered by overhead electric wires  
- Run on either exclusive or shared rights-of-way with or without grade crossings, or occasionally in mixed traffic lanes on city streets.  
- Tracks can be laid in any of three generic right-of-way (ROW) categories  
- Cars are typically articulated, about 28 m long by 2.65 m wide, with about 75 seats  
- Trains vary from 2-4 cars, with a 4-car train capable of carrying about 300 seated passengers, and a total of up to 750 passengers.
5. **Commuter Rail / Regional Rail**

- Commuter Rail is a mode of transportation that is based on operating passenger trains on the tracks of the general railroad system, which is shared with freight trains.
- The Commuter rail can carry about 75,000 passengers per hour per direction.

6. **BRT Buses**

- By use of exclusive or reserved rights-of-way (bus ways) that permit higher speeds and avoidance of delays from general traffic flows.
- Include reverse lane operation on limited access roadways, and/or prioritization of at grade bus movements through signalized intersections.
- A standard BRTS bus can carry 5000 pphpd and with an overtaking lane, this number could reach 8000.

**BRIEF DESCRIPTION OF VARIOUS TRANSIT MODES**

1. Taxis: automobiles operated by a drives and hired by users for individual trips, tailored entirely to the user’s desire
2. Dial a ride or dial a bus: minibuses or vans directed from a central dispatching office. Passengers call the office and give their origin, destination and desired time of travel. The office plans the bus routing to maximize the number of passengers on a single trip.
3. Jitneys: privately owned automobiles or vans that operate generally on a fixed route, but many deviate in some cases, without fixed schedules.
4. Subscription buses: buses with paid drivers, operating between, say, a residential neighborhood and a particular employment area, involving some route deviation for minor collection and distribution patterns at either end of the trip.
5. Carpools: prearranged ride-sharing services where parties of two or more people travel together in a car on a regular basis. It is private transport and therefore cannot be organized, scheduled, or regulated by an agency, but it can be encouraged by employers.
6. Vanpools: privately or publicly provided vans transporting groups of persons to and from work on a daily basis.
7. Regular buses: buses operating along fixed routes on fixed schedule
8. Express buses: buses that
COMPARISON BETWEEN TRANSIT SYSTEMS

<table>
<thead>
<tr>
<th>Mode</th>
<th>Used as</th>
<th>Grade separation</th>
<th>Curves Negotiability</th>
<th>Gradient Negotiability</th>
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</thead>
<tbody>
<tr>
<td>METRO RAIL</td>
<td>Intra-city</td>
<td>Grade separated</td>
<td>300m</td>
<td>3%</td>
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<tr>
<td>COMMUTER RAIL</td>
<td>Suburbs</td>
<td>At-grade</td>
<td>300m</td>
<td>1-2%</td>
</tr>
<tr>
<td>LIGHT RAIL</td>
<td>Intra-city</td>
<td>At-grade or Grade separated</td>
<td>25m</td>
<td>3%</td>
</tr>
<tr>
<td>BUS RAPID</td>
<td>Intra-city</td>
<td>At-grade generally</td>
<td>Road bends</td>
<td>3%</td>
</tr>
<tr>
<td>MONORAIL</td>
<td>Intra-city</td>
<td>Grade separated</td>
<td>70m</td>
<td>6%</td>
</tr>
</tbody>
</table>

- BRT, LRT and Monorail can go around sharp road bends and hence reduce the need for property acquisition.
- Additionally, Monorail can negotiate steep gradients, thus reducing the need for long ramps.
- Between these 3 modes, Monorail is elevated while BRT and LRT can be at grade or elevated modes.

**BRT vs. LRT vs. Monorail**

- LRT reportedly needs 2 to 3 lanes of road space compared to 3 to 4 lanes needed for BRT (WB) and gives better capacity.
- LRT is mostly proposed when service is possible at-grade for a substantial length of the corridor.
- Monorail can be considered when the road is narrow and congested. It permits more daylight and air underneath that is relevant when building lines that lie close to the edge of the road ROW.

**Metro Rail vs. Light Rail**

- Metro rail requires flat curves (necessitating property acquisition) and long ramps taking up a lot of road space.
- Light rail transit, on the other hand, can go round road bends and does not require property acquisition.
- It provides savings in running cost due to low axle load (11t) compared to Metro rail (17 t).

**At-grade vs. Grade-Separated Construction**
At-grade construction is most convenient for commuters. Grade separated systems increase trip time to account for the need to go up and down.

In Indian cities, several factors such as jay walking to cross the road, high volumes of demand, and congested roads militate against the at-grade option.

Elevated LRT would be a good solution.

Aesthetic considerations such as passing through heritage areas may require an underground option.

**Underground vs. over ground**

The decision on the choice of vertical separation depends upon the impacts of the following parameters:

- Capital cost
- Right-of-way availability
- Visual and aesthetic impact
- Construction impacts
- Vibration
- Noise
- Air pollution
- City’s future development potential
Para-transit system

“Paratransit vehicles are a for-hire flexible passenger transportation that does not necessarily follow fixed routes and schedules. They provide two types of services: one involving trips along a more or less defined route with stops to pick up or discharge passengers on request. The other is a demand-responsive transport which can offer a door-to-door service from any origin to any destination in a service area.

Factors influencing Para-transit

- Longer travel time, Higher cost and Lack of connectivity, Reduced Ridership of major public transport systems
High cost of introduction and maintenance of mass public transportation
Short Trip lengths: The average trip length in medium and small size cities is less than five kilometer
High percentage of low income groups
Creates employment opportunities
They provide first mile-last mile connectivity
Ideal feeder system for the MRTS, Metro/Mono Rail, BRTS etc

Benefits of Para-transit system

- Increase in Ridership of existing Public Transport Systems
- Reduce in Modal share of Private Vehicles
- Time utility, increased productivity and economic growth
- Bridging Urban and Rural mobility, especially Urban poor
- Employment and livelihood opportunities
- Stepping towards Sustainable Urban Transport

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Between</th>
<th>Transit Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Mode</td>
<td>Commuter Rail</td>
<td>Metro</td>
</tr>
<tr>
<td>ROW Options</td>
<td>Exclusive ROW / Sharing with Long Distance Trains</td>
<td>Exclusive ROW Grade Separated</td>
</tr>
<tr>
<td>Station Spacing (Approx)</td>
<td>3 - 15 km</td>
<td>1 - 2 km</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Locomotives with set of Passenger coaches</td>
<td>High platform cars operating in multiple car trains sets</td>
</tr>
<tr>
<td>Seated Capacity</td>
<td>90-185 per car</td>
<td>60-80 Per Car</td>
</tr>
<tr>
<td>Total Capacity</td>
<td>-</td>
<td>100 - 250 per car</td>
</tr>
<tr>
<td>Average Speed</td>
<td>40-70 kmph</td>
<td>25-55 kmph</td>
</tr>
<tr>
<td>Headways</td>
<td>-</td>
<td>3 min</td>
</tr>
<tr>
<td>Passenger Throughput</td>
<td>Up to 75,000</td>
<td>40,000 - 60,000</td>
</tr>
<tr>
<td>Min. Curve Radius</td>
<td>50 m</td>
<td>150 m</td>
</tr>
<tr>
<td>App 0 &amp; M Cost per km</td>
<td>40-60 Lakh</td>
<td>100-200 Lakh</td>
</tr>
<tr>
<td>App Capital Cost per km (Rupess)</td>
<td>90 Crores</td>
<td>250 Crores (Elevated)</td>
</tr>
<tr>
<td>Environmental sound level</td>
<td>75 dBA</td>
<td>90 dBA</td>
</tr>
<tr>
<td>Implemented Cities (International)</td>
<td>Moscow, Jakarta, Johanneburg, Buenos Aires</td>
<td>Bangkok, Kuala Lumpur, Mexico City, Cairo</td>
</tr>
<tr>
<td>Implemented Cities (India)</td>
<td>Mumbai, Chennai, Kolkata, Hyderabad</td>
<td>Delhi, Kolkata, Bangalore, Chennai</td>
</tr>
</tbody>
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MODULE : 2


2. ORGANIZATION OF SURVEYS AND ANALYSIS

Surveys are of particular importance to transport and land-use planning in several specific areas. Land-use surveys are an integral component of transport planning information requirements. The amount of travel which takes place between land-uses will depend on the quality and quantity of the transport system which connects the land-uses, and surveys of the transport system inventory play a major role in specifying the location and characteristics of the available transport system. This system, which includes both public and private modes of transport, may be described in terms of three basic components: the right-of-way, terminals, and vehicles.

i. The right-of-way includes the roads, tracks and paths which may be used by different types of vehicles and which can be described in terms of length, direction of movement, capacity, and design standards.

ii. The terminals include public transport stations, modal interchanges and parking stations and can be described in terms of location, throughput capacity, and holding capacity.

iii. The vehicles include both public and private vehicles and may be described in terms of total number, passenger (or goods) capacity, comfort level, and various operating characteristics.

The combination of land-use activity and a transport system invariably results in trip-making, and to measure the type and extent of trip-making it is necessary to conduct travel pattern surveys by one means or another. Such travel patterns may be described in terms of who is going
where, with whom, at what time, by which mode and route, and for what purpose. The measurement of such travel patterns is perhaps the unique part of transport survey methods. To establish whether the transport system is coping adequately with the demands being placed on it, it is therefore necessary to conduct transport system performance surveys. Such surveys seek to measure performance characteristics, such as travel times, travel time variability, passenger waiting times, vehicle occupancies, and system safety. The conduct of a survey is not an informal procedure. Rather, it should follow a series of logical, interconnected steps which progress toward the final end product of the survey. The stages in a typical sample survey are shown in Figure.
2.1 The issues to be addressed within each of these stages are listed
(a) Preliminary Planning
   (i) Overall Study Objectives
   (ii) Specific Survey Objectives
   (iii) Review of Existing Information
   (iv) Formation of Hypotheses
   (v) Definition of Terms
   (vi) Determination of Survey Resources
   (vii) Specification of Survey Content

(b) Selection of Survey Method
   (i) Selection of Survey Time Frame
   (ii) Selection of Survey Technique
   (iii) Consideration of Survey Errors

(c) Sample Design
   (i) Definition of Target Population
   (ii) Sampling Units
   (iii) Sampling Frame
   (iv) Sampling Method
   (v) Sampling Error and Sampling Bias
   (vi) Sample Size and Composition
   (vii) Estimation of Parameter Variances
   (viii) Conduct of Sampling

(d) Survey Instrument Design
   (i) Types of Survey Instrument
   (ii) Question Content
   (iii) Trip Recording Techniques
   (iv) Physical Nature of Forms
   (v) Question Types
   (vi) Question Format
   (vii) Question Wording
(viii) Question Ordering
(ix) Question Instructions

(e) Pilot Survey(s)
(i) Adequacy of Sampling Frame
(ii) Variability within Survey Population
(iii) Estimation of Non-Response Rate
(iv) Size of the Pilot Survey
(v) Suitability of Survey Method
(vi) Adequacy of Questionnaire (schedule)
(vii) Efficiency of Interviewer Training
(viii) Suitability of Coding, Data Entry, and Editing Procedures
(ix) Suitability of Analysis Procedures
(x) Cost and Duration of Surveys
(xi) Efficiency of Organisation

(f) Administration of the Survey
(i) Procedures for Survey Administration of: Self-Completion, Personal Interview, Telephone, Intercept and In-depth Interview Surveys
(ii) Survey Execution and Monitoring
(iii) Quality Control
(iv) The Use of the Computer in Transport Surveys

(g) Data Processing
(i) Selection of Coding Method
(ii) Preparation of Code Format
(iii) Development of Data Entry Programs
(iv) Coder and Data Entry Training
(v) Coding Administration

(h) Data Editing
(i) Editing of Field Sheets
(ii) Verification of Data Entry
(iii) Development of Editing Computer Programs
(iv) Consistency and Range Checks
(i) Data Correction and Expansion
(i) Editing Check Corrections
(ii) Secondary Data Comparisons
(iii) Corrections for Internal Biases
(j) Data Analysis and Management
(i) Exploratory Data Analysis
(ii) Model Building
(iii) Interpretation of Results
(iv) Database Management
(v) Provision of Data Support Services

(k) Presentation of Results

(i) Verbal Presentations
(ii) Visual Presentations
(iii) Preparation of Reports
(iv) Publication of Results

3. Definition of the Study Area:

- In transportation planning process we should first defined the study area for which transportation facilities are being planned.
- The transportation planning can be at the national level, the regional level or at the urban level. For planning at the urban level, the study area should embrace the whole continuous towns and cities 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 external cordon.
- The area inside the external cordon line determines the travel pattern to a large extent and as such is surveyed in great detail.
- The land-use pattern and the economic activities are studied intensively and detailed surveys (home interview survey) are conducted in this area to determine the travel characteristics.
4. **Selection of External Cordon Line:**

The selection of the external cordon line for an urban transportation study should be done with due weightage to the following factors:

- The external cordon line should cover the area which is already built up and also likely to be developed during the design period.
- The external cordon line should contain all areas of systematic daily life of the people oriented towards the city centre and should in effect be the ‘Commuter shed’.
- The external cordon line should be compatible with previous studies of the area of studies planned for the future.
- The external cordon line should be continuous and uniform in its course so that movements cross it only once. The line should intersect roads where it is safe and convenient to carry out traffic surveys.
- The external cordon line should be compatible with previous studies of the area and of studies planned for the future.

5. **Zoning:**

The defined study area is subdivided 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 subdivided into zones. Zones can themselves be subdivided 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.
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 behaviour.

Anticipated change in land use should be considered when sub-dividing the study area into zones.

It would be advantages, if the subdivision follows closely that adopted by other bodies (e.g. census department) for data collection. This will facilitate correlation of data.

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.

The zones should preferably have regular geometric form for easily determining the centroid, which represent the origin and destination of travel.

the sectors should represent the catchment of trips generated on a primary route.

Zones should be compatible with screen lines and cordon lines.

Zone boundaries should preferably be watersheds of trip making.

Natural or physical barriers such as canals, rivers, etc. can form convenient zone boundaries.

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 convenitally located along physical or natural barriers having a few crossing points.

Examples of such barriers are river, railway lines, canals, etc.
6. **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.

6. 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 cover 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.
There are two type of data collection:

1. **Primary Data** – Data collected through actual field surveys i.e. through primary sources.

   It includes the following

   - Inventories of objects and their characteristics derived from observation, e.g., the location and properties of a road link (starting node, end node, length, number of lanes, presence of parking, surface quality, gradient, etc.), the route and characteristics of a bus service (operating hours, stops served, headways, type of vehicle, etc.) and the services offered by a location (number and type of activities possible, size of facilities, opening hours, price level, service quality).

   - Data on current behavior obtained from observation, in particular counts, or from traveler surveys, frequently referred to as revealed preference data. – Data on traveler attitudes and values provided by the travelers through responses in surveys.

   - Decisions and assessments in hypothetical situations or markets obtained from the users through surveys, frequently referred to in transport as stated preference data.

2. **Secondary Data** – Data collected through indirect (secondary sources). Such as,

   - Census of persons or firms, detailing their characteristics obtained from primary surveys of the persons or firms concerned or derived from other primary sources, such as population registers and decennial censuses.

   - Population, land use, vehicle ownership, employment data, economic data, establishment data etc.

7. **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.

A. Road-side interview surveys.

Road Side Interview Surveys

Road side interview survey is one of the methods of carrying out screen-line or cordon survey. It can be done either by directly interviewing the drivers of the vehicles at selected survey points or by issuing prepaid post cards with questionnaires in it.

For small towns, say with a population range of 5000, a single circular cordon line at the periphery of the town is enough and for areas with population greater than 5000, two cordon lines are necessary (an external cordon at the edge of the urban development & an internal cordon at the limits of the CBD).
it is not generally possible to stop and interview all the vehicles and hence, sampling is necessary. The no. of the samples depends on the no. of interviewers and the traffic volume. A convenient method is to sample one in a fixed no. of vehicles like every tenth, fifteenth vehicle etc. Another simple method is to collect the next vehicle as soon as each interview is completed.

During the interview, the other traffic flow should not be interrupted and along with the interview there should at least one observer to record the traffic flow with the period of interviewing.

The period and duration of the survey is to be carefully planned out and it is the practice to obtain data for each work day (Monday - Friday).
It is necessary to frame and design the questions with care for obtaining a complete data about the trip and the interviewers should be well trained.

Since the survey is carried out by sampling method, expansion factors are necessary to calculate the total no. of trips. These expansion factors will be calculated separately for each class of vehicle and for different time periods.

Eq: Let

\[ x_c = \text{No. of cars interviewed in a particular time} \]
\[ X_c = \text{No. of cars counted in total during this time} \]

\[ \text{Expansion factor} = \frac{x_c}{X_c} \]

B. HOME-INTERVIEW SURVEY

- Home-interview survey is one of the most reliable type of surveys for collection of origin and destination data. The survey is essentially intended to yield data on the travel pattern of the residents of the household and the general characteristics of the household influencing trip making. The information on the travel pattern includes number of trips made, their origin and destination, purpose of trip, travel mode, time of departure from origin and time of arrival at destination and so on. The information on household characteristics includes type of dwelling unit, number of residents, age, sex, race, vehicle ownership, number of drivers, family income and so on. Based on these data it is possible to relate the amount of travel to household and zonal characteristics and develop equations for trip generation rates. It is impractical and unnecessary to interview all the residents of the study area. Since travel patterns tend to be uniform in a particular zone. The size of the sample is usually determined on the basis of the population of the study area. And the standards given by the Bureau of Public Roads as shown in below table.
<table>
<thead>
<tr>
<th>Population of Study Area</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 50000</td>
<td>1 in 5 households</td>
</tr>
<tr>
<td>50,000 – 150,000</td>
<td>1 in 8 households</td>
</tr>
<tr>
<td>150,000 – 300,000</td>
<td>1 in 10 households</td>
</tr>
<tr>
<td>300,000 – 500,000</td>
<td>1 in 15 households</td>
</tr>
<tr>
<td>500,000 – 1,000,000</td>
<td>1 in 20 households</td>
</tr>
<tr>
<td>Over 1,000,000</td>
<td>1 in 25 households</td>
</tr>
</tbody>
</table>

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:

a- Size of household.
b- Age of all the numbers of the households.
c- Sex.
d- Structure of households.
e- Employee.
f- Occupation.
g- Place of work.
h- No. of vehicles owned.
i- Household income.
c. Commercial Vehicle Surveys,

![Image](https://via.placeholder.com/150)

9. **Sampling:**

All the surveys discussed above require a careful sampling strategy. Sampling is the process of selecting units (e.g., people, households, organizations) from a population of interest so that by studying the sample we may fairly generalize our results back to the population from which they were chosen.

The selection of a proper sample is an obvious prerequisite to a sample survey. A sample is defined to be a collection of units which is some part of a larger population and which is specially selected to represent the whole population.

**Four aspects of this definition are of particular importance:**

- First, what are the units which comprise the sample?
- Second, what is the population which the sample seeks to represent?
- Third, how large should the sample be; and
- Fourth, how is the sample to be selected?

**SAMPLING UNITS**

The survey population is composed of individual elements. The selection of a sample from this population was based on the selection of sampling units from the population. Sampling units may or may not be the same as elements of the population; in many cases, they are aggregations of elements.

In more general situations, sampling units may typically include such entities as:

(a) Individuals
(b) Households
(c) Companies
(d) Geographic regions (zones, cities, states, nations)
(e) Vehicles
(f) Intersections or road links

10. SAMPLING FRAME

Depending on the population and sampling units being used, some examples of sampling frames which could be used for various transport surveys include:

(a) Electoral rolls
(b) Block lists (lists of all dwellings on residential blocks)
(c) Lists by utility companies (e.g. electricity service connections)
(d) Telephone directories
(e) Mailing lists
(f) Local area maps
(g) Census lists (if available)
(h) Society membership lists
(i) Motor vehicle registrations

Each of these sampling frames, however, suffers from one or more of the deficiencies outlined below:

Inaccuracy: All sampling frames will generally contain inaccuracies of one sort or another. Lists of individuals will contain mis-spelt names and incorrect addresses. Maps will often have incorrect boundary definitions, will not be true to scale and will have streets and other features which simply do not exist.

Incompleteness: As well as having incorrect entries, sampling frames may simply not have some valid entries at all.

Duplication: Entries may also be duplicated on some sampling frames. For example, telephone directories may list individuals and companies more than once under slightly different titles.

Inadequacy: A sampling frame is said to be inadequate if it simply does not provide a close correspondence with the desired survey population, but has been adopted for the sake of convenience.
Out-of-date: Whilst a sampling frame may once have been adequate, accurate, complete and with no duplications, this situation may not last forever. Conditions change and, with these changes, sampling frames go out-of-date.

The sampling methods are as follows:

1. Random sampling: This is the simplest method of sampling and involves selecting a random sample from a population, using a sampling frame with the units numbered. Using a suitable random number, source numbers are selected at random and the members of the population are chosen to form the sample.

2. Stratified sampling: In this method, based on the prior information, the population/households are divided into homogeneous groups or strata, based on some measure or combination of measures that can be used to group subjects. The grouping should result in those subjects in a group being similar to one another in relation to measures of interest to the survey, while the groups are dissimilar to one another. For example, assuming that car ownership affects trip making and that a survey of trip making is to be performed; grouping the population according to whether a household has no cars, one car, two cars, or more than two cars should result in creating groups such that households in a car ownership group have more similar trip-making characteristics than the households in other groups.

3. Cluster sampling: This is a non-random-sampling method that is often adopted in face-to-face household surveys, because it offers a potential of considerable cost savings for this type of survey. In cluster sampling, the units of interest in the survey are aggregated into clusters representing some type of proximity that affects survey economics. For example, if the survey is of households, households may be aggregated into blocks, where a block is defined by all the houses in a spatial area that is bounded by streets, but not cut by a street.

4. Systematic sampling: This is a non-random sampling method that is particularly important for roadside interviews and for sampling from very lengthy lists. It involves selecting
each nth entry from a list or each nth unit from a passing stream of units. Selecting the first unit at random is quite a useful idea, but does not result in making the systematic sample random.

5. **Choice-based sampling**: This sampling is not strictly random. It applies to any form of sampling where those who are sampled are sampled because they have already made a choice of relevance to the study. The sample may be drawn from within this subset of the total population using any of the preceding methods. For example any type of on-board transit survey, a roadside survey, and an intercept survey.

**SAMPLING RATE EXAMPLE**

The “Preliminary Result of National Population Census 2011” which contained the total population and number of household by district was issued in September 2011. No other data was released until July 2012. An accurate population and number of household in Kathmandu survey area in 2011 could not be captured since there was no other population statistics available other than the Census 2001. In this study, a method for sampling and population estimation was established using the following assumption:

1) Total population and number of household in Kathmandu, Lalitpur, and Bhaktapur districts in 2001 and 2011 are shown in the following table.

<table>
<thead>
<tr>
<th>Year</th>
<th>Districts</th>
<th>Population</th>
<th>Household Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Three Districts*</td>
<td>345,562</td>
<td>1,645,091</td>
</tr>
<tr>
<td>2011</td>
<td>Three Districts*</td>
<td>656,672</td>
<td>2,501,788</td>
</tr>
</tbody>
</table>

* Three districts: Kathmandu, Lalitpur, and Bhaktapur

National Population Census 2011 (Major Highlights of the Preliminary Results), Central Bureau of Statistics

2) The survey area excluded five VDCs in Kathmandu District and 20 VDCs in Lalitpur District. Population and number of household in the survey area were estimated based on the proportion of the survey area to the district. Estimated population and number of households are shown in Table 5.2.3.

<table>
<thead>
<tr>
<th>Survey Area</th>
<th>Population</th>
<th>Household Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>643,100</td>
<td>2,444,151</td>
</tr>
</tbody>
</table>

Source: JICA Survey Team

3) Since the statistics of population by age group in 2011 was not issued, the population with age five years and above, the target of the household survey, was estimated by using the ratio of the 2001 population with age five years and above.
Accuracy and Reliability

A trip generation model should be accurate and reliable. Accuracy means that the model should replicate as closely as possible the actual number of trips originating or ending in zones and that there should be no bias (which is a systematic under- or overestimating of trips). Reliability means that the amount of error is minimized.
These criteria have two implications which are somewhat at odds. First, we have to choose models that replicate as closely as possible the number of trips originating or ending in a zone. In general, this would be a model that had the highest overall predictability. But, second, we have to choose models that minimize total prediction errors.

This allows a model to replicate the number of trips for as many zones as possible. The two criteria are somewhat contradictory because crime trips are highly skewed. That is, a handful of zones will have a lot of crimes originating or ending in them while many zones will have few or no crimes. The zones with the most crimes will have a disproportionate impact on the final model. Thus, a model that obtains as high a prediction as possible (i.e., highest log likelihood or R2) may actually only predict accurately for a few zones and may be very wrong for the majority
Module - 8

TRIP GENERATION

INTRODUCTION

The analysis and model building phase of transportation planning process starts with the step commonly known as Trip Generation.

DEFINITION & OBJECTIVE

Trip generation is a general term used in the Transportation Planning Process to cover the field of calculating the number of trip ends in a given area.

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

TRIPS

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

Trips are usually divided into two types. They are:

1) Home-based trips
2) Non-home-based trips

Home-based trips are those having one end of the trip (either origin or destination) at home of the person making the trip.
Consider an example of the trip from the home of a person making the trip to the place of work where the person works and return to the home.

![Diagram](image)

**HOME - BASED TRIPS**

Both the trips are home-based because one end of the trips is the home. Both these trips are considered to have generated at home zone and attracted to the work zone. Thus, we have two work purpose trip end generations in the home zone and two work purpose trip end attractions in the work zone.

**NON-HOME-BASED TRIPS**

Non-home-based trips are those having neither end at the home of the person making the trip.

Consider an example of the trip from the place of the work to the shop and return to the place of work.

![Diagram](image)

**NON-HOME-BASED TRIPS**

Both these trips are non-home-based because neither end of the trip is the home of the person making the trip. Both these trips are considered to have been generated at the work zone and attracted to the shop zone.
Thus, we have two shopping purpose trip end generations in the work zone and two shopping purpose trip end attractions in the shop zone.

The trip ends are classified into trip generations and trip attractions. The trip generation/production is used to describe the trips generated by the residential zones while trip attraction is the term used to describe trips generated at the non-home end of a trip.

**Trip Purpose**

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

1. Work
2. School
3. Business
4. Social or recreational, sports
5. Others

The break-up of trips by purpose is normally done for the home-based trips which represent nearly 80-90% of the total trips.

**Factors Governing Trip Generation and Attraction Rates**

Factors governing the trip generation and attraction rates are:

1. Family Income
2. Motor vehicle ownership
3. Family size & composition
4. Land-use characteristics
5. Distance of the zone from town centre
(b) Accessibility to public transport system and its efficiency.

(c) Employment opportunities, floor space in the industrial and shopping units and offices, sales figures in shops, etc.

FAMILY INCOME

The ability to pay for a journey influences the household family members to perform more trips. A general trend is that higher the income, higher is the trip generation and the high income of the family provides a stimulus for owning a motor vehicle in the society.

MOTOR VEHICLE OWNERSHIP

The ability to satisfy travel demand is related to the availability of individual's own modes of transport and the quality of the road network system. Increased motor vehicle ownership generates more trips per unit household.

FAMILY SIZE & COMPOSITION

Travel is a function of human activities. The bigger the family, the more the trips are likely to be generated. Apart from the size, the composition of the family also is important. For instance, if both the husband and wife are employed, the trips generated will be more than when only husband is employed. If there are many school-going children, the no. of school-purpose trips will be large. The occupation of the family is also a factor that influences the travel pattern.

LAND-USE CHARACTERISTICS

Land-use is one of the major attributes of trip generation activities because it can be predicted through high
degree of accuracy. Different uses of land produce different
trip generation rates. For example, land developed for shop
ping or offices could be expected to generate more trips than
that developed for purely residential use.

Other uses of land considered to be significant in
terms of trip generation are educational, industrial and
recreational developments. The most commonly used measure
of the intensity of development at an educational institution
is the magnitude of school and college enrolments.

DISTANCE OF THE ZONE FROM TOWN CENTRE.

This determines the amount of travel that people
might make to the town centre. The farther the town centre
the less is the number of trips likely to be generated.

ACCESSIBILITY TO PUBLIC TRANSPORT SYSTEM AND ITS
EFFICIENCY.

This determines to some extent the desire of people
to make trips. An easily accessible and efficient public
transport system generates more trips.

EMPLOYMENT OPPORTUNITIES, FLOOR SPACE IN INDUSTRIAL AND
SHOPPING UNITS & OFFICES, SALES FIGURES IN SHOPS, ETC.

The employment potential of an industrial or
shopping unit or an office establishment directly governs
the trip attraction rate.

Similarly, the floor space in the industrial or shop
or office premises also influences the trip attraction rate.
PROBLEM

(1) Given that a zone has 275 households with access to car and 275 households without access to car and the average trip generation rates for each group are 5 and 2.5 trips per day, respectively. Assuming that in the future, households will have similar distribution with access and without access to car, as per the existing situation. There will be an addition of 550 households with a similar distribution of car ownership. Find the growth factor and future trips from that zone.

⇒ SOLUTION

Current trip rate \( (t_i) = 275 \times 2.5 + 275 \times 5 \)
\[ = 2062.5 \text{ trips per day} \]

growth factor \( (F_i) \) = \( \frac{V_d}{V_c} = \frac{1100}{550} \) = 2

\( (275 + 275 + 550 = 1100) \)

\[ \therefore \text{Number of future trips} \ (T_i) = F_i \cdot t_i \]
\[ = 2 \times 2062.5 \]
\[ = 4125 \text{ trips per day} \]

Trip Generation By Regression Analysis Technique

Multiple Linear Regression Analysis

The technique of predicting the number of trips in the future (called dependent variable) from measurements of other independent variables is called regression analysis. The relationship between the independent and dependent variable is linear, then the analysis is known as linear regression. If the independent variables are two or more in number, then the analysis is known as Multiple Linear Regression Analysis.
Linear Regression Analysis

MLR analysis is a statistical technique which measures the separate influence of each factor acting in association with the other factors. The aim of the analysis is to develop an equation in the following form to estimate the future trips from any zone, given the values for a set of land-use and socio-economic parameters:

\[ Y_p = a_1 x_1 + a_2 x_2 + a_3 x_3 + \ldots + a_n x_n + U \]

where,
- \( Y_p \) = No. of trips for specified purpose, \( p \)
- \( x_1, x_2, \ldots, x_n \) = Independent variables relating to land-use, socio-economic factors, etc.
- \( a_1, a_2, \ldots, a_n \) = Co-efficients of the respective independent variable \( x_1, x_2, \ldots, x_n \) obtained by linear regression analysis.
- \( U \) = Disturbance term, which is a constant and represents that portion of the value of \( Y_p \) not explained by the independent variables.

Assumptions

The MLR analysis is based on the following important assumptions:

1) All the variables are independent of each other.
2) All the variables are normally distributed.
3) All the variables are continuous.
4) A linear relationship exists between the dependent variable and independent variable.
5) Inclusion of each variable in the equation contributes a distinct portion of the trip numbers.
Types of MLR Analysis

MLR Analysis is of two types:

i) Aggregated or Zonal least-square regression - Each traffic zone is treated as one observation.

ii) Disaggregated or Household least-square regression - Each household is treated as one observation.

Aggregated analysis is most widely used and is based on the assumption that households exhibit a certain amount of similarity in travel characteristics. This assumption allows the data in a zone to be grouped and the mean value of the independent variable is used for further calculations.

Disaggregated analysis is not widely used and all the data that is collected is used more effectively resulting in a more meaningful description of the characteristics. This analysis produces better results and remains stable over time.

Criteria for Evaluation of Regression Equations

1) The multiple correlation coefficient should have a value at least 0.75 or even higher. A value close to 1.0 shows a very good correlation.

2) The standard error of the estimate of the dependent variable should be sufficiently small.

3) The 'F' test should be carried out to examine evidence of the degree of certainty that a meaningful relationship exists between the dependent and independent variables.

4) The equation should have accuracy, validity, simplicity, sharpness and constancy.
LIMITATIONS OF MLR ANALYSIS

a) The equation derived is purely empirical and fails to establish a meaningful relationship between the dependent and independent variables.

b) The regression coefficients established initially is believed to remain unchanged in the future and can be used for predictions of future travel too.

CATEGORY ANALYSIS

Category Analysis is based on the estimate of the average number of trips generated by a set of defined household groups with the given range of income, level of car ownership and household structure.

This method was developed by Wetton and Pick and this method is also known as Cross Classification Technique. The independent variables themselves are classified into a definite number of discrete class intervals.

ASSUMPTIONS

b) The household is the fundamental unit in the trip generation process and most journeys begin or end in response to the requirements of the family.

c) The trips generated by the household depend upon the characteristics of that household and its location relative to its required facilities such as shops, school and workplace. The household with one set of characteristics generate different rates of trips from the households having another set of characteristics.

c) Only three factors are of prime importance for affecting the
amount of travel to the household, i.e., car ownership, income, and household structure.

(4) Within each of the above three factors, a limited number of ranges can be established so as to describe the trip generation capacity of a household by a limited number of categories. Trip generation rates are stable over a time.

The different ranges for the three factors are given below:

(i) Car ownership: It comprises of three levels:
   (0 car, 1 car and more than 1 car).

(ii) Disposable income: There are six classes of disposable income:
   (i) < £500 p.a.
   (ii) £500 - £1000 p.a.
   (iii) £1000 - £1500 p.a.
   (iv) £1500 - £2000 p.a.
   (v) £2000 - £2500 p.a.
   (vi) > £2500 p.a.

(iii) Household structure: It consists of the following:
   (i) No. of employed residents and one non-employed adult
   (ii) No. of employed residents and two or more non-employed adults
   (iii) One employed resident and one or less non-employed adult
   (iv) One employed resident and two or more non-employed adults
   (v) Two or more employed residents and one or less non-employed adult
   (vi) Two or more employed residents and two or more non-employed adults.
The above system gives in all $3 \times 6 \times 6 = 108$ categories. The following is the mathematical expression of category analysis:

$$P_i = \leq h_i \cdot t_p$$

where $P_i =$ Number of trips produced by zone $i$,

$h_i =$ Number of households in zone $i$,

$t_p =$ Trip production rate of the household.

ADVANTAGES

1. The whole concept of household trip-making is the simplification of this technique. The technique categorizes the household according to certain socio-economic characteristics and this appears rational.

2. Unlike regression analysis technique, no mathematical relationship is derived between trip-making and household characteristics. This takes away many of the statistical drawbacks of the regression analysis.

3. Since the data from the census can be directly used, it saves considerable effort, time and money spent on home interviews survey.

4. The computations are simpler.

5. The technique simulates human behaviour more realistically than general aggregation process since disaggregated data are used.
DISADVANTAGES

1. It is difficult to test the statistical significance of the various explanatory variables.
2. The technique makes use of the studies carried out in the past made elsewhere with a lot of corrections.
3. In the analysis, it is assumed that income and car ownership increase in future.
4. New variables cannot be introduced at a future date.
5. Large samples are needed to assign trip rates to any one category.
PROBLEMS

1. Twenty households in a city were sampled for household income, autos per household, and trips produced.

<table>
<thead>
<tr>
<th>HOUSEHOLDS</th>
<th>TRIPS</th>
<th>INCOME (dollars)</th>
<th>AUTOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4000</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>6000</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>17000</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>11000</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>4500</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>17000</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>9500</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>9000</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>7000</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>13</td>
<td>19000</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>18000</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>21000</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>9</td>
<td>7000</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>11</td>
<td>11000</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>11000</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>11</td>
<td>13000</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>12</td>
<td>15000</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>11000</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>8</td>
<td>13000</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>9</td>
<td>15000</td>
<td>1</td>
</tr>
</tbody>
</table>

Develop matrices connecting income to automobiles available, and also draw a graph connecting trips per household to income. How many trips will a household with an income of 10,000 dollars owning one auto make per day?
**Solution**

**Step 1:** A matrix based on family income and auto availability is set up with cells and numbers representing the appropriate field sample numbers.

<table>
<thead>
<tr>
<th>INCOME (thousands of dollars)</th>
<th>AUTOS AVAILABLE</th>
<th>0</th>
<th>1</th>
<th>2 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 6</td>
<td></td>
<td>1,2</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6-9</td>
<td></td>
<td>8</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>9-12</td>
<td></td>
<td>4</td>
<td>7,16</td>
<td>11,15</td>
</tr>
<tr>
<td>12-15</td>
<td></td>
<td>-</td>
<td>19,20</td>
<td>16,17</td>
</tr>
<tr>
<td>&gt;15</td>
<td></td>
<td>-</td>
<td>11,12</td>
<td>3,6,10</td>
</tr>
</tbody>
</table>

**Step 2:** The average number of trips the household generates in each cell is calculated.

For example, the average trip rate for households with 0 or more autos and an income between 12,000 and 15,000 dollars is \[ \frac{11 + 12}{2} = 11.5 \]

These average rates are shown below:

<table>
<thead>
<tr>
<th>INCOME (thousands of dollars)</th>
<th>AUTOS AVAILABLE</th>
<th>0</th>
<th>1</th>
<th>2 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 6</td>
<td></td>
<td>3</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6-9</td>
<td></td>
<td>4</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>9-12</td>
<td></td>
<td>5</td>
<td>7,5</td>
<td>10,5</td>
</tr>
<tr>
<td>12-15</td>
<td></td>
<td>-</td>
<td>8,5</td>
<td>11,5</td>
</tr>
<tr>
<td>&gt;15</td>
<td></td>
<td>-</td>
<td>8,5</td>
<td>12,7</td>
</tr>
</tbody>
</table>
(4) A large suburban zone on the outskirts of a city is likely to have the following activities and housing development in the next 10 years. Calculate the total trip attractions.

- Number of DU = 3000
- High school students = 800
- Elementary school students = 1800
- Shopping center retail employees = 200
- Other retail employees = 100
- Non-retail employees = 50

**SOLUTION**

The trip attractions are obtained as follows, based on sample attraction rates indicated:

- Home-based work attractions = 1.7 (total zonal employees) = 1.7 \times 350 = 595
- Home-based shop attractions = 2.0 (CBD retail employees) + 9.0 (shopping center retail employees) + 4.0 (other retail employees) = 2(0) + 9(200) + 4(100) = 2200.
Home-based school attractions = 0.90 (university students) + 1.60 (high school students) + 1.20 (other school students) = 0.90 (0) + 1.6 (800) + 1.2 (800) = 3440.

Home-based other attractions = 0.7 (no. of households) + 0.6 (non-retail employees) + 1.10 (CBD retail employees) + 4.0 (shopping center retail employees) + 2.30 (other retail employees) = 0.7 (3000) + 0.6 (50) + 1.1 (0) + 4.0 (200) + 2.3 (100) = 3160.

Non-home-based attractions = 0.3 (no. of households) + 0.4 (non-retail employees) + 1.0 (CBD retail employees) + 4.6 (shopping center retail employees) + 2.30 (other retail employees) = 0.3 (3000) + 0.4 (50) + 1.0 (0) + 4.6 (200) + 2.3 (100) = 2070.

Total attractions = 11,465 trip attractions.
**INTRODUCTION**

After having obtained an estimate of the trips generated from and attracted to various zones, it is necessary to determine the direction of travel. The number of trips generated in every zone of the area under study has to be apportioned to the various zones to which these trips are attracted.

Trip distribution which is considered after trip generation is a part of transportation demand estimates which relate the distribution of trips between the given number of origins and the destinations in a matrix form.

Thus, if $g_i$ is the number of trip ends generated in zone $i$ and $a_j$ is the number of trip ends attracted to zone $j$, trip distribution stage determines the number of trips $t_{i,j}$ which would originate from zone $i$ and terminate in zone $j$.

![Graph showing trip distribution matrix](image)

<table>
<thead>
<tr>
<th>D (ATTRACTIONS)</th>
<th>GENERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 2 3 4 i</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td></td>
</tr>
</tbody>
</table>

$g_i = \sum_{j=1}^{m} t_{i,j}$

$O-D$ MATRIX
* The horizontal axis of the matrix represents the zones of attraction (destinations, D), 1, 2, 3, ..., i, ..., m.
* The vertical axis of the matrix represents the zones of generation (origin, O), 1, 2, 3, ..., i, ..., m.
* \( t_{ij} \) represents the number of trips originally in zone \( i \) and terminating zone \( j \).
* \( g_j \) represents the total number of trips generated in zone \( j \).
* \( a_i \) represents the total number of trips terminated in zone \( i \).

**METHODS OF TRIPS DISTRIBUTION**

There are two types of trip distribution methods, namely:

1. Growth Factor Methods
2. Synthetic Methods

**GROWTH FACTOR METHODS**

This method is based on the assumption that present travel patterns can be projected for the design year in the future by using certain expansion factors.

Following are the important growth factor methods:

1. Uniform Factor Method
2. Average Factor Method
3. Iteration Method
4. Juarez Method

**SYNTHETIC METHODS**

This method uses the existing data to derive a relationship between trip making, the resistance to travel between the zones, and the relative attractiveness of the zones for travel.
Following are the important synthetic methods:

(i) Gravity Model
(ii) Tanner Model
(iii) Intervening Opportunities Model
(iv) Competing Opportunities Model.

**Uniform Factor Method**

This is the oldest and the simplest method of projecting future trip distribution. This method is quite easier and simpler than the other methods of trip distribution.

A single growth factor 'E' is calculated for the entire area under study by dividing the future number of trip ends expected in the survey area for the design year by the trip ends in the base year. The future trips between zones i & j, 'T_{i-j}' are then calculated by applying the uniform factor 'E' to the base year trips between zone i & j. Thus, this can be represented by the formula:

\[ T_{i-j} = t_{i-j} \times E \]

where, \( T_{i-j} \) = Design year (future) number of trips from zone 'i' to 'j',
\( t_{i-j} \) = Observed base year number of trips from zone 'i' to 'j',
\( E \) = Growth Factor

**Problems**

1. An area has been divided into four zones A, B, C and D. The result of the trip generation analysis and the present trip distribution matrix are given below. Determine the future trips.
### Trip Ends For Different Zones

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Present</strong></td>
<td>75</td>
<td>45</td>
<td>90</td>
<td>40</td>
</tr>
<tr>
<td><strong>Future</strong></td>
<td>150</td>
<td>85</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td><strong>Attracted Trips</strong></td>
<td>60</td>
<td>50</td>
<td>95</td>
<td>65</td>
</tr>
<tr>
<td><strong>Future</strong></td>
<td>90</td>
<td>150</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

### Trip Distribution Matrix

<table>
<thead>
<tr>
<th>O</th>
<th>D</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>15</td>
<td>25</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**Solution**

\[
T_{ij} = \frac{T_{ij}}{E} \times E
\]

\[
E = \frac{T_{ij}}{T_{ij} + T_{ij}}
\]

\[
E = \frac{\text{All future produced & attracted trips}}{\text{All present produced & attracted trips}}
\]

\[
E = \frac{150 + 85 + 135 + 120 + 90 + 150 + 150 + 100}{75 + 45 + 90 + 40 + 60 + 80 + 150 + 150 + 65}
\]

\[
E = \frac{980}{500}
\]

\[
E = 1.96 \approx 2
\]

Using this \( E \) value, all the values of the present distribution matrix should be multiplied to get the future trips. They are tabulated as follows:
(2) An area has been divided into three zones 1, 2, 3. The present trip distribution matrix is given below. The future trips generated in zones 1, 2, 3 are expected to be 300, 1260 and 3120 respectively. Obtain the future trips to be generated and check.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

**Future Trips**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>300</td>
<td>20</td>
</tr>
</tbody>
</table>

**Solution**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Ti-j</th>
<th>Ti-j</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>100</td>
<td>200</td>
<td>360</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>300</td>
<td>420</td>
<td>1260</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>300</td>
<td>20</td>
<td>520</td>
<td>3120</td>
</tr>
<tr>
<td>Total</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
<td>4740</td>
<td></td>
</tr>
</tbody>
</table>

New:

\[
Ti-j' = Ti-j \times \Delta
\]

\[
\Delta = \frac{Ti-j}{Ti-j} = \frac{4740}{1300} = 3.64
\]
Using this value of $E$, all the values of the present distribution matrix should be multiplied to get the future trips.

$$T_{i-1} = t_{i-1} \times E$$

$$T_{i-1} = 60 \times 3.646 = 218$$

Similarly,

<table>
<thead>
<tr>
<th>D</th>
<th>$T_i$</th>
<th>$T_i^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>218</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>365</td>
<td>1280</td>
</tr>
<tr>
<td>3</td>
<td>729</td>
<td>3120</td>
</tr>
<tr>
<td>Total</td>
<td>4340</td>
<td>4740</td>
</tr>
</tbody>
</table>

Average Factor Method

In this method, a growth factor for each zone is calculated based on the average of the growth factors calculated for both ends of the trip. The factor thus represents the average growth associated both with the origin and the destination zones. This can be represented by the following relation:

$$T_{i-j} = t_{i-j} \left[ \frac{E_i + E_j}{2} \right]$$

where,

- $T_{i-j}$ = Future trips from zone $i$ to zone $j$.
- $t_{i-j}$ = Present trips from zone $i$ to zone $j$.
- $E_i = \frac{P_i^{*}}{P_i}$ = Generated trips growth factor for zone $i$. 

Scanned by CamScanner
\[ E_j = \frac{A_j}{a_j} \quad \text{Attracted trips growth factor for zone } j \]

\[ P_i = \text{Future generated trips for zone } i \]

\[ p_i = \text{Present generated trips for zone } i \]

\[ A_j = \text{Future attracted trips for zone } j \]

\[ a_j = \text{Present attracted trips for zone } j \]

**Problems**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>D</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>300</td>
<td>20</td>
</tr>
</tbody>
</table>

The future trips generated in zones 1, 2, and 3 are 360, 1260, and 3120 respectively.

**Solution**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>( p_i )</th>
<th>( P_i )</th>
<th>( E_i = \frac{P_i}{p_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>100</td>
<td>200</td>
<td>P1</td>
<td>360</td>
<td>P1</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>300</td>
<td>P2</td>
<td>1260</td>
<td>P2</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>300</td>
<td>20</td>
<td>P3</td>
<td>3120</td>
<td>P3</td>
</tr>
<tr>
<td></td>
<td>a_i</td>
<td>a_j</td>
<td>A_j</td>
<td>F_j</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>420</td>
<td>1260</td>
<td>1300</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ F_j = \frac{a_i}{a_j} \]

Now,

\[ T_{i-j} = t_{i-j} \left( \frac{E_i + E_j}{2} \right) \]

\[ T_{1-1} = 60 \times \left( \frac{1+1}{2} \right) = 60 \quad ; \quad T_{1-2} = 100 \times \left( \frac{1+2}{2} \right) = 200 \]

\[ T_{1-3} = 200 \times \left( \frac{1+3}{2} \right) = 700 \]
\[ T_{2-1} = 100 \times \frac{3+1}{2} = 200 \; ; \; T_{2-2} = 20 \times \frac{3+3}{2} = 60 \; ; \]

\[ T_{2-3} = 300 \times \frac{3+6}{2} = 1350. \]

\[ T_{3-1} = 200 \times \frac{6+1}{2} = 700 \; ; \; T_{3-2} = 300 \times \frac{6+3}{2} = 1350 \; ; \]

\[ T_{3-3} = 20 \times \frac{6+6}{2} = 120. \]

The matrix thus becomes,

<table>
<thead>
<tr>
<th>0</th>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>p_i^*</th>
<th>P_i^*</th>
<th>E_i^* = P_i^<em>/p_i^</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>200</td>
<td>700</td>
<td>960</td>
<td>360</td>
<td>0.375</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>60</td>
<td>1350</td>
<td>1610</td>
<td>1260</td>
<td>0.483</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>1350</td>
<td>120</td>
<td>2170</td>
<td>3120</td>
<td>1.138</td>
<td></td>
</tr>
<tr>
<td>q_i^j</td>
<td>960</td>
<td>1610</td>
<td>2170</td>
<td>4340</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a_i^j</td>
<td>360</td>
<td>1240</td>
<td>3120</td>
<td>4340</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E_i^j = a_i^j/q_i^j</td>
<td>0.345</td>
<td>0.463</td>
<td>1.138</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCED TRIPS</td>
<td>PRESENT</td>
<td>45</td>
<td>45</td>
<td>90</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>FUTURE</td>
<td>150</td>
<td>85</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td>ATTRACTED TRIPS</td>
<td>PRESENT</td>
<td>60</td>
<td>50</td>
<td>95</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>FUTURE</td>
<td>90</td>
<td>150</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

Trip Distribution Matrix as in previous method - Problem 1

**Solution**

Growth factors in production zones:

\[ F_A = \frac{150}{75} = 2 \; ; \; F_B = \frac{85}{45} = 1.89 \; ; \; F_C = \frac{135}{90} = 1.5 \; ; \]

\[ F_D = \frac{120}{40} = 3 \]
Growth factors in attraction zones,

\[
F_A = \frac{90}{60} = 1.5; \quad F_B = \frac{150}{50} = 3; \quad F_C = \frac{150}{45} = 2; \quad F_D = \frac{100}{65} = 1.54
\]

The future growth tribes distribution can be calculated by using the average growth factor method.

### Iteration 1

<table>
<thead>
<tr>
<th>O/D</th>
<th>A (1.5)</th>
<th>B (3)</th>
<th>C (2)</th>
<th>D (1.54)</th>
<th>( p_i )</th>
<th>( P_i )</th>
<th>( E_i = P_i / p_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (2)</td>
<td>20 ( \left( \frac{2+1.5}{2} \right) )</td>
<td>20 ( \left( \frac{2+3}{2} \right) )</td>
<td>20 ( \left( \frac{2+2}{4} \right) )</td>
<td>15 ( \left( \frac{2+1.5}{2} \right) )</td>
<td>152</td>
<td>150</td>
<td>0.99</td>
</tr>
<tr>
<td>B (1.89)</td>
<td>10 ( \left( \frac{1.89+1.5}{2} \right) )</td>
<td>10 ( \left( \frac{1.89+3}{2} \right) )</td>
<td>15 ( \left( \frac{1.89+2}{2} \right) )</td>
<td>10 ( \left( \frac{1.89+1.5}{2} \right) )</td>
<td>90</td>
<td>85</td>
<td>0.94</td>
</tr>
<tr>
<td>C (1.5)</td>
<td>10 ( \left( \frac{1.5+1.5}{2} \right) )</td>
<td>15 ( \left( \frac{1.5+3}{2} \right) )</td>
<td>25 ( \left( \frac{1.5+2}{2} \right) )</td>
<td>30 ( \left( \frac{1.5+1.5}{2} \right) )</td>
<td>154</td>
<td>135</td>
<td>0.89</td>
</tr>
<tr>
<td>D (3)</td>
<td>10 ( \left( \frac{3+1.5}{2} \right) )</td>
<td>5 ( \left( \frac{3+3}{2} \right) )</td>
<td>15 ( \left( \frac{3+2}{2} \right) )</td>
<td>10 ( \left( \frac{3+1.5}{2} \right) )</td>
<td>99</td>
<td>120</td>
<td>1.21</td>
</tr>
<tr>
<td>( a_j )</td>
<td>105</td>
<td>124</td>
<td>152</td>
<td>114</td>
<td>4.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_i )</td>
<td>90</td>
<td>150</td>
<td>150</td>
<td>100</td>
<td>490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( E_i = A_i / a_j )</td>
<td>0.86</td>
<td>1.2</td>
<td>0.99</td>
<td>0.99</td>
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### Iteration 2

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<tr>
<th>O/D</th>
<th>A (0.86)</th>
<th>B (1.2)</th>
<th>C (0.99)</th>
<th>D (0.99)</th>
<th>( p_i )</th>
<th>( P_i )</th>
<th>( E_i = P_i / p_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (0.99)</td>
<td>35 ( \left( \frac{0.86+1.2}{2} \right) )</td>
<td>55</td>
<td>39.6</td>
<td>25.2</td>
<td>152</td>
<td>150</td>
<td>0.99</td>
</tr>
<tr>
<td>B (0.94)</td>
<td>15.3</td>
<td>26.8</td>
<td>28.9</td>
<td>16.3</td>
<td>87.3</td>
<td>85</td>
<td>0.97</td>
</tr>
<tr>
<td>C (0.89)</td>
<td>25.9</td>
<td>35.4</td>
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<td>40.3</td>
<td>142.5</td>
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<td>D (1.21)</td>
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<td>120</td>
<td>-1.11</td>
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<tr>
<td>( a_j )</td>
<td>97.4</td>
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<td>151.4</td>
<td>105.8</td>
<td>489.8</td>
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<tr>
<td>( A_i )</td>
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<td>150</td>
<td>150</td>
<td>100</td>
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<tr>
<td>( E_i = A_i / a_j )</td>
<td>0.92</td>
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</table>

Scanned by CamScanner
FRATAR METHOD

This method is based on predicting future interzonal movements by successive approximations.

According to this method, the total trips for each zone distributed to the (movements) interzonal movement, 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 as in proportion to the expected growth of each other zone. This may be expressed mathematically as below:

\[ T_{i,j} = t_{i,j} \times \frac{P_i}{p_i} \times \frac{A_j}{a_j} \times \frac{\frac{k}{\sum A_k}}{t_{i-k}} \]

where, \( T_{i,j} \) = Future trips from zone i to zone j.
\( t_{i,j} \) = Present trips from zone i to zone j.
\( P_i \) = Future trips produced at zone i.
\( p_i \) = Present trips attracted to zone i.
\( A_j \) = Future trips attracted to zone j.
\( a_j \) = Present trips attracted to zone j.
\( k \) = Total number of zones.

PROBLEMS

(1) Estimate the future trip distribution as per FRATAR Method.

The estimated future trips are 80, 114, 148 and 38.
Solution

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>10</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>-</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>14</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td>18</td>
<td>14</td>
<td>6</td>
<td>-</td>
</tr>
</tbody>
</table>

| Present Trips | 40 | 38 | 32 | 38 |
| Estimated Future Trips | 80 | 114 | 48 | 38 |
| Growth Factor | 2 | 3 | 1.5 | 1 |

Note:

\[
T_{A-B} = t_{A-B} \times \frac{P_A}{P_A} \times \frac{A_B}{A_B} \times \frac{t_{AB} + t_{AC} + t_{AD}}{t_{AB} \cdot E_B + t_{AC} \cdot E_C + t_{AD} \cdot E_D}
\]

\[
= 10 \times \frac{80}{40} \times \frac{114}{38} \times \frac{40}{10 \times 3 + 12 \times 1.5 + 18 \times 1}
\]

\[
= 36.4
\]

\[
T_{A-C} = t_{A-C} \times \frac{P_A}{P_A} \times \frac{A_C}{A_C} \times \frac{t_{AB} + t_{AC} + t_{AD}}{t_{AB} \cdot E_B + t_{AC} \cdot E_C + t_{AD} \cdot E_D}
\]

\[
= 12 \times \frac{80}{40} \times \frac{48}{32} \times \frac{40}{10 \times 3 + 12 \times 1.5 + 18 \times 1}
\]

\[
= 21.8
\]
\[ T_{A-D} = t_{A-D} \times \frac{P_A}{P_A} \times \frac{A_D}{a_D} \times \frac{t_{AB} + t_{AC} + t_{AD}}{t_{AB} \cdot E_B + t_{AC} \cdot E_C + t_{AD} \cdot E_D} \]

\[ = 18 \times \frac{80}{40} \times \frac{38}{38} \times \frac{40}{10 \times 3 + 12 \times 1.5 + 18 \times 1} \]

\[ = 21.8 \]

\[ T_{B-A} = t_{B-A} \times \frac{P_B}{P_B} \times \frac{A_A}{a_A} \times \frac{t_{BA} + t_{BC} + t_{BD}}{t_{BA} \cdot E_A + t_{BC} \cdot E_C + t_{BD} \cdot E_D} \]

\[ = 10 \times \frac{114}{38} \times \frac{80}{40} \times \frac{38}{10 \times 2 + 11 \times 1.5 + 11 \times 1} \]

\[ = 41.5 \]

\[ T_{B-C} = t_{B-C} \times \frac{P_B}{P_B} \times \frac{A_C}{a_C} \times \frac{t_{BA} + t_{BC} + t_{BD}}{t_{BA} \cdot E_A + t_{BC} \cdot E_C + t_{BD} \cdot E_D} \]

\[ = 14 \times \frac{114}{38} \times \frac{48}{38} \times 0.69 \]

\[ = 43.5 \]

\[ T_{B-D} = t_{B-D} \times \frac{P_B}{P_B} \times \frac{A_D}{a_D} \times \frac{t_{BA} + t_{BC} + t_{BD}}{t_{BA} \cdot E_A + t_{BC} \cdot E_C + t_{BD} \cdot E_D} \]

\[ = 14 \times \frac{114}{38} \times \frac{38}{38} \times 0.69 \]

\[ = 29 \]

\[ T_{C-A} = t_{C-A} \times \frac{P_C}{P_C} \times \frac{A_A}{a_A} \times \frac{t_{CA} + t_{CB} + t_{CD}}{t_{CA} \cdot E_A + t_{CB} \cdot E_B + t_{CD} \cdot E_D} \]

\[ = 18 \times \frac{48}{32} \times \frac{80}{40} \times \frac{32}{12 \times 2 + 11 \times 3 \times 6 \times 1} \]

\[ = 16 \]

\[ T_{C-B} = t_{C-B} \times \frac{P_C}{P_C} \times \frac{A_B}{a_B} \times \frac{t_{CA} + t_{CB} + t_{CD}}{t_{CA} \cdot E_A + t_{CB} \cdot E_B + t_{CD} \cdot E_D} \]
\[
\begin{array}{cccccc}
A - B & A - C & A - D & B - C & B - D & C - D \\
36.4 & 21.8 & 21.8 & 43.5 & 29.0 & 3.9 \\
41.5 & 16.0 & 15.8 & 28.0 & 18.3 & 4.0 \\
Total & 77.9 & 37.8 & 37.6 & 71.5 & 47.3 & 7.9 \\
Average & 39.0 & 18.9 & 18.8 & 35.7 & 23.6 & 4.0 \\
\end{array}
\]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39.0</td>
<td>39.0</td>
<td>18.9</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>18.9</td>
<td>35.7</td>
<td>35.7</td>
<td>23.6</td>
</tr>
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<td>18.8</td>
<td>23.6</td>
<td>4.0</td>
<td>4.0</td>
</tr>
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<tr>
<td>DESIRED TOTALS</td>
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<td>114.0</td>
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<td>1.04</td>
<td>1.16</td>
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<td>0.82</td>
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</tbody>
</table>

The process is then repeated to obtain a second approximation on the same lines, but using new growth factors for new values of the inter-zonal movement obtained from the first approximation.

<table>
<thead>
<tr>
<th>O</th>
<th>D</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
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<td>A</td>
<td>39.0</td>
<td>18.9</td>
<td>18.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>39.0</td>
<td>35.7</td>
<td>23.6</td>
<td></td>
<td></td>
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<tr>
<td>C</td>
<td>18.9</td>
<td>23.6</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>18.8</td>
<td>4.0</td>
<td>-</td>
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</tr>
<tr>
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<tr>
<td>NEW GROWTH FACTOR</td>
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<td>1.16</td>
<td>0.82</td>
<td>0.82</td>
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</tr>
</tbody>
</table>

Note:

\[ T_{A-B} = 39 \times 1.04 \times 1.16 \times 1 = 47.39 \text{, or } 47.4 \]
\[ T_{C-B} = 14 \times 1.5 \times 3 \times 0.44 = 28 \]
\[ T_{C-D} = 6 \times 1.5 \times 1 \times 0.44 = 4 \]
\[ T_{D-A} = 18 \times 1 \times 2 \times 0.439 = 15.8 \]
\[ T_{D-B} = 14 \times 1 \times 3 \times 0.439 = 18.3 \]
\[ T_{D-C} = 6 \times 1 \times 1.5 \times 0.439 = 3.9 \]

### First Approximation

<table>
<thead>
<tr>
<th>ZONE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Sum Of Products Of Trips And Growth Factors</th>
<th>Desired Trips</th>
<th>Ratio Of Desired Ne Total Trips To Sum Of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth Factor</td>
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<td>3</td>
<td>1.5</td>
<td>1</td>
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<tr>
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<td>(1)</td>
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<td>12</td>
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<td></td>
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<td>18</td>
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<td>(3)</td>
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<td>21.8</td>
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<td>21</td>
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<td>(2)</td>
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<tr>
<td>(3)</td>
<td>15.8</td>
<td>18.3</td>
<td>3.9</td>
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</tbody>
</table>
\[ T_{A-C} = 18.9 \times 1.04 \times 0.82 \times 1 = 16.3 \]
\[ T_{A-D} = 18.8 \times 1.04 \times 0.82 \times 1 = 16.3 \]
\[ T_{B-A} = 39 \times 1.16 \times 1.04 \times 1.102 = 51.9 \]
\[ T_{B-C} = 35.7 \times 1.16 \times 0.82 \times 1.102 = 37.4 \]
\[ T_{B-D} = 23.6 \times 1.16 \times 0.82 \times 1.102 = 24.7 \]
\[ T_{C-A} = 18.9 \times 0.82 \times 1.04 \times 0.911 = 14.7 \]
\[ T_{C-B} = 35.7 \times 0.82 \times 1.16 \times 0.911 = 30.9 \]
\[ T_{C-D} = 4.0 \times 0.82 \times 0.82 \times 0.911 = 2.4 \]
\[ T_{D-A} = 18.8 \times 0.82 \times 1.04 \times 0.924 = 14.8 \]
\[ T_{D-B} = 23.6 \times 0.82 \times 1.16 \times 0.924 = 20.7 \]
\[ T_{D-C} = 4.0 \times 0.82 \times 0.82 \times 0.924 = 2.5 \]

### Second Approximation

<table>
<thead>
<tr>
<th>ZONE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Sum. Of Products Of Trips And Growth Factors</th>
<th>Desired Trips</th>
<th>Ratio Of Desired Net Total Trips To Sum. Of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROWTH FACTOR</td>
<td>1.04</td>
<td>1.16</td>
<td>0.82</td>
<td>0.82</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>FOR ZONE A</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>(1)</td>
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<td></td>
<td>39.2</td>
<td>18.9</td>
<td>18.8</td>
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</table>
The process is repeated to obtain a third approximation.

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<th>D</th>
<th>NEW Totals</th>
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<td>0.93</td>
<td>0.997</td>
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<td>80.0</td>
<td>106.55</td>
<td>53.1</td>
<td>38.0</td>
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<tr>
<td>0.45</td>
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<td>A-B</td>
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<td>A-C</td>
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<td>16.3</td>
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<td>16.3</td>
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<td>16.3</td>
<td>16.3</td>
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<tr>
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<td>16.3</td>
<td>16.3</td>
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**Average**

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<td>99.3</td>
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</tr>
<tr>
<td>14.7</td>
<td>1.14</td>
</tr>
<tr>
<td>15.5</td>
<td>1.06</td>
</tr>
</tbody>
</table>

**For Zone B**

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>19.55</td>
<td>44.56</td>
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<tr>
<td>(2)</td>
<td>19.6</td>
<td>41.11</td>
</tr>
<tr>
<td>(3)</td>
<td>31.9</td>
<td>51.9</td>
</tr>
</tbody>
</table>

**For Zone C**

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
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</thead>
<tbody>
<tr>
<td>(1)</td>
<td>18.9</td>
<td>35.7</td>
</tr>
<tr>
<td>(2)</td>
<td>19.6</td>
<td>41.11</td>
</tr>
<tr>
<td>(3)</td>
<td>30.9</td>
<td>51.9</td>
</tr>
</tbody>
</table>

**For Zone D**

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
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<tbody>
<tr>
<td>(1)</td>
<td>14.8</td>
<td>39.0</td>
</tr>
<tr>
<td>(2)</td>
<td>23.6</td>
<td>23.6</td>
</tr>
<tr>
<td>(3)</td>
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<td>24.7</td>
</tr>
</tbody>
</table>

**For Zone E**

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
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<td>24.5</td>
</tr>
<tr>
<td>(2)</td>
<td>24.5</td>
<td>24.5</td>
</tr>
<tr>
<td>(3)</td>
<td>24.5</td>
<td>24.5</td>
</tr>
</tbody>
</table>
Estimate the future trip distribution as per Fratarc method. The estimated future trips are 80, 76, 64, 76.

Furness Method
This method has been developed by K.P. Furness. It is concerned with the traffic movements which are made to agree alternatively with the future traffic until both the future production and attraction ends closely match with the last iterated values of production and attraction.

Problems
0) Estimate the future trip distribution as per Furness Method. The predicted future trips are also given in the table below:

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Predicted Future Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>3</td>
<td>16</td>
<td>15</td>
<td>147</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

(Predicted Future Trips: 39, 24, 68, 120)
### Solution

<table>
<thead>
<tr>
<th>P</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total Present Trips</th>
<th>Predicted Future Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4.2</td>
<td>14.7</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>3</td>
<td>16</td>
<td>15</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>28</td>
<td>4.2</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>29</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Total Present Trips</td>
<td>26</td>
<td>24</td>
<td>34</td>
<td>40</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Predicted Future Trips</td>
<td>39</td>
<td>24</td>
<td>68</td>
<td>120</td>
<td>251</td>
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</tr>
<tr>
<td>Destination Growth Factors</td>
<td>1.5</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
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<td></td>
</tr>
</tbody>
</table>

#### First Iteration

<table>
<thead>
<tr>
<th>P</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total Present Trips</th>
<th>Predicted Future Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>92</td>
<td>147</td>
</tr>
<tr>
<td>1</td>
<td>(8x1.5)</td>
<td>1.2</td>
<td>3</td>
<td>16</td>
<td>3.2</td>
<td>145</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>9</td>
<td>16</td>
<td>15</td>
<td>49</td>
<td>142</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>8</td>
<td>6</td>
<td>24</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>14</td>
<td>36</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>24</td>
<td>68</td>
<td>120</td>
<td>251</td>
<td></td>
</tr>
<tr>
<td>Predicted Total</td>
<td>39</td>
<td>24</td>
<td>68</td>
<td>120</td>
<td>251</td>
<td></td>
</tr>
</tbody>
</table>

#### Second Iteration

<table>
<thead>
<tr>
<th>P</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total Present Trips</th>
<th>Predicted Future Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>72</td>
<td>147</td>
</tr>
<tr>
<td>1</td>
<td>(12x1.6)</td>
<td>19.2</td>
<td>51.2</td>
<td>72</td>
<td>147.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.74</td>
<td>13.76</td>
<td>12.9</td>
<td>42</td>
<td>142.14</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.8</td>
<td>3.6</td>
<td>11.4</td>
<td>31.8</td>
<td>32</td>
<td>142.14</td>
</tr>
<tr>
<td>4</td>
<td>2.08</td>
<td>7.28</td>
<td>18.72</td>
<td>29.64</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>37.50</td>
<td>19.42</td>
<td>45.84</td>
<td>118.02</td>
<td>250.78</td>
<td></td>
</tr>
</tbody>
</table>
This iterative procedure is repeated until all the growth factors are unity or sufficiently near to unity.

(2) Estimate the future trip distribution by Furness Method.

---

**Solution**

---

Scanned by CamScanner
### First Iteration

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.2</td>
<td>44.4</td>
<td>33.3</td>
<td>39.6</td>
</tr>
<tr>
<td>2</td>
<td>46.2</td>
<td>35.2</td>
<td>37.4</td>
<td>30.8</td>
</tr>
<tr>
<td>3</td>
<td>58.2</td>
<td>40.74</td>
<td>48.5</td>
<td>52.38</td>
</tr>
<tr>
<td>4</td>
<td>20.8</td>
<td>18.72</td>
<td>33.28</td>
<td>27.04</td>
</tr>
</tbody>
</table>

\[ a_j^1 = 147.4 \]
\[ A_j^1 = 150 \]
\[ F_j^1 = \frac{A_j^1}{a_j^1} = 1.02 \]

### Second Iteration

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>( p_i^1 )</th>
<th>( p_i^2 )</th>
<th>( F_i^1 = \frac{p_i^1}{p_i^2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.6</td>
<td>38.2</td>
<td>39.3</td>
<td>42.4</td>
<td>142.5</td>
<td>140</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>44.1</td>
<td>30.3</td>
<td>44.1</td>
<td>33.0</td>
<td>154.5</td>
<td>150</td>
<td>0.97</td>
</tr>
<tr>
<td>3</td>
<td>59.4</td>
<td>35.0</td>
<td>57.2</td>
<td>56.0</td>
<td>207.6</td>
<td>200</td>
<td>0.96</td>
</tr>
<tr>
<td>4</td>
<td>21.2</td>
<td>21.8</td>
<td>39.3</td>
<td>29.0</td>
<td>111.3</td>
<td>100</td>
<td>0.90</td>
</tr>
</tbody>
</table>

### Third Iteration

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.15</td>
<td>37.44</td>
<td>38.51</td>
<td>41.55</td>
</tr>
<tr>
<td>2</td>
<td>45.69</td>
<td>29.39</td>
<td>42.48</td>
<td>32.01</td>
</tr>
<tr>
<td>3</td>
<td>57.01</td>
<td>33.60</td>
<td>54.91</td>
<td>54.91</td>
</tr>
<tr>
<td>4</td>
<td>19.08</td>
<td>19.62</td>
<td>35.37</td>
<td>26.10</td>
</tr>
</tbody>
</table>

\[ a_j^2 = 143.94 \]
\[ A_j^2 = 150 \]
\[ F_j^2 = \frac{A_j^2}{a_j^2} = 1.04 \]

### Fourth Iteration

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>( p_i^3 )</th>
<th>( p_i^4 )</th>
<th>( F_i^3 = \frac{p_i^3}{p_i^4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.04</td>
<td>37.44</td>
<td>40.44</td>
<td>43.21</td>
<td>144.13</td>
<td>140</td>
<td>0.97</td>
</tr>
<tr>
<td>2</td>
<td>47.52</td>
<td>29.39</td>
<td>44.92</td>
<td>33.29</td>
<td>155.13</td>
<td>150</td>
<td>0.97</td>
</tr>
<tr>
<td>3</td>
<td>59.30</td>
<td>33.60</td>
<td>57.66</td>
<td>57.11</td>
<td>207.6</td>
<td>200</td>
<td>0.96</td>
</tr>
<tr>
<td>4</td>
<td>19.84</td>
<td>19.62</td>
<td>37.14</td>
<td>27.14</td>
<td>103.4</td>
<td>100</td>
<td>0.96</td>
</tr>
</tbody>
</table>

\[ F_j^3 = \frac{A_j^3}{a_j^3} = 1.05 \]
The iteration continues till the growth factor becomes unity.

**MAIN ADVANTAGES AND DISADVANTAGES OF GROWTH FACTOR MODELS**

**ADVANTAGES**

1. They are easily understood and applied with an estimation of the growth factors.
2. The simple process of iteration quickly generates a balance between the observed (Ti) and the computed trip ends. These iteration processes are time-consuming but can also be solved using basic algorithms.
3. They are simple in operation and application, and can be used to distribute trips by different modes for different purposes and at different times a day.
4. They have been well tested and found to be reasonable when applied to the areas where the pattern and the density of development is stable.

**DISADVANTAGES**

1. Major shortcomings in these growth factor models are that these are weak to calculate the future distributions of trips for these
areas which are not developed or yet to be developed during the present year.

(2) These models do not take effect of the change of accessibility and travel impedance between the zones.

**MODULE 4**

**A. GRAVITY MODEL**

This is one of the well known synthetic model based on Newton's concept of gravity.

This model assumes that the interchange of trips between zones in an area is dependent upon the relative attraction between the zones and the spatial separation between them as measured by an approximate function of distance. This function of spatial separation adjusts the relative attraction each zone for the ability, desire or necessity of the trip makers to overcome the spatial separation, whereas the trip interchange is directly proportional to the measure of spatial separation.

A simple equation representing the above relation is given by:

\[ T_{ij} = \frac{K_P_i A_j}{d_{ij}^n} \]

where,

- \( T_{ij} \) = Trips between zones \( i \) and \( j \)
- \( P_i \) = Trips produced in zone \( i \)
- \( A_j \) = Trips attracted to zone \( j \)
- \( d_{ij} \) = Distance between zone \( i \) and zone \( j \) (or the time (or) cost of travelling between the zones)
- \( K \) = A constant, usually independent of \( i \)
\[ n \quad \text{A exponential constant, whose value is usually found to lie between 1 and 2.} \]

The following formula is also used by dispensing the proportionality constant:

\[ T_{i-j} = P_i \times \frac{A_i^j}{(d_i-j)^n} + \ldots + \frac{A_k}{(d_i-k)^n} \]

where \( k \) = Total number of zones.

**PROBLEMS**

6) A self-contained town consists of four residential areas A, B, C and two industrial estates X and Y. Generation equations show that, for the design year in question, the trips from home to work generated by each residential area per 24 hour day are as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1000</td>
</tr>
<tr>
<td>B</td>
<td>2250</td>
</tr>
<tr>
<td>C</td>
<td>1750</td>
</tr>
<tr>
<td>D</td>
<td>3200</td>
</tr>
</tbody>
</table>

There are 3400 jobs in industrial estate X and 4500 in industrial estate Y. It is known that the attraction between zones is inversely proportional to the square of the journey times between zones. The journey times in minutes from home to work are:

<table>
<thead>
<tr>
<th>ZONES</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>D</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>
Calculate and tabulate the interzonal trips for journeys from home to work.

**Solution**

\[
T_{i-j} = P_i \times \frac{A_i}{(d_{i-j})^2}
\]

\[
T_{A-x} = \frac{1000 \times 3700}{15^2} \frac{3700 + 4500}{15^2 + 20^2}
\]

\[
T_{A-x} = \frac{1000 \times 16.44}{16.44 + 11.25} = 59.4
\]

\[
T_{A-y} = \frac{1000 \times 4500}{20^2} \frac{3700 + 4500}{15^2 + 20^2}
\]

\[
T_{A-y} = \frac{1000 \times 11.25}{16.44 + 11.25} = 40.6
\]

\[
T_{B-x} = \frac{2250 \times 3700}{15^2} \frac{3700 + 4500}{15^2 + 20^2}
\]

\[
T_{B-x} = \frac{2250 \times 16.44}{16.44 + 4.5} = 60.2
\]

\[
T_{B-y} = \frac{2250 \times 4500}{10^2} \frac{3700 + 4500}{15^2 + 10^2}
\]
\[ T_{B-y} = \frac{3250 \times 4.5}{16.44 + 4.5} = 16.48 \]

\[ T_{C-x} = \frac{1750 \times 3700}{10^2} \]

\[ = \frac{3700 + 4500}{10^2} \]

\[ T_{C-x} = \frac{1750 \times 3.7}{3.7 + 4.5} = 790 \]

\[ T_{C-y} = \frac{1750 \times 4500}{10^2} \]

\[ = \frac{3700 + 4500}{10^2} \]

\[ T_{C-y} = \frac{1750 \times 4.5}{3.7 + 4.5} = 960 \]

\[ T_{D-x} = \frac{3200 \times 3700}{15^2} \]

\[ = \frac{3700 + 4500}{15^2} \]

\[ T_{D-x} = \frac{3200 \times 16.44}{16.44 + 11.25} = 1900 \]

\[ T_{D-y} = \frac{3200 \times 4500}{20^2} \]

\[ = \frac{3700 + 4500}{15^2} \]

\[ T_{D-y} = \frac{3200 \times 11.25}{16.44 + 11.25} = 1300 \]

The results are tabulated in the matrix as shown:
It can be seen that the total attractions do not tally with the predicted attractions. Therefore, the total attractions are first adjusted, using the following formula:

\[ A_{jk} = \frac{A_j}{C_j^{(m-1)}} \times A_j^{(m-1)} \]

where \( A_{jm} \) = Adjusted attraction factor, iteration \( m \)
\( A_j \) = Desired attraction
\( A_j^{(m-1)} \) = Attraction factor, iteration \( m-1 \)
\( C_j^{(m-1)} \) = Actual attraction factor, iteration \( m-1 \)

For second iteration, \( m = 2 \)

\[ A_{j1} \text{ for zone } X = \frac{3700}{3886} \times 8200 = 3523 \]

\[ A_{j2} \text{ for zone } Y = \frac{4500}{4314} \times 8200 = 4694 \]

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>( T_{ij} ) For Origin Zones A, B, C, D Total Productions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>594</td>
<td>406</td>
<td>1000</td>
</tr>
<tr>
<td>B</td>
<td>602</td>
<td>1648</td>
<td>2250</td>
</tr>
<tr>
<td>C</td>
<td>90</td>
<td>960</td>
<td>1750</td>
</tr>
<tr>
<td>D</td>
<td>1900</td>
<td>1300</td>
<td>3800</td>
</tr>
<tr>
<td>Total Calculated Attractions, ( C_j )</td>
<td>( \frac{3886}{4314} )</td>
<td>( \frac{8200}{8200} )</td>
<td></td>
</tr>
<tr>
<td>Total Predicted Attractions, ( A_j )</td>
<td>( \frac{3700}{4500} )</td>
<td>( \frac{8200}{8200} )</td>
<td></td>
</tr>
</tbody>
</table>
Recalculating,

\[ T_{A-x} = \frac{1000 \times 3523}{15^2} \]
\[ \frac{3523}{15^2} + \frac{4694}{10^2} \]
\[ T_{A-x} = \frac{1000 \times 15.66}{15.66 + 11.34} = 572 \]

\[ T_{A-y} = \frac{1000 \times 11.34}{15.66 + 11.34} = 4.29 \]

\[ T_{B-x} = \frac{2250 \times 3523}{15^2} \]
\[ \frac{3523}{15^2} + \frac{4694}{10^2} \]
\[ T_{B-x} = \frac{2250 \times 15.66}{15.66 + 46.94} = 563 \]

\[ T_{B-y} = \frac{2250 \times 46.94}{15.66 + 46.94} = 1684 \]

\[ T_{C-x} = \frac{1750 \times 3523}{10^2} \]
\[ \frac{3523}{10^2} + \frac{4694}{10^2} \]
\[ T_{C-x} = \frac{1750 \times 35.23}{35.23 + 46.94} = 750 \]

\[ T_{C-y} = \frac{1750 \times 46.94}{35.23 + 46.94} = 999 \]
\[ T_{D-x} = \frac{3200 \times 3523}{15^2} \]
\[ = \frac{3523 + 4694}{15^2} \]
\[ = \frac{3200 \times 15.66}{15.66 + 11.74} = 1829 \]

\[ T_{D-y} = \frac{3200 \times 11.74}{15.66 + 11.74} = 1371 \]

The results are tabulated in the matrix below:

<table>
<thead>
<tr>
<th>A</th>
<th>572</th>
<th>429</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>563</td>
<td>1684</td>
<td>2850</td>
</tr>
<tr>
<td>C</td>
<td>750</td>
<td>999</td>
<td>1750</td>
</tr>
<tr>
<td>D</td>
<td>1829</td>
<td>1371</td>
<td>3200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Calculated Attractions, C_j</th>
<th>3714</th>
<th>4486</th>
<th>8200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Predicted Attractions, A_j</td>
<td>3700</td>
<td>4500</td>
<td>8200</td>
</tr>
</tbody>
</table>

The results are now closer to the total predicted attractions. If more accuracy is needed, further iterations can be done.

(2) The total trips produced in and attracted to the three zones A, B and C of a survey area in the design year are tabulated below:
<table>
<thead>
<tr>
<th>ZONE</th>
<th>TRIPS PRODUCED</th>
<th>TRIPS ATTRACTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td>B</td>
<td>3000</td>
<td>4000</td>
</tr>
<tr>
<td>C</td>
<td>4000</td>
<td>2000</td>
</tr>
</tbody>
</table>

It is known that the trips between two zones are inversely proportional to the second power of the travel time between zones, which is uniformly 20 minutes. If the trip interchange between zones B and C is known to be 600, calculate the trip interchange between zones A and B, A and C, B and A and C and B.

⇒ SOLUTION

Using the formula,
\[ T_{i-j} = \frac{K \cdot P_i \cdot A_j}{t^2} \]

\[ T_{B-C} = \frac{K \cdot P_B \cdot A_C}{t^2} \]

600 = \[ \frac{K \times 3000 \times 2000}{20^2} \]

\[ K = 0.04 \]

\[ T_{A-B} = \frac{0.04 \times 2000 \times 4000}{20^2} = 800 \]

\[ T_{A-C} = \frac{0.04 \times 2000 \times 2000}{20^2} = 400 \]

\[ T_{B-A} = \frac{0.04 \times 3000 \times 3000}{20^2} = 900 \]

\[ T_{C-B} = \frac{0.04 \times 4000 \times 4000}{20^2} = 1600 \]
TANNER'S MODEL

Tanner has suggested that the inverse of \( m \)th power, in the gravity model formula cannot give valid estimates at very small and very large distances. In this place, he proposed the function \( (e^{\lambda d}/d^n) \), where \( \lambda \) and \( m \) are constants. The formula suggested by him is of the form:

\[
t_{1-2} = m \frac{P_1 P_2 e^{-\lambda d}}{d_{1-2}^m} \left[ \frac{1}{C_1} + \frac{1}{C_2} \right]
\]

where, \( t_{1-2} \) = Number of journey per day between the two places 1 and 2.

\( m, \lambda, m \) = Constants

\( P_1, P_2 \) = Populations, or other measures of size of the two places.

\( d_{1-2} \) = Distance between places 1 and 2 or the time or cost of travelling between them.

\( C_1, C_2 \) = Constants, one for each place, \( C_1 \) is given by:

\[
C_1 = \frac{1}{\lambda} P_i e^{-\lambda d_{i-j}}
\]

OPPORTUNITY MODEL

Opportunity models are based on the statistical theory of probability as the theoretical foundation. The two well-known methods are given below:

1) Intervening opportunities models
2) Competing opportunities models

Opportunity model can be represented by general form:

\[
T_{i-j} = 0_i \times P(D_j)
\]
where,  

\( T_{i,j} = \) Predicted number of trips from zone \( i \) to \( j \)  

\( O_i = \) Total number of trips originating in zone \( i \)  

\( P(D_j) = \) Calculated probability of a trip terminating in zone \( j \)  

\( D_j = \) Total of Trip destinations attracted to zone \( j \)  

**INTERVening OPPORTUNITIES Model**

In the intervening opportunities model, it is assumed that the trip interchange between an origin and a destination zone is equal to the trips emanating from the origin zone multiplied by the probability that each trip will find an acceptable terminal at the destination.

It is further assumed that the probability that a destination will be acceptable is determined by two zonal characteristics: the size of the destination and the order in which it is encountered as trips proceed from the origin.

The intervening opportunity model can be represented by the formula below:

\[ T_{i,j} = Q_i \left( e^{-LP} - e^{-LA} \right) \]  

\[ A = B + D_j \]

where,  

\( Q_i = \) Total no. of trips originating in zone \( i \).  

\( T_{i,j} = \) Predicted no. of trips from zone \( i \) to zone \( j \).  

\( P = \) Probability per destination  

\( A = \) No. of destinations between \( i \) and \( j \) (including \( j \))  

\( B = \) No. of destinations between \( i \) and \( j \) (excluding \( j \))
Competing Opportunity Model

In this model, the adjusted probability of a trip in a zone is the product of two independent probabilities: the probability of a trip being attracted to a zone and the probability of a trip finding a destination in that zone. The model can be represented by the formula below:

\[ T_{i-j} = P_j \cdot \frac{A_j}{\sum_j A_j} \]

\[ \sum_j \left( \frac{A_j}{\sum_j A_j} \right) \]
INTRODUCTION

Modal Split is one of the most important aspects of transportation planning. It is the process of segregating person trips by the mode of travel. It is usually expressed as the percentage of the total number of trips. It refers to the trips made by private car and other private vehicles as opposed to public transport (road or rail).

Future Modal Split can be accurately forecast if the mode choice behaviour of the travellers is analysed in a scientific manner. There are many factors that govern the individual’s choice of modes which are very complex. Therefore, the issue of mode choice is one of the most important elements in transport planning and policy-making.

FACTORS AFFECTING MODAL SPLIT

The following are the primary factors affecting the modal choice of travellers:

1. Characteristics of the trip
2. Household Characteristics
3. Zonal Characteristics
4. Transport system Characteristics

CHARACTERISTICS OF THE TRIP

1. Trip Purpose - The trip purpose to certain extent influence the choice of mode of travel. For example, home-based school trips have a high rate of usage of public transport. Whereas for home-based shopping trips have a higher rate of private car.
(2) **TRIP LENGTH** - The trip length also influences the choice of mode of travel. For longer distance travel, people prefer public modes of transportation, whereas for short distance travel, people use private vehicles. Trip length can also be measured by the travel time and the cost of travelling.

**HOUSEHOLD CHARACTERISTICS**

(1) **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. Lower income groups usually prefer public transport.

(2) **CAR OWNERSHIP** - Car ownership is determined by the income and for this reason, both income and car ownership are interrelated in the analysis of modal choice. Families which own a car prefer private cars for trips and families without a car prefer to travel through public transport.

(3) **FAMILY SIZE AND COMPOSITION** - The number of persons in family, number of people earning, unemployed and other socio-economic factors of family greatly influence the mode choice. Some of these factors are responsible for certain trips in public transport.

**ZONAL CHARACTERISTICS**

(1) **RESIDENTIAL DENSITY** - The use of public transport increases as the residential density increases. This is due to the fact that the areas with the highest residential density are generally inhabited by people with varying ranges of income, demand...
ed by low income group and middle income group.

2) CONCENTRATION OF WORKERS

3) DISTANCE FROM CBD

TRANSPORT SYSTEM CHARACTERISTICS

1) Accessibility Ratio - It is a measure of the relative accessibility of that zone to all other zones w.r.t mass transit network and highway network.

2) Travel Time Ratio - The ratio of the travel time by public transport to the travel time by private car gives a measure of the attractiveness of that zone.

3) Travel Cost Ratio - It is the ratio of cost of travel by public transport to the cost of travel by private car, and is a measure of income level or vehicle ownership level on the choice of travel mode.

MODAL SPLIT IN URBAN TRANSPORT PLANNING

Basically, two variations are possible:
1) Pre-distribution Modal Split
2) Post-distribution Modal Split

Pre-Distribution Modal Split

It is one in which the modal split is considered before the trip distribution stages. This procedure is also known as Trip End Modal Split Procedure.

In this procedure, there are again two possibilities:
(i) At trip generation stage itself
(ii) After trip generation, but before trip distribution.

If the modal split is considered at the trip generation stage itself, it is necessary to derive separate MNL equations for each mode of transport. The factors that are normally considered to influence modal choice in this type of procedure are car ownership, residential density, distance of the trip of origin from the CBD, etc.

If the modal split is carried out after generation but before distribution, the trip generations are calculated on the assumption that the mode of travel has no influence on trip generation. After this, determining the total trip productions and attractions, these trips are allocated to the public transport system and private cars by considering the relative attractiveness of each mode and then distribution is carried out.

ADVANTAGES

(1) They are less difficult and less costly as compared to pure distribution methods.
(2) The possibility of separate public transport and private distribution is afforded by this method because of the differing trip lengths.
(3) This method reflects factors such as income, car ownership, family size, employment which are characteristics of trip generation.

DISADVANTAGES

(1) It does not consider the trip generation characteristics fully.
(2) It is insensitive to future developments in interregional travel.
Flow Diagram for Modal Split Carried Out Between Trip Generation and Trip Distribution

- Public Transport System Characteristics
- Land-Use Characteristics
- Socio-Economic Characteristics
- Highway Characteristics

→ Trip Generation → Modal Split

- Public Transport Trip Distribution
- Road Vehicle Trip Distribution

→ Public Transport Traffic Assignment → Highway Traffic Assignment

Post-Distribution Modal Split

It is one in which the modal split is considered after trip distribution stage. This procedure is also known as Trip Interchange Modal Split Procedure.

In the post-distribution models, one possibility is to carry out modal split after distribution, but before assignment. In this procedure, the zone-to-zone home-based trips are known. Using this as input, the procedure determines the
Flow Diagram for Modal Split Carried out After Trip Distribution

1. Public Transport System Characteristics
2. Land-use Characteristics
3. Socio-Economic Characteristics
4. Highway Characteristics

→ Trip Generation

→ Total Person Trip Distribution

→ Modal Split

- Zone-to-Zone Public Transport Person Trips
- Zone-to-Zone Private Car Person Trips
- Zone-to-Zone Car Vehicle Trips
- Develop Zone-to-Zone Car Occupancy

Public Transport Traffic Assignment

Highway Traffic Assignment

Zone-to-zone public transport travellers on the basis of various characteristics of the person making the journey and characteristics of the transport system — all measured on zone-to-zone basis. By subtracting the zone-to-zone public transport trips from the total zone-to-zone person trips.
the person trips made by motor vehicle are derived. The assignment of these trips is carried out as the next stage.

ADVANTAGES

(1) It is useful in situations where serious consideration is given to public transport planning.
(2) This is beneficial for long-term decision-making.
(3) The method considers private car and public transport usage on a zone-to-zone basis instead of a zonal basis as in pre-distribution models.

DISADVANTAGES

(1) This model is more complex if the number of zones are large.
(2) The total person trip distribution is carried out before any modal choice is considered.

RECENT DEVELOPMENTS IN MODAL SPLIT ANALYSIS

The following techniques are used for determining modal split are:

(a) Probit Analysis
(b) Logit Analysis
(c) Discriminant Analysis

PROBIT ANALYSIS

Probit Analysis is based on the principle that if members of population are subjected to a stimulus that can range over an infinite scale, the frequency of response to stimulus will be normally distributed.

In modal choice, the stimulus is assumed to be made up
of the relative disadvantages of travel on two modes and of the characteristics of the user. The probit equation can be written as:

\[ Y = a_0 + a_1 x_1 + a_2 x_2 + \ldots \]

where, \( Y \) = Probit value for the probability of transit mode choice,

\( x_1, x_2 \) = Disability variables

**DISADVANTAGE** - Determination of \( a_0, a_1, a_2, \ldots \) is done by calibration procedures, often lengthy and time-consuming.

**LOGIT ANALYSIS**

Logit Analysis assumes that the probability of the occurrence of an event varies w.r.t. function \( F(x) \) as a sigmoid curve called the logistic curve. The logit model can be written as:

\[ P_i = \frac{1}{1 + e^{b(x)}} \]

where, \( P_i \) = Probability of an individual choosing mode 1

1 - \( P_i \) = Probability of an individual choosing mode 2

\( b(x) = x_1 (C_1 - C_2) + x_2 (t_1 - t_2) + x_3 (\ldots) + \ldots \)

\( x_1, x_2, x_3, \ldots \) = Model parameters

\( C_1, C_2 \) = Cost of travel by modes 1 and 2.

\( t_1, t_2 \) = Time of travel by modes 1 and 2.

**ADVANTAGE** - Simpler than Probit Analysis for use and interpretation.

**PROBLEMS**

1) Given the utility expression,

\[ U_k = A_k - 0.05T_a - 0.04T_w - 0.02T_n - 0.01C \]
where $T_a$ is the access time, $T_w$ is the waiting time, $T_r$ is the riding time, $U_k$ is the utility, $A_k$ is the constant value, and $C$ is the out of pocket cost.

(i) Apply the logit model to calculate the division of usage between the motorised two-wheeler mode ($A_k = -0.005$) and bus ($A_k = -0.05$) (data is as per Table below)

(ii) Estimate the shift of patronage that would result from doubling the bus out of pocket cost.

<table>
<thead>
<tr>
<th>MODE</th>
<th>$T_a$ min</th>
<th>$T_w$ min</th>
<th>$T_r$ min</th>
<th>CRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorised two-wheeler</td>
<td>10</td>
<td>0</td>
<td>45</td>
<td>150</td>
</tr>
<tr>
<td>Bus</td>
<td>20</td>
<td>20</td>
<td>60</td>
<td>100</td>
</tr>
</tbody>
</table>

Solution

Part (i) is solved by substituting the given values into the utility functions and solving the logit model equation:

$$P = \frac{e^{U_k}}{e^{U_k} + e^{U_x}}$$

<table>
<thead>
<tr>
<th>MODE</th>
<th>$T_a$</th>
<th>$T_w$</th>
<th>$T_r$</th>
<th>$C$</th>
<th>$A_k$</th>
<th>$U_k$</th>
<th>$e^{U_k}$</th>
<th>$e^{U_x}$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorised two-wheeler</td>
<td>10</td>
<td>0</td>
<td>45</td>
<td>150</td>
<td>-0.005</td>
<td>-2.905</td>
<td>0.055</td>
<td>0.764</td>
<td>0.072</td>
</tr>
<tr>
<td>Bus</td>
<td>20</td>
<td>20</td>
<td>60</td>
<td>100</td>
<td>-0.05</td>
<td>-4.050</td>
<td>0.017</td>
<td>0.236</td>
<td></td>
</tr>
</tbody>
</table>

Part (ii) is essentially identical to part (i) except for the change in the out of pocket cost for bus travel.
2.3 Transport demand and supply

The concept of demand and supply are fundamental to economic theory and is widely applied in the field to transport economics. In the area of travel demand and the associated supply of transport infrastructure, the notions of demand and supply could be applied. However, we must be aware of the fact that the transport demand is a derived demand, and not a need in itself. That is, people travel not for the sake of travel, but to practice in activities in different locations.

The concept of equilibrium is central to the supply-demand analysis. It is a normal practice to plot the supply and demand curve as a function of cost and the intersection is then plotted in the equilibrium point as shown in Figure 2.1. The demand for travel \( T \) is a function of cost \( C \) is easy to conceive. The classical approach defines the supply function as giving the quantity \( T \) which would be produced, given a market price \( C \). Since transport demand is a derived demand, and the benefit of transportation on the non-monetary terms (time in particular), the supply function takes the form in which \( C \) is the unit cost associated with meeting a demand \( T \). Thus, the supply function encapsulates response of the transport system to a given level of demand.

In other words, supply function will answer the question what will be the level of service of the system, if the estimated demand is loaded to the system. The most common supply function is the link travel time function which relates the link volume and travel time.

2.4 Travel demand modeling

Travel demand modeling aims to establish the spatial distribution of travel explicitly by means of an appropriate system of zones. Modeling of demand thus implies a procedure for predicting what travel decisions people would like to make given the generalized travel cost of each alternatives. The base decisions include the choice of destination, the choice of the mode, and the choice of the route. Although various modeling approaches are adopted, we will discuss only the classical transport model popularly known as four-stage model (FSM).

The general form of the four stage model is given in Figure 2.2. The classic model is presented as a sequence of four sub models: trip generation, trip distribution, modal split, trip
assignment. The models starts with defining the study area and dividing them into a number of zones and considering all the transport network in the system. The database also include the current (base year) levels of population, economic activity like employment, shopping space, educational, and leisure facilities of each zone. Then the trip generation model is evolved which uses the above data to estimate the total number of trips generated and attracted by each zone. The next step is the allocation of these trips from each zone to various other destination zones in the study area using trip distribution models. The output of the above model is a trip matrix which denote the trips from each zone to every other zones. In the succeeding step the trips are allocated to different modes based on the modal attributes using the modal split models. This is essentially slicing the trip matrix for various modes generated to a mode specific trip matrix. Finally, each trip matrix is assigned to the route network of that particular mode using the trip assignment models. The step will give the loading on each link of the network.

The classical model would also be viewed as answering a series of questions (decisions) namely how many trips are generated, where they are going, on what mode they are going, and finally which route they are adopting. The current approach is to model these decisions using discrete choice theory, which allows the lower level choices to be made conditional on higher choices. For example, route choice is conditional on the mode choice. This hierarchical choices of trip is shown in Figure 2.3 The highest level to find all the trips originating from a zone is calculated based on the data and aggregate cost term \( C_{ij} \). Based on the aggregate travel cost \( C_{ij} \) from zone \( i \) to the destination zone \( j \), the probability \( p_{m|ij} \) of trips going to zone \( j \) is computed and subsequently the trips \( T_{ij} \) from zone \( i \) to zone \( j \) by all modes and all routes are computed. Next, the mode choice model compute the probability \( p_{m|ij} \) of choosing mode \( m \) based on the travel cost \( C_{jm} \) from zone \( i \) to zone \( j \), by mode \( m \) is determined. Similarly, the route choice gives the trips \( T_{ijn|r} \) from zone \( i \) to zone \( j \) by mode \( m \) through route \( r \) can be computed. Finally the travel demand is loaded to the supply model, as stated earlier, will
produce a performance level. The purpose of the network is usually measured in travel time which could be converted to travel cost. Although not practiced ideally, one could feed this back into the higher levels to achieve real equilibrium of the supply and demand.

2.5 Summary

In a nutshell, travel demand modeling aims at explaining where the trips come from and where they go, and what modes and which routes are used. It provides a zone wise analysis of the trips followed by distribution of the trips, split the trips mode wise based on the choice of the travelers and finally assigns the trips to the network. This process helps to understand the effects of future developments in the transport networks on the trips as well as the influence of the choices of the public on the flows in the network.

2.6 Problems

1. Link travel time function relates travel time and
   (a) link volume
   (b) link cost
   (c) level of service
   (d) none of the above

2. What is the first stage of four-stage travel demand modeling?
   (a) Trip generation
   (b) Trip distribution
   (c) Modal split
(d) Traffic assignment

2.7 Solutions

1. Link travel time function relates travel time and
   (a) link volume√
   (b) link cost
   (c) level of service
   (d) none of the above

2. What is the first stage of four-stage travel demand modeling?
   (a) Trip distribution
   (b) Trip generation√
   (c) Modal split
   (d) Traffic assignment
Module-5

Traffic Assignment: Diversion Curves; Basic Elements of Transport Networks, Coding, Route Properties, Path Building Criteria, Skimming Tree, All-or-Nothing Assignment, Capacity Restraint Techniques, Reallocation of Assigned Volumes, Equilibrium Assignment. Introduction to land use planning models, land use and transportation interaction.

Traffic assignment is stage in the transport planning process wherein the trip interchanges are allocated to different parts of the network forming the transportation system. In this stage of transportation planning the route to be travelled is determined and the interzonal flows are assigned to the selected routes.

The applications of traffic assignment are

1. To determine the deficiencies in the existing transportation system by assigning the future trips to the existing system.
2. To evaluate the effects of limited improvements and additions to the existing transportation system by assigning estimated future trips to the improved network.
3. To develop construction priorities by assigning estimated future trips for the intermediate years to the transportation system proposed for those years.
4. To test alternative transportation system proposals by systematic and readily repeatable procedures.
5. To provide design hour traffic volumes on highway and turning movements at junctions.

The major aims of traffic assignment procedures are:

1. To estimate the volume of traffic on the links of the network and possibly the turning movements at intersections.
2. To furnish estimates of travel costs between trip origins and destinations for use in trip distribution.
3. To obtain aggregate network measures, e.g. total vehicular flows, total distance covered by the vehicle, total system travel time.
4. To estimate zone-to-zone travel costs(times) for a given level of demand.
5. To obtain reasonable link flows and to identify heavily congested links.
6. To estimate the routes used between each origin to destination (O-D) pair.
7. To analyses which O-D pairs that uses a particular link or path.
8. To obtain turning movements for the design of future junctions.

Basic Elements of Transport Networks

In order to understand the demand of mobility it is necessary to represent transportation infrastructure in formal, simple and sufficiently detailed way. The method adopted to represent
the transportation infrastructure is by a set of links and a set of nodes. The relationship between the links and nodes are referred as network topology.

Components of basic transport network are as defined below

1. **Node.** Any location that has access to a transportation network.
2. **Link.** Physical transport infrastructures that enable to connect two nodes.
3. **Flow.** The amount of traffic that circulates on a link between two nodes and the amount of traffic going through a node.
4. **Gateway.** A node that is connecting two different systems of circulation that are usually separate networks (nodes) and which acts as compulsory passage for various flows. An intermodal function is performed so that passengers or freight are transferred from one network to the other.
5. **Hub.** A node that is handling a substantial amount of traffic and connects elements of the same transport network, or different scales of the network (e.g. regional and international).
6. **Feeder.** A node that is linked to a hub. It organizes the direction of flows along a corridor and can be considered as a consolidation and distribution point.
7. **Corridor.** A sequence of nodes and links supporting modal flows of passengers or freight. They are generally concentrated along a communication axis, have a linear orientation and connect to a gateway.
A transport network may be formally represented as a set of links and a set of nodes.

A link connects two nodes and a node connects two or more links.

Links may be either directed, in which case they specify the direction of movement, or undirected.

Two links are said to be parallel if they connect the same pair of nodes in the same direction.

A loop is a link with the same node at either end. Some of the algorithms described later require the exclusion of parallel links and loops.

Links may have various characteristics. In the context of transportation network analysis, the following are some of the characteristics of interest:

- Link length (in metres or perhaps in average number of vehicles);
- Link cost (sometimes travel time but more generally a linear combination of time and distance);
- Link capacity (maximum flow). A link may be regarded as a conduit for flow whose units of measurement will depend on the application (for example, vehicles per hour or passengers per hour).

Flow consists of one or more commodities. While the commodities may refer to different kinds of goods and services, in this context they often refer to other aspects of a unit of flow, like its origin or its destination (sometimes referred to as the source and sink respectively). If there is only one origin and one destination, and no other relevant classification, flow is said to be single commodity. In addition to commodities, user classes are sometimes identified to distinguish between units of flow with different forms of travel behavior. A movement in a transportation network corresponds to a flow with a distinct origin and destination. Origins and destinations may correspond to specific buildings, like a house or an office, or to zones, depending on the level of aggregation. From the perspective of a transportation network, an origin or destination is represented by a kind of node, referred to as a centroid. Each centroid is connected to one or more internal nodes by a kind of link referred to as a centroid connector (or just a connector). While links tend to correspond to identifiable pieces of transport infrastructure (like a section of road or railway), centroid connectors are artifacts, especially when the respective centroid
corresponds to a zone with, in reality, multiple entrances and exits. Figure provides an example of a transportation network with one origin centroid, two destination centroids, five links, four internal nodes, three connectors and 5 paths.

Other useful terms with mostly intuitive interpretations are:

- A **path**, which is a sequence of distinct nodes connected in one direction by links; a cycle, which is a path connected to itself at the ends;
- A **tree**, which is a network where every node is visited once and only once; and a cutset, which is a minimal collection of links whose removal from the network would cut the network in two with no links between the two resulting sub-networks.

**Transport Network Representation**

A network may be specified as a directed graph consisting of finite set of elements called nodes, pairs of which are joined by one or more arcs usually referred to as links.

Ms. SHILPA Asst Prof, SVCE
Links: The transport network consists of four basic types of links, which are: Centroid connector. Schematic representation of the local network connecting the zonal trips to the network. The location and number of centroid connectors can have a significant impact on how traffic is assigned to the network. Centroid connectors should represent, as closely as possible, the local streets within the zone and reasonable access points to collectors/arterials in the system. Figure shows a sample centroid connector in a network.

Road links: Road links are classified on the basis of their capacity and speed-flow relationships. For an example in typical road network there will be different links of Freeways, arterial roads, etc. each having different capacities and speed limits. Figure shows typical road links in a network.
Public Transport Links: Public transport links includes bus route, railway lines etc. within which each could be classified based on their capacity.

DIVERSION CURVES

Diversion curve models was developed in early 1950s to know how many drivers would be diverted from arterial streets to a proposed freeway in order to make decisions related to the geometric design and capacity of proposed urban freeways.

This model employs empirically derived curves to compute the percentage of trips that would use the freeway in route between two points on some measure of relative impedance between the freeway route and the fastest arterial route between the two points.

The diversion curves can be constructed using a variety of variable such as:

i. Travel time saved
ii. Distance covered
iii. Travel time ratio
iv. Distance ratio
v. Travel time and distance saved
vi. Distance and speed ratio
vii. Travel cost ratio
Figure: simple diversion curves using one variable.
Figure: diversion curves for expressways in India

California diversion curves

These curves used travel-time and travel-distance differences between two alternative paths to estimate the percentage of trips that would use the freeway. The formula for determining percentage usage of the freeway in route between two points is given by

\[ P = 50 + \frac{50(d+0.5t)}{[(d-0.5t)^2 + 4.5]^{0.5}} \]

Where

- \( P \) = percentage usage
- \( d \) = distance saved in miles
- \( t \) = time saved in minutes

![Diagram of California diversion curves]

Figure: California diversion curves

Detroit diversion curves

The Detroit area transportation study from a somewhat different viewpoint, still using two-parameters found to be related to freeway usage where the ratio of expressway speed to arterial speed, and the ratio of expressway distance to arterial distance. The diversion curves developed by Detroit transportation study is given in figure

Ms. SHILPA Asst Prof, SVCE
Bureau of public roads diversion curve

The most widely used method of diversion curve is Bureau of public roads diversion curve. This form of diversion is dependent on one parameter only, the ratio of travel times by quickest combined arterial freeway route to the quickest arterial only route. With a one parameter relationship, one single diversion curve defines the relationship. The form of S-shaped diversion curve is similar to those used in Detroit study for higher speed ratios.
The following formula can be fitted to these curves:

\[ F = \frac{100}{1 + t_r^p} \]

Where \( p \) = percent of traffic diverted to new system
\[ t_r = \text{travel time ratio} = \frac{\text{time on new system}}{\text{time on old system}}. \]

**ASSIGNMENT TECHNIQUES**

There are a number of methods of assignment of vehicle trip interchange between the routes. These are:

1. All – or – nothing assignment
2. Capacity restraint assignment
3. Incremental traffic assignment
4. Diversion curves
5. Multiple route assignment
6. User equilibrium assignment
7. Dynamic assignment
8. Probabilistic assignment

The selection criteria for choosing a route by drivers are important for traffic assignment process. Following are the various criteria for route selection

1. Travel time
2. Travel distance
3. Travel cost
4. Generalized cost
5. comfort
6. level of service

**All-Or-Nothing assignment**

In this method the trips from any origin zone to any destination zone are loaded onto a single, minimum cost, path between them. This model is unrealistic as only one path between every O-D pair is utilized even if there is another path with the same or nearly same travel cost. Also, traffic on links is assigned without consideration of whether or not there is adequate capacity or heavy congestion; travel time is a fixed input and does not vary depending on the congestion on a link. However, this model may be reasonable in sparse and uncongested networks where there are few alternative routes and they have a large difference in travel cost. This model may also be
used to identify the *desired path*: the path which the drivers would like to travel in the absence of congestion. In fact, this model's most important practical application is that it acts as a building block for other types of assignment techniques. It has a limitation that it ignores the fact that link travel time is a function of link volume and when there is congestion or that multiple paths are used to carry traffic.

<table>
<thead>
<tr>
<th>Zone Centroid</th>
<th>To Zone Centroid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

**Capacity restraint assignment**

It is a process in which the travel resistance of a link is increased according to a relation between the practical capacity of link and the volumes assigned to the link. This system clearly restrains the number of vehicles that can use any particular corridor, if the assigned volume are beyond the capacity of the network, and redistributes the traffic to realistic alternative paths.

Its procedure as follows:

1. The best path is determined as in all-or-nothing assignment procedure.

<table>
<thead>
<tr>
<th>Link</th>
<th>Traffic flow (vehicles/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>4500</td>
</tr>
<tr>
<td>B-C</td>
<td>45000</td>
</tr>
<tr>
<td>A-C</td>
<td>2500</td>
</tr>
<tr>
<td>C-D</td>
<td>7000</td>
</tr>
<tr>
<td>D-E</td>
<td>5000</td>
</tr>
<tr>
<td>D-E</td>
<td>4000</td>
</tr>
</tbody>
</table>
ii. The traffic is then assigned to the minimum paths and as the assigned volume on each link approaches the capacity of the link, the new set of travel time on the link is calculated

iii. New minimum path trees are built using new travel time

iv. Interzonal trip interchanges are then assigned on all-or-nothing basis to the shortest path trees.

**Incremental assignment**

Incremental assignment is a process in which fractions of traffic volumes are assigned in steps. In each step, a fixed proportion of total demand is assigned based on all-or-nothing assignment. After each step, link travel times are recalculated based on link volumes. When there are many increments used, the flows may resemble an equilibrium assignment; however, this method does not yield an equilibrium solution. Consequently, there will be inconsistencies between link volumes and travel times that can lead to errors in evaluation measures. Also, incremental assignment is influenced by the order in which volumes for O-D pairs are assigned, raising the possibility of additional bias in results.

**Multiple route assignment**

This method of traffic assignment of this method was developed by Burell. The main assumption of this method is that a trip-maker does not know the correct travel time. He only considers the supposed travel time, which are generalized by the model by drawing a random travel time from a distribution of travel times. The correct travel time is considered to be the mean travel time.

A network with the correct travel time along with the distribution of supposed travel time, and plus and minus 20%. Correct travel time is presented below. In this case, the following three routes are considered:

i. Through nodes 1-2-3

ii. Through nodes 1-4-3

iii. Through nodes 1-5-3

A dice which has six sides can be tossed to generate a random number, pertaining to the supposed and correct travel time. For example,

- A throw of one or two simulates the correct travel times
- A throw of three or four represent the supposed travel time with minus 20% of correct travel time
- A throw of five or six represent the supposed travel time with plus 20% of correct time
To find the shortest path between zone 1 and zone 3, the following are the alternatives:

Alternative 1:
This includes zone 1 to zone 3 via zone 2 which finds that the dice throws 3 and 6,

\[ = 16 + 48 \]
\[ = 64 \]

Alternative 2:
It includes zone 1 to zone 3 via zone 4 which finds that the dice throws 4 and 1

\[ = 24 + 36 \]
\[ = 60 \]

Alternative 3:
It includes zone 1 to zone 3 via zone 5 which finds that the dice throws 4 and 1

\[ = 32 + 20 \]
=52

Therefore, we set the first traveller likes to be assigned on the route i.e, 1-5-3

**User equilibrium assignment (UE)**

The user equilibrium assignment is based on Wardrop's first principle, which states that no driver can unilaterally reduce his/her travel costs by shifting to another route. If it is assumed that drivers have perfect knowledge about travel costs on a network and choose the best route according to Wardrop's first principle, this behavioural assumption leads to deterministic user equilibrium. This problem is equivalent to the following nonlinear mathematical optimization program,

\[ t_k(t_k - t_u) = 0 \]  \hspace{1cm} (i)

\[ t_k \cdot t_u \geq 0 \]  \hspace{1cm} (ii)

Where, \( t_k \) is the traffic flow on path ‘k’

\( t_k \) is the travel cost on path ‘k’

\( t_u \) is the minimum cost

Equation (2) can be the following two states:

i. If \( (t_k - t_u) = 0 \), then from (i), \( t_k = 0 \) . this means that all used paths will have the same travel time

ii. \( t_k - t_u > 0 \), then from (1), \( t_k \) is not equal to zero. This means that all unused paths will have the minimum cost path.

**Assumptions**

i. The user has a perfect knowledge of the path cost

ii. Travel time on a given link is a function of the flow on that link only

iii. Travel time functions are positive and increasing

**Dynamic Assignment**

Dynamic user equilibrium, expressed as an extension of Wardrop's user equilibrium principle, may be defined as the state of equilibrium which arises when no driver can reduce his disutility of travel by choosing a new route or departure time, where disutility includes, schedule delay in addition in to costs generally considered. Dynamic stochastic equilibrium may be similarly defined in terms of perceived utility of travel. The existence of such equilibria in complex
networks has not been proven theoretical and even if they exist the question of uniqueness remains open.

The specific limitations of the assignment models are highlighted below.

1. Most of the cost functions, such as the BPR function, do not take into consideration emission-related factors.
2. Interactions between links are not considered; the travel time on one link is independent of the volumes on other links. This is an obvious oversimplification. At intersections, link travel times are affected by volumes on other approaches and opposing left turns. On freeways, merging and weaving conditions can greatly affect travel times. Queuing caused by bottlenecks on other links can also be a factor. Queues build as volumes approach the bottleneck.
3. Although some software packages allow node-based capacities, delays, or performance functions which allows for better modeling of intersection dynamics. However, many of the problems described above cannot be eliminated through network solutions. Some of these issues can be addressed by considering the effects of flows on other links and the delays at a junction, on the link under investigation.

**Introduction to land use planning models**

Land use characteristics and transportation are mutually interrelated. The use of the term land use is based on the fact that through development, urban space put up a variety of human activities. Land is a convenient measure of space and land use provides a spatial framework for urban development and activities. The location of activities and their need for interaction creates the demand for transportation, while the provision of transport facilities influences the location itself. Land uses, by virtue of their occupancy, are supposed to generate interaction needs and these needs are directed to specific targets by specific transportation facilities. The following diagram explains the transportation land use interaction.

![Transportation Diagram]

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Land use means spatial distribution or geographical pattern of the city, residential area, industry, commercial areas and the space set for governmental, institution or recreational purposes. Most human activities, economic, social or cultural involve a multitude of functions, such as production, consumption and distribution. These functions are occurring within an activity system where their locations and spatial accumulation form the land uses. So, the behavioral patterns of individuals, institutions and firms will have an impression on the land use.

**Land use system**

The essential components of the land use system in terms of land use transport modeling are location and development. The urban land use is largely modeled by simulating the mechanisms that effect the spatial allocation of urban activities in the city. A number of other important economic concepts underpin land use transport models, serving as proxies for the complex interactions and motivations driving urban location. Among these are the ideas of bid rent, travel costs, inertia (stability of occupation of land), topography, climate, planning, and size.

**Transport system**

The second major component of a land use transport model, simulated along side land use is the transport system the traditional way of characterizing the transportation system in urban simulation models is a four stage process. The process begins with modeling travel demand and generating an estimate of the amount of trips expected in the urban system. The second phase trip distribution allocates the trips generated in origin zones to destinations in the urban area. The third phase is modal split. Here trips are apportioned to various modes of transport. The four stage simulation processes concludes with trip assignment module that takes estimated trips that have been generated, distributed and sorted by mode and loads it on to various segments of the transport network.

**Factors affecting transport land use relationship**

1. Urban land development
2. Dominance of private vehicle ownership
3. Context of land use and transportation decision making
4. Different time contexts for response.

**CLASSIFICATION OF LAND USES**

The representation of this impression requires a typology of land use, which can be formal or functional as explained below:
- **Formal land use representations** are concerned by qualitative attributes of space such as its form, pattern and geographical aspects and are descriptive in nature.
- **Functional land use representations** are concerned by the level of spatial accumulation of economic activities such as production, consumption, residence, and transport, and are mainly a socioeconomic description of space.

Land use, both in formal and functional representations, implies a set of relationships with other land uses e.g. commercial land use has relationships with its supplier and customers. While relationships with suppliers will dominantly be related with movements of freight, relationships with customers would also include movements of passengers. Since each type of land use has its own specific mobility requirements, transportation is a factor of activity location, which in turn is associated with specific land uses.

**LAND USE AND TRANSPORTATION**

The movement of people and goods in a city, referred as traffic flow, is the joint consequence of land activity and the capability of the transportation system to handle this traffic flow exactly like that of principle of demand and supply. There is a direct interaction between the type and intensity of land use and transportation facilities provided. Ensuring efficient balance between land use activity and transportation capability is primary concern of urban planning. Land use is one of the prime determinants of movement and activity i.e. trip generation which needs streets and transport systems for movement. This will lead to increased accessibility which further enhances value of land and land use.

A transportation / land use system can be divided in three subcategories of models
Land use models which are generally concerned about the spatial structure of macro and microeconomic components, often correlated with transportation requirements. For instance, by using a set of economic activity variables, such as population and level of consumption it becomes possible to calculate the generation and attraction of passengers and freight flows.

**Spatial interactions models** which are mostly concerned about the spatial distribution of movements, a function of land use (demand) and transportation infrastructure (supply). They produce flow estimates between spatial entities, symbolized by origin-destination pairs, which can be disaggregated by nature, mode and time of the day.

**Transportation network models** are which try to evaluate how movements are allocated over a transportation network, often of several modes, notably private and public transportation. They provide traffic estimates for any given segment of a transportation network.

To provide a comprehensive modeling framework, all these models must share information to form an integrated transportation / land use model. For instance, a land use model can calculate traffic generation and attraction, which can be a input to the spatial interaction model. The origin-destination matrix provided by a spatial interaction model can be an input to traffic assignment model, resulting in simulated flows on the transportation network.
Different Land Use Models

The purpose of land use transport models is to assess the policy impacts in terms of the implications of the future growth patterns on both land use and travel related issues. For this purpose, several researchers have developed various models with different theoretical backgrounds and data requirements. From the early developments of land use transport models to the latest state of art, can be broadly classified into three categories (i) Early models (ii) Intermediate era models (iii) Modern era models.

LOWRY LAND USE MODEL

The original Lowry was published in 1964 and since then several important extensions of the original model have been applied to practical planning problems (Hutchinson, 1974). The Lowry model conceives of the major spatial features of an urban area in terms of three broad sectors of activity i.e. basic employment sector, the population serving employment and the household sector.

The basic employment is employment whose products and services are utilized outside the study area. With Lowry model, spatial distribution of basic employment is allocated exogenously to the model while the other two activity sectors are calculated by the model by applying an iterative procedure, until the constraints, which are maximum no. of household for each zone and minimum population serving employment for any zone, are satisfied. The flow diagram for this model is shown below.
The model views the spatial properties in terms of:

1. Employment in basic industries
2. Employment in population serving industries
3. Household or population sector

Basic Employment: - employment in those industries whose products or services depend on markets on external to the region under study.

The activities which the model defines are population, service employment and these activities correspond to residential, service and industrial land uses.

Some of the salient features of Lowry model are

a) It assumes an economic base mechanism where employment is divided into basic and non-basic sectors. Basic employment is defined as that employment which is associated with industries whose products are largely used outside the region, where as the products of the service employment are consumed within the region.
b) It is assumed that the location of basic industry is independent of the location of residential areas and service centers.

c) Population is allocated in proportion to the population potential of each zone and service employment in proportion to market potential of each zone.

d) The model ensures that populations located in any zones do not violate a maximum density or holding capacity constraint is placed on each category of service employment.

e) Lowry model relates population and employment at one particular time horizon.