MODULE – 1

URBAN TRANSPORT PLANNING

Nisarga P, Assistant Professor

SJB Institute of Technology

Department of Civil Engineering

Lecture - 1

Urbanization: Urbanization &Urban Class Group

SYLLABUS

Module: I

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.

Module: II

Data Collection and Inventories: Collection of data – Organization of surveys and Analysis, Study Area, Zoning, Types and Sources of Data, Road Side Interviews, Home Interview Surveys, Commercial Vehicle Surveys, Sampling Techniques, Expansion Factors, Accuracy Checks, Use of Secondary Sources, Economic data – Income – Population – Employment – Vehicle Owner Ship

Module: III

Trip Generation & Distribution: UTPS Approach, Trip Generation Analysis: Zonal Models, Category Analysis, Household Models, Trip Attraction models, Commercial Trip Rates; Trip Distribution by Growth Factor Methods. Problems on above

Module: IV

Trip Distribution: Gravity Models, Opportunity Models, Time Function Iteration Models. Travel demand modeling: gravity model, opportunity models, Desire line diagram.

Modal split analysis. Problems on above

Module: V

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.

COURSE OUTCOMES

CO1	Analyze the data required for transportation planning
CO2	Formulate transport project planning and development
CO3	Predict future trip generation and distribution rate for the study area
CO4	Develop modal split and trip assignment techniques for various travel pattern
CO5	Validate the developed model for long term transportation plan

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C.1	2											
C.2	2											
C.3	3	3				1						1
C.4	3	3				1						1
C.5	2	1				1						1
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What Is Urbanization?

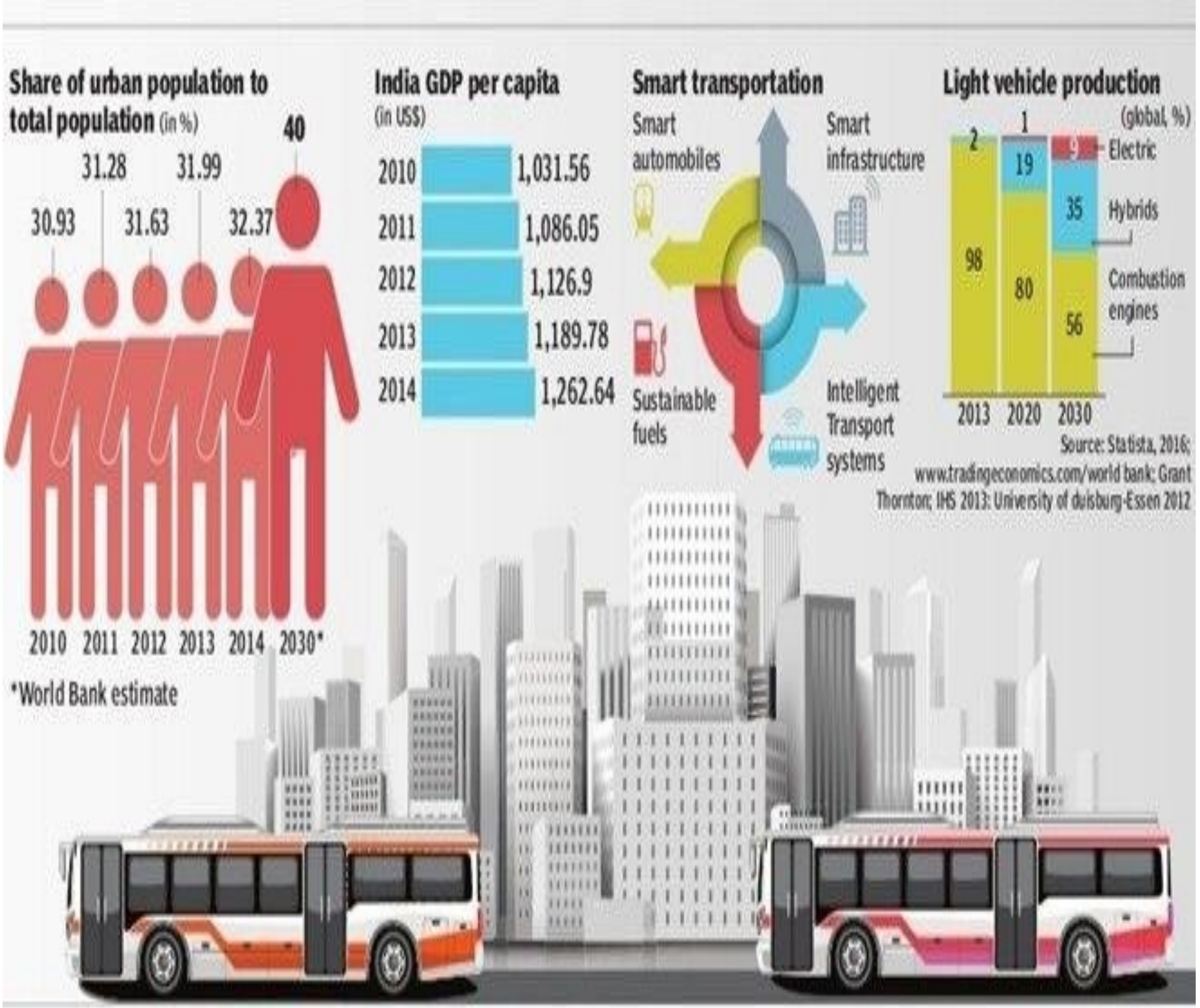
- Movement of people **from the country to towns and cities**
- Refers to the **expansion of cities**, i.e., growth of urban areas

REASONS ???

- People believe they will enjoy a better standard of living.
- For better jobs, education, healthcare, and other services.
- People 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"

Urbanisation in India



Urbanization in India began to accelerate after, due to the country's adoption of a mixed economy, which gave rise to the development of the private sector.

Urbanization is taking place at a faster rate in India.

Population residing in urban areas in India, according to 1901 census, was 11.4%. This count increased to 28.53% according to 2001 census, and crossing 30% as per 2011 census, standing at 31.16%

In numbers increased to 34%, according to **The World Bank.**

According to a **UN State** of the World Population report in 2007, by 2030, 40.76% of population is expected to reside in urban areas.

Effects of Urbanization?

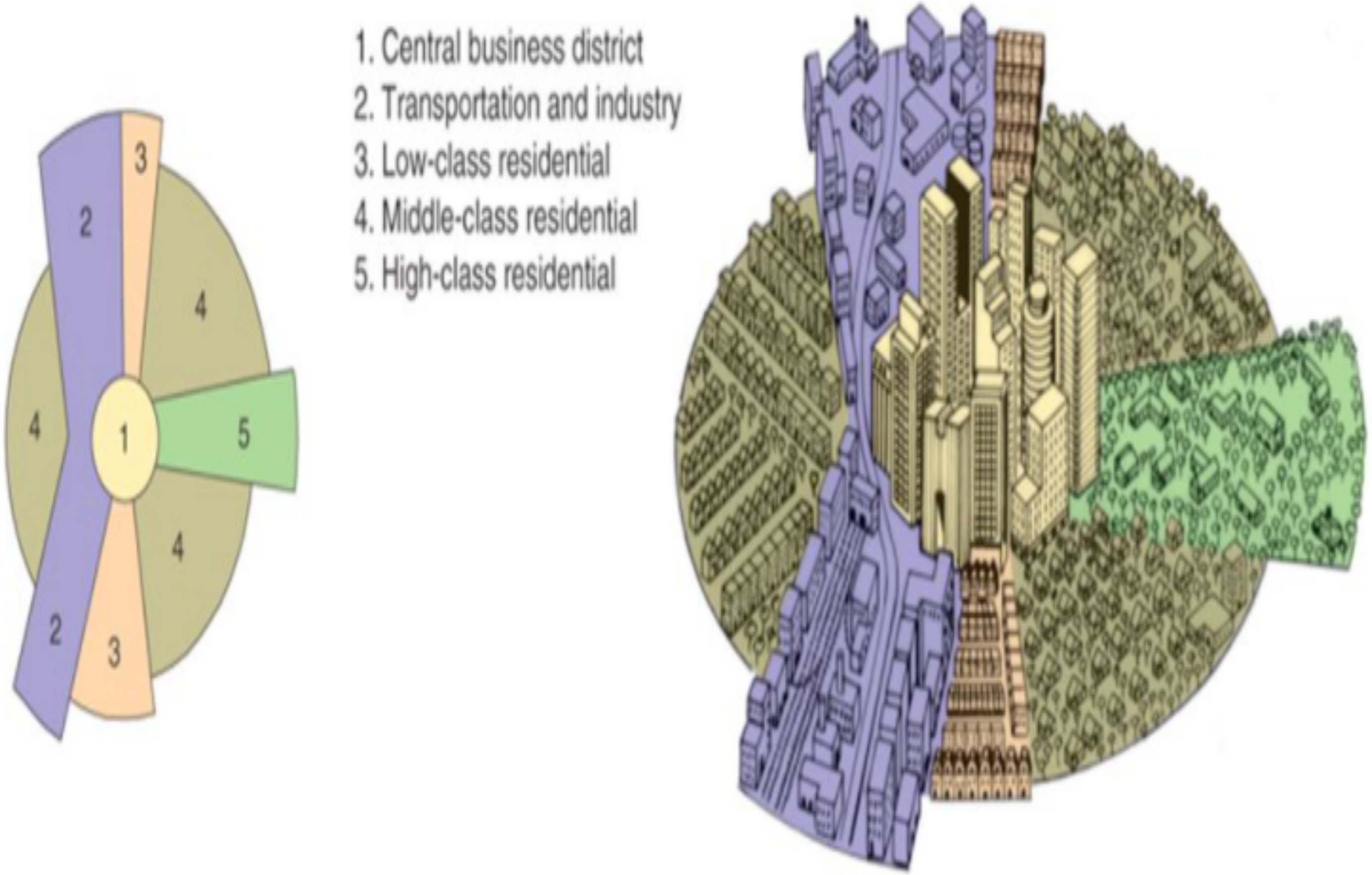
ADVANTAGES

- It leads to new employment opportunities.
- Technology and infrastructure make advances.
- Transportation and communication usually improve.
- Educational and medical services are better.
- Overall, the person who migrated enjoys a better standard of living.
- GDP growth tends to go hand-in-hand with urbanization. GDP stands or Gross Domestic Product. The term refers to all the goods and services that a country produces within a set period.

DISADVANTAGES

- Housing problems
- Overcrowding
- Unemployment
- Slums
- Poor sanitation and disease spread
- Traffic
- Crime

Urban Class Groups



Commercial Land use

- Banks, department stores, cinemas, restaurants, theatres and offices
- The CBD is the largest commercial district in cities
- CBD is the most accessible part of the city where transport networks meet
- Space is limited and rents high
- Office buildings are multistory and car parking charges are high and are limited

Transport Land use

- Road, car parks, bus depots, train stations and railways take up a lot of space in the cities

Industrial Land use

- Earlier, industrial areas were close to residential areas because people walked to work
- Today heavy industries such as oil refining, cement plants and steelworks are found in port areas of the cities
- Manufacturing industries are located at the edge of cities where large and cheaper sites are available and ring roads allow access for truck

Residential Land use

- This is largest single land use cities today
- Housing density varies with in a city and is high close to city center because of cost of land (multi story apartments)

Recreational Land use

- Recreational land is land used for purposes of recreation, for example, sports fields, gymnasiums, playgrounds, public parks and green areas, public beaches and swimming pools, and camping sites.

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MODULE – 1

URBAN TRANSPORT PLANNING

Nisarga P, Assistant Professor

Lecture - 2

Transportation Problem, Identification & Impact

Role of Transportation

Economic role of transportation:

- Economics involves production, distribution and consumption of goods & services wrt The place, time, quality and utility of goods
- Resources to satisfy the needs, These resources can range from material things to knowledge and skills like movement of doctors and technicians to the places where there is need of them.

Social role of transportation:

- Transportation influences the formation of urban societies w.r.t formation, size and pattern, and growth of urban centers.

Political role of transportation:

- Administration of an area includes laws to be followed, security and other needful information.
- Political choices in transport classified as communication, military movement, travel of persons and movement of freight (goods).

Environmental role of transportation :

The negative effects of transportation is more dominating than its useful aspects as far as transportation is concerned.

- Safety
- Air Pollution
- Noise pollution
- Energy consumption

Impacts of Transportation

- Energy consumption in Transport
- Air pollution
- Noise pollution
- Visual Intrusion and degrading the Aesthetics
- Severance and Land consumption

Global	• Contribution to green house effect
Regional	• Damage of vegetation, acid and nitrogen deposition
Local	• Direct pollution, noise, pollution of soil and water, barrier effect

Impacts of Transportation

Energy consumption in Transport

- Transportation requires energy mainly for vehicle operation and to some extent for manufacturing of vehicles
- Consumption of energy in car is more among urban transport modes

Noise pollution

- Noise generated from various parts of the vehicles like engine, exhaust, breaks, horns, chassis, loads in the vehicle, door slamming etc
- Noise contributed by the interaction between vehicle and road surface
- Noise dependent on the speed, flow, density of traffic

Air pollution

The major source of the pollutants in the exhaust gas emitted by the internal combustion engine

- **CO_2**: Important contributor to climatic change
- **CO**: Reduces oxygen uptake in blood (Headache, dizziness, nausea)
- **NO_x**: Damages respiratory tracts (Asthma, bronchitis, whooping cough. Lung diseases)
- **Lead**: Causes anxiety
- **Smoke**: Dangerous in combination with other compounds

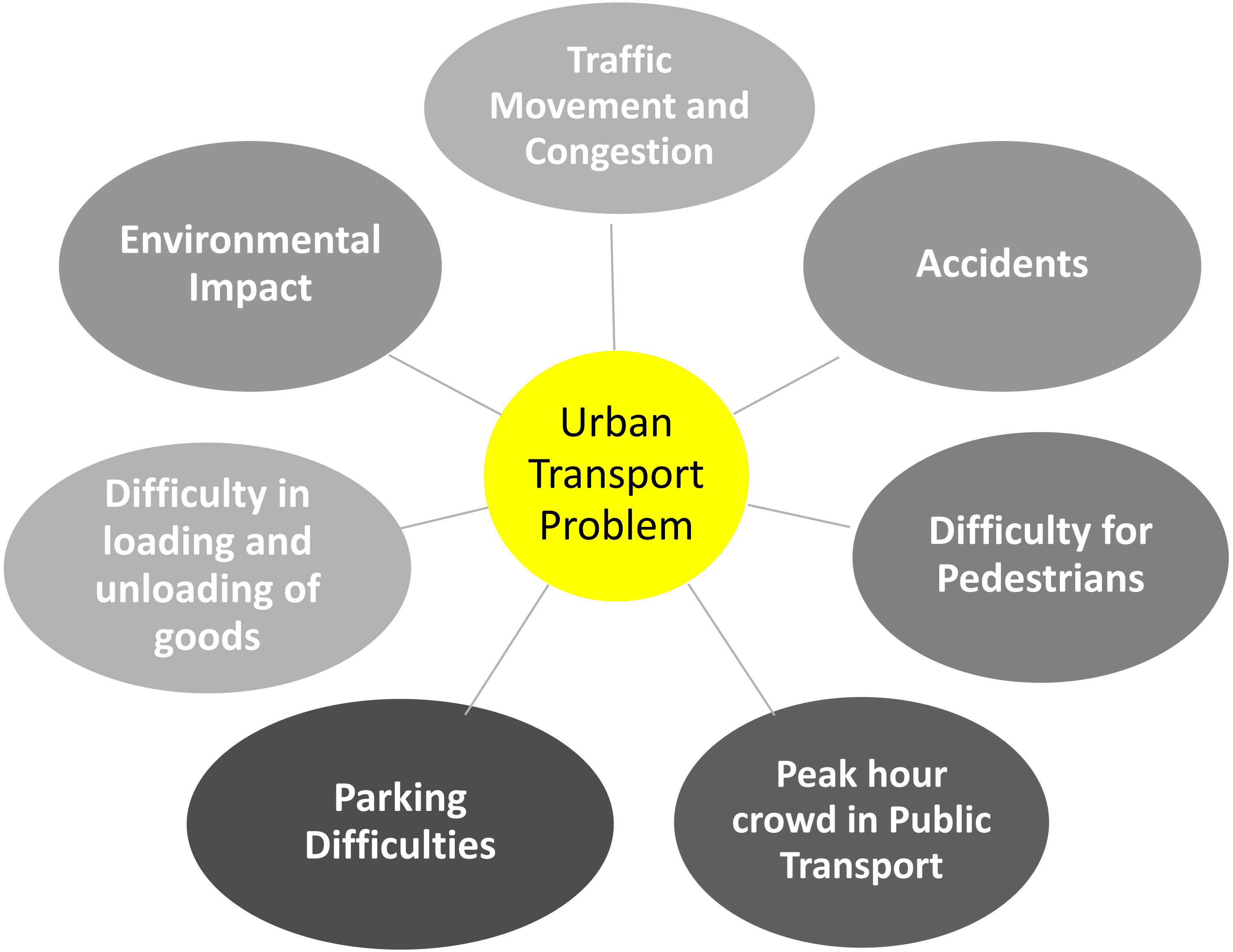
Visual Intrusion and degrading the Aesthetics

- Motor vehicles have been competing for space for movement and it appears that buildings seem to raise from the plinth of cars.
- The tranquillity and openness of parks and squares has been occupied and spoiled
- Signs, signals and bill board have sprung up all along streets, spoiling the beauty

Severance and Land consumption

Severance is the general term denoting the psychological, cultural and physical disturbance caused by a traffic facility on the neighbourhood, land, society and life cycle.

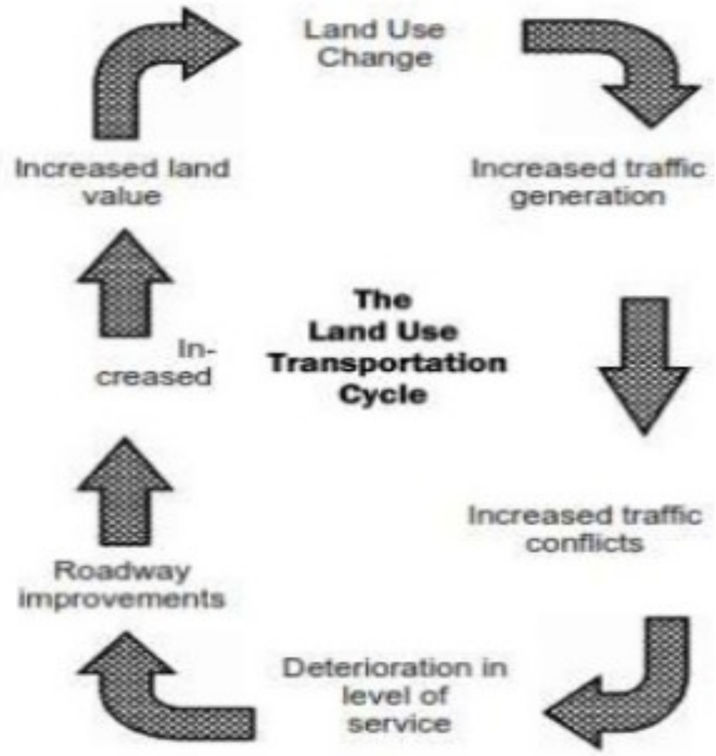
Urban Transport Problems



Land use and Transport Cycle

LAND USE AND TRANSPORTATION CYCLE

- Land use change
- Increased traffic generation
- Increasing traffic conflicts
- Level of service
- Improvement in service
- Increase land value

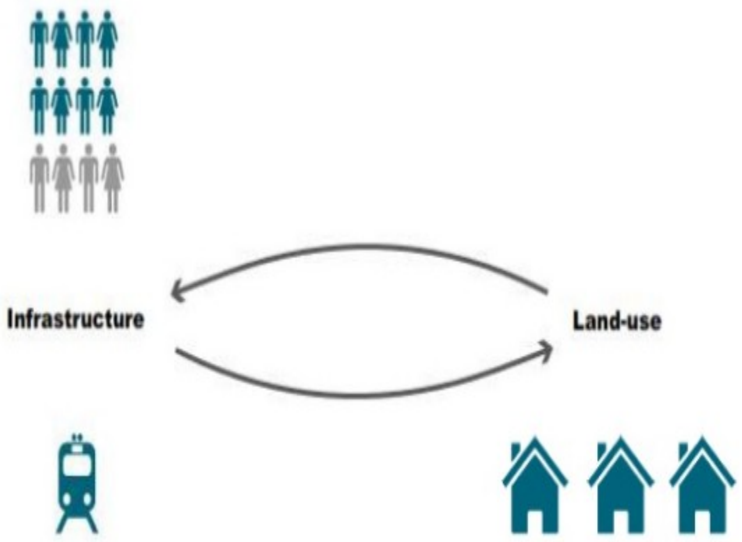


Mitchell & Rapkin (1954)

- Activities are based on land use
- Generates different amount and kinds of traffic

Buchannan

- Inter-relationship b/w traffic and buildings



System Approach to Transportation

Stages in Transport Planning

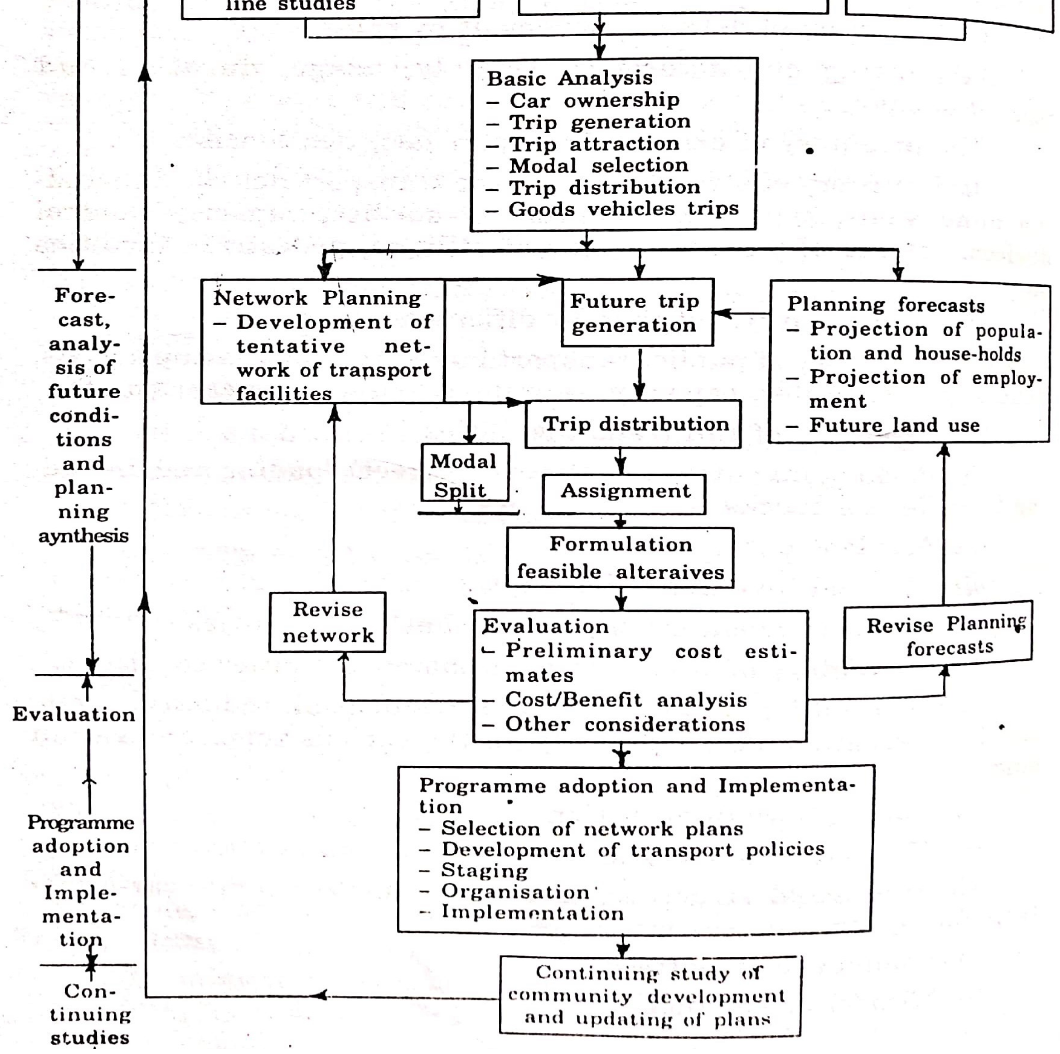
1. Survey and analysis of existing condition
2. Forecast, analysis of future condition and plan synthesis
3. Evaluation
4. Programme adoption and implementation
5. Continuing study

Eg: Knowing the expected rate of GNP (Gross National Product), expected traffic growth T can be calculated as:

$$\log T = A_0 + A_1 \log(GNP)$$

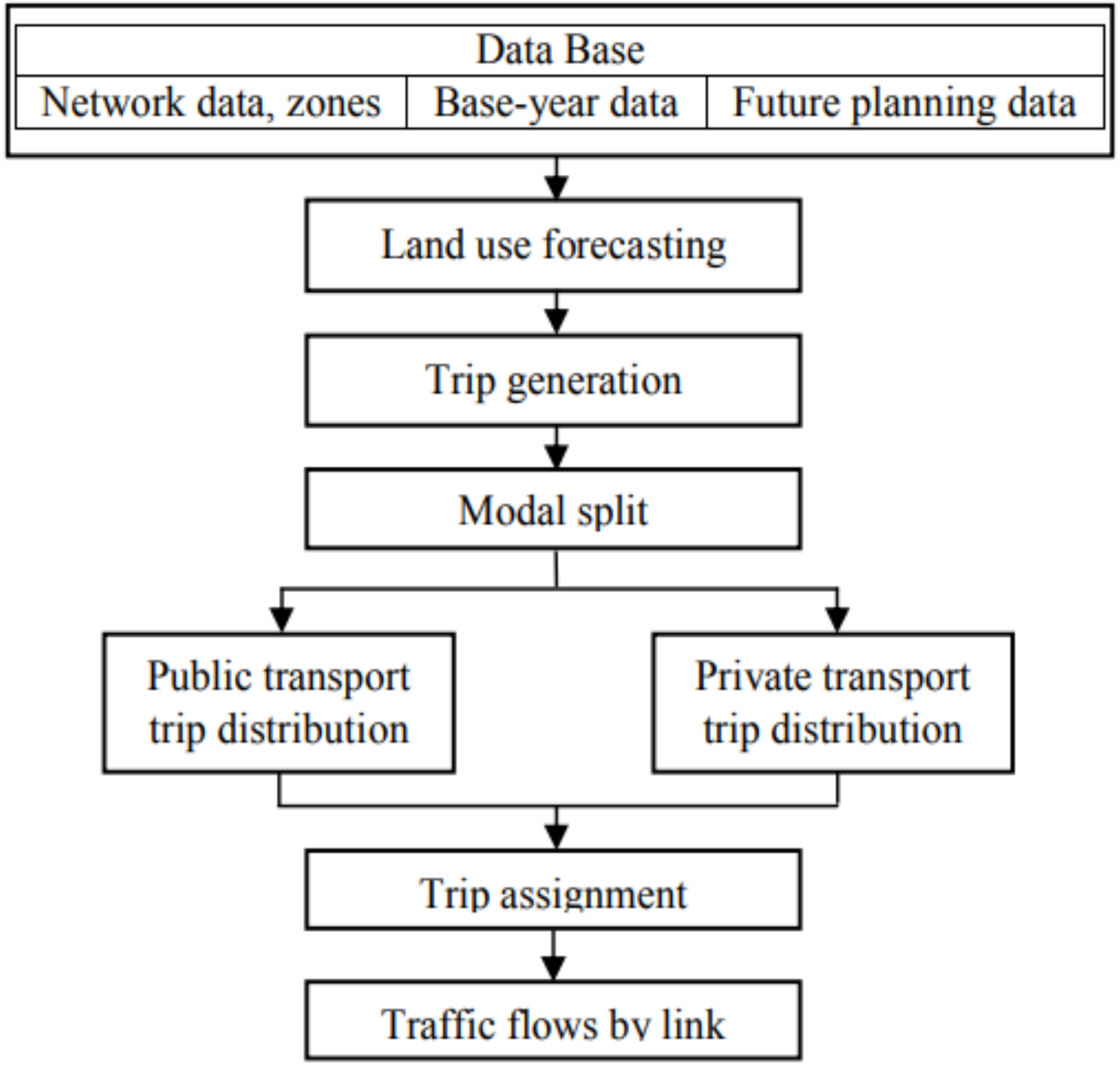
Where, A_0 = regression constant

A_1 = regression co-efficient/ elasticity co-efficient


line studies
Basic Analysis
– Car ownership
– Trip generation
– Trip attraction
– Modal selection
– Trip distribution
– Goods vehicles trips
Fore-cast, analy-sis of future condi-tions and plan-ning aynthesis
Network Planning
– Development of tentative net-work of transport facilities
Future trip generation
Planning forecasts
– Projection of popula-tion and house-holds
– Projection of employ-ment
– Future land use
Trip distribution
Modal Split
Assignment
Formulation feasible alteraives
Revise network
Evaluation
– Preliminary cost esti-mates
– Cost/Benefit analysis
– Other considerations
Revise Planning forecasts
Evaluation
Programme adoption and Implementa-tion
– Selection of network plans
– Development of transport policies
– Staging
– Organisation
– Implementation
Programme adoption and Imple-menta-tion
Continuing study of community development and updating of plans
Con-tinuing studies

Transportation Planning Processes

- Urban transport planning is the process that leads to **decisions** on **transportation policies and programs**.
- In this process, planners **develop information** about the impacts of implementing **alternative courses of action** involving transportation services, such as new highways, introduction of new modes of public transport etc, or parking restrictions etc.
- The **fundamental objective** of transportation is to **provide efficient and safe levels of mobility.**



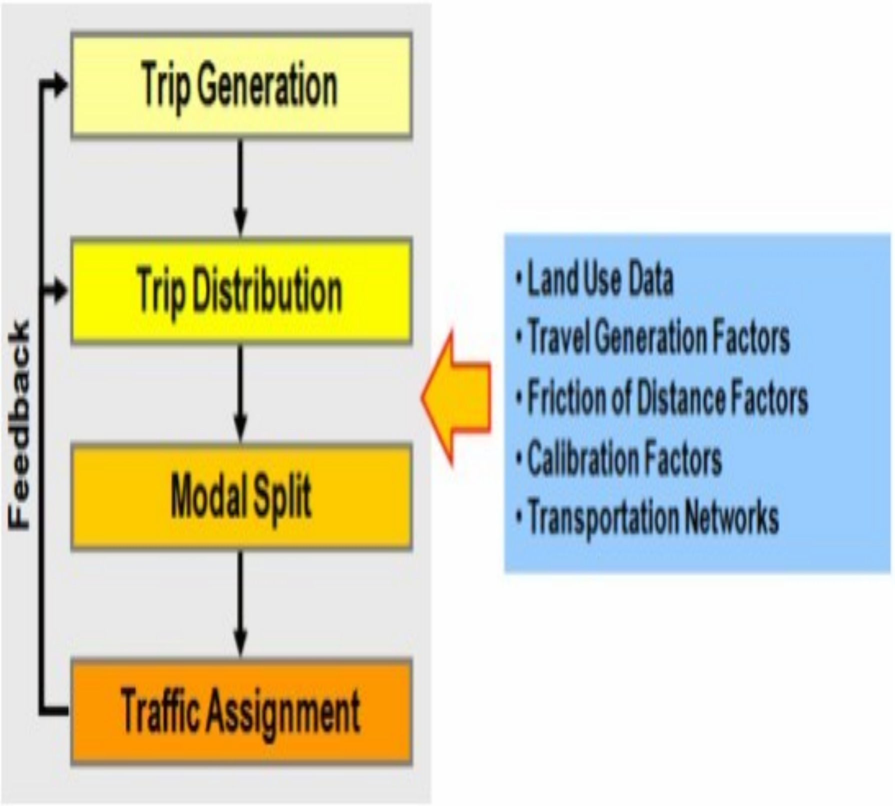
General form of the four stage transportation modeling

Travel Demand

Refers to the amount and type of travel people would choose under specific conditions. Considering factors such as the quality of transport option available and their prices.

Traditionally, an approach known as the "Four Step Process". The process had four basic phases:

1. **Trip generation** (the number of trips to be made);
2. **Trip distribution** (where those trips go);
3. **Mode choice** (how the trips will be divided among the available modes of travel); and
4. **Trip assignment** (predicting the route trips will take). By looking at these four areas, we can answer the following questions:



Four Stage Travel Demand Model

Trip Generation

Trip generation is the first stage of transportation demand models. It is a general term used in the transportation planning process to cover the number of trip ends in the given area. Trip generation is classified into production and attraction.

Production (Origin): Number of trip end originated in zone i

Attraction(Destination): Number of trip end attracted to zone j

There are basically two tools for trip generation analysis:

a) Multiple linear regression analysis
b) Category analysis

Trip Distribution

The decision to travel for a given purpose called trip generation. The decision to choose destination from origin is directional distribution and forms the second stage of travel demand modelling.

Trip distribution is determined by the number of trip ends originated in zone-i to number of trips attracted to zone-j, which can be understand by matrix between zones. The matrix is called origin-destination (O&D) matrix.

The trip generation models include:

a) Growth factor models

- Uniform growth factor
- Average growth factor
- Fratar method
- Furness method

b) Synthetic modes

- Gravity model
- Opportunity model

Modal Split

- The third stage in travel demand modelling is modal split.
- Modal split is determined by number of trips of people process by the different mode of travel.
- In other words, modal split is used to distribute the total travel demand in two or more mode categories like public transport riders and personal/private riders.

Modal split methods

1. Probit Model
2. Logit Model

Trip Assignment

- Trip assignment is fourth and final phase of the four-stage modelling.
- Travelers will choose the route which will take minimum travel time, minimum travel distance dependent on the traffic volume on the road.

Traffic assignment models

1. All or nothing assignment
2. Multiple route assignment model
3. Capacity restraint assignment model
4. Capacity restraint multipath route assignment model
5. Diversion curves technique model

Classification of Transit Systems

- Urban transportation consists of a family of modes, which range from walking and bicycles to urban freeways, metro and regional rail systems.
- The basic classification of these modes, based on the type of their operation and use, is into three categories:

  (a) Private transportation

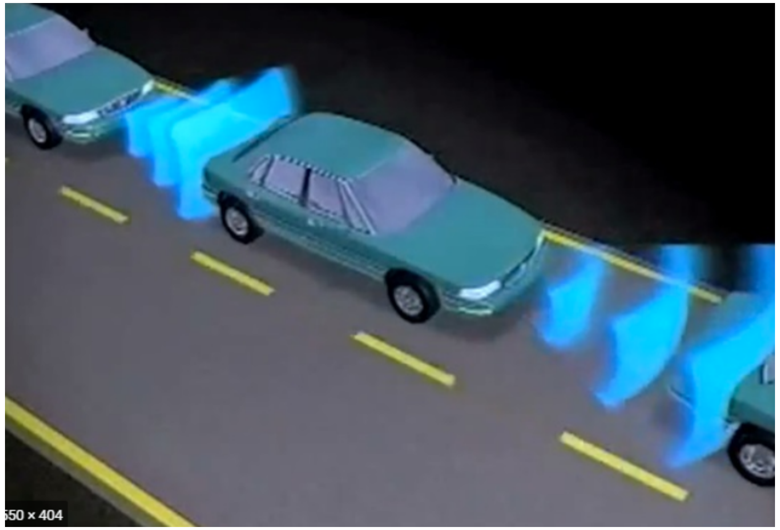
  (b) Paratransit or for-hire transportation

  (c) Urban transit, mass transit or public transportation

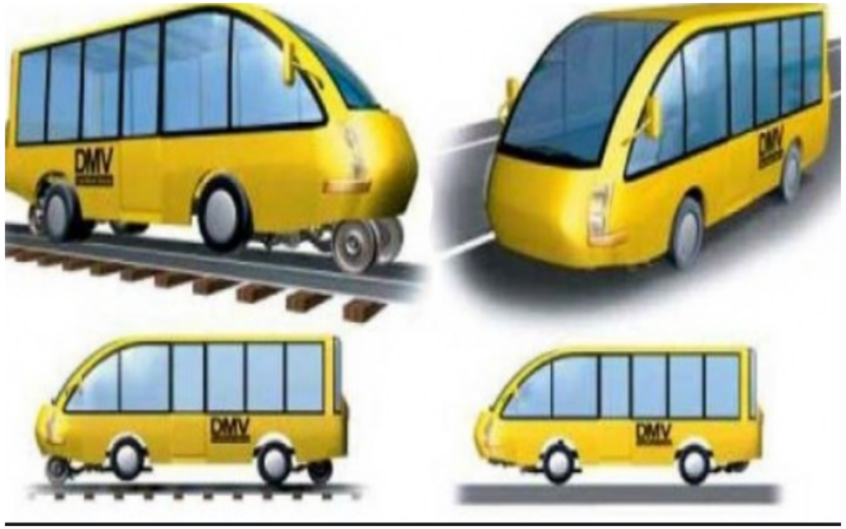
Personalised/ Private Vehicle System

The personalised motor vehicles have grown popularity because of greatest advantage it has over other forms of transport system like flexibility in travel route and travel time, door to door service. But the problems of fuel shortages, congestion, parking, environmental pollution etc. hampered the further development in this system

ADVANCEMENTS



Automated Highway System



Dual mode system

Battery powered small cars

Bus Rapid Transit System (BRTS)

- BRTS includes roadway that is dedicated to buses and gives priority to buses at intersections where buses may interact with other traffic.
- A capacity upto 40,000 seats per hour or 550 buses per hour is possible on exclusive bus lanes

Telangana BRTS

BUS RAPID TRANSIT SYSTEMS IN INDIA

OPERATIONAL: 1000.82 km

City (State)	Network Length	Lines	Since
Rainbow BRTS, Pune and Pimpri-Chinchwad (Maharashtra)	61.0 km	6	Dec, 2006
Ahmedabad BRTS (Gujarat)	118.0 km	12	14 Oct, 2009
Jaipur BRTS (Rajasthan)	26.0 km	2	31 Jul, 2010
Rajkot BRTS (Gujarat)	63.0 km	1	1 Oct, 2012
Surat BRTS (Gujarat)	114.0 km	2	26 Jan, 2013
Indore BRTS (Madhya Pradesh)	126.5 km	10	2013
Bhubaneswar BRTS (Odisha)	66.32 km	2	2015
Raipur BRTS (Chhattisgarh)	60.0 km	2	1 Nov, 2016
Visakhapatnam BRTS (Andhra Pradesh)	42.0 km	2	2 Oct, 2016
Amritsar BRTS (Punjab)	68.0 km	7	15 Dec, 2016
Bhopal BRTS (Madhya Pradesh)	186.0 km	10	27 Sep, 2013
Hubli-Dharwad BRTS (Karnataka)	70.0 km	2	2 Oct, 2018

UNDER CONSTRUCTION/UNDER PLANNED: 164.1 km

City (State)	Network Length	Lines	Status
Kolkata BRTS (West Bengal)	15.5 km	1	Under construction
Mumbai BRTS (Maharashtra)	11.7 km	1	Under construction
Chennai BRTS (Tamil Nadu)	70.3 km	1	Planned
Coimbatore BRTS (Tamil Nadu)	27.6 km	1	Planned
Hyderabad BRTS (Telangana)	39.0 km	2	Approved

Rapid Rail Transit System

- Railway transit is a well-known means of rapid transit along high density corridors. They can be surface/ underground/ elevated.

Elevated Metro- Bengaluru

Underground Metro- Mumbai

Calcutta

16.4 km

Advantages of Mass Transit

1. Reduction in Congestion: The main idea behind mass transit is to reduce the number of vehicles on the road by providing a larger facility which carries higher number of passengers thus eliminating congestion
2. Saves Time: Mass transit reduces the travel time to a great extent as it moves at high speeds and stops only at specific spots
3. Cost effective: Mass transit is comparably cheaper than other modes of public transport
4. Environmental impact
5. Social impact
6. Economic impact

Disadvantages

1. Mass transit systems are economically feasible only in areas that have relatively large population. As the number of inhibits per square km decreases, the efficiency of mass transit system also decreases.
2. Mass transit system are also very expansive to build and operate. When this system has to be installed in cities where development had already taken place and disruption of existing structure is a serious problem
3. While using mass transit people need to wait for a long time to have a bus or train. Flexibility in time to reach the destination in desired time is not possible.
4. Risk of being the criminal victim is high. Rapes and snatch crime is the most common cases that caused by the public transport
5. In addition, people cannot have a comfortable journey to their destination. Some of the mass transit system are usually crowded, dirty and smelly. Also, some special people such as disables person and old folks may be treated bad.

Para-Transit Transport

- Paratransit service is the general terms for a "demand-response" service which a passenger must reserve a ride in advance.
- It includes all public and private automobile travel and fixed route and fixed schedule bus and rail transit.
- It also includes carpools and vanpools (shared ride modes), public autos (station cars), charter buses, exclusive and shared ride taxi cabs and bus transportation operating on flexible routes and flexible schedules in response to individual request for service. Hence termed as " Demand-Responsive" or 'Dial-a-ride" service.

Light Rail Transit (LRT)

LRT is popularly known as the tram or the street car. Trams used to operate on the roads of Delhi and Bombay where they have now been discontinued. However, continue to be run in Calcutta

Advantages:

1. Trams is an electrically based system. The fuel crisis has made oil-based bus transport system costly. Trams is free from the uncertainties associated with availability of oil.
2. Trams are relatively cheaper than conventional sub-urban rail systems.
3. Trams are suitable for pedestrian malls.

Magnetic Levitation (Maglev) System

Maglev is a rail system running on monorail and capable of running at high speeds of 400 km/hr. The technology based on the principle of magnetic levitation. Entire trains are suspended and propelled towards by magnetic farces without touching the rail track.

Advantages:

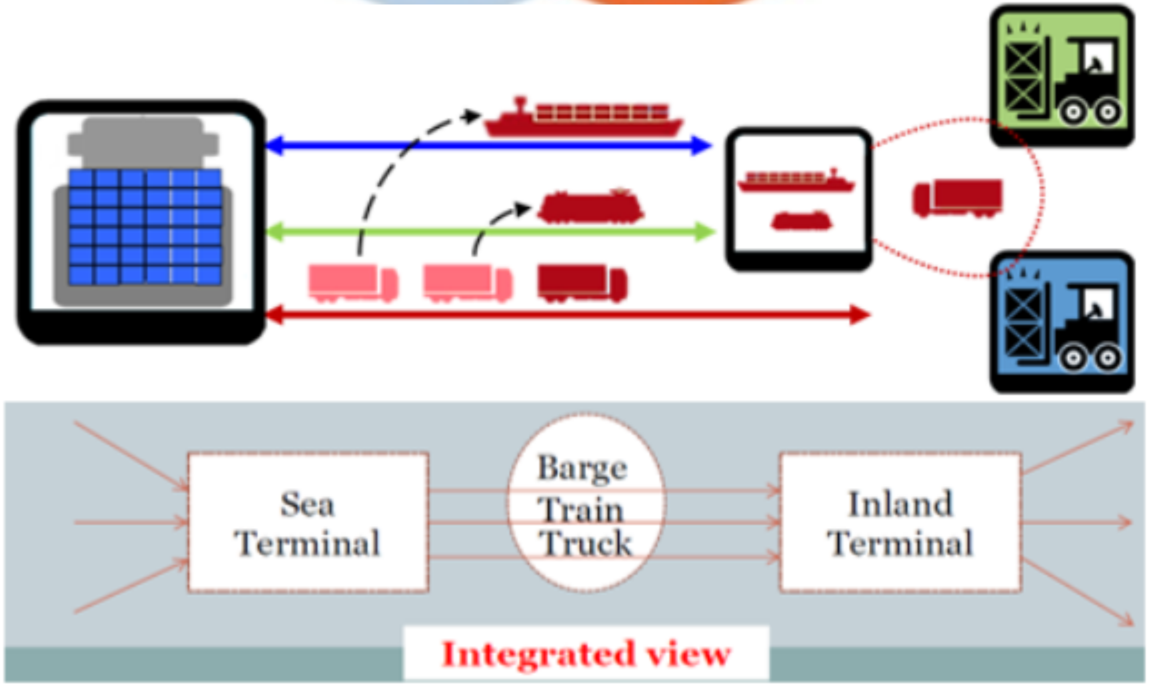
1. Tracks requires less maintenance
2. High speeds are possible
3. Low noise

A line of 0.6km long is already operation in Birming Ham (UK)

Modal Integration (Co-ordination of System)

NEED

- All modes of transportation have their own role to play.
- This should be clearly recognised by National Transportation Planning.
- No single mode should be allowed to develop at the cost of any other or to the detrimental of the nation's overall economy.
- Hence requires a co-ordinated approach



- The goods produced in the factory are stuffed into a container and moved by road to an Internal Container Depot (ICD) or Container Freight Station (CFS). From there it is by rail to a port and then on it travels by help

- "Piggy-back" system or trailer-on-flat-car (TOFC) where in the trailer of truck is moved ob flat rail wagons over long distance which helps in saving fuel, reducing congestion and reliving the truck driver from the long-distance driving.

  Konkan Railway Corporation in India is operating this system

- "Road-trailer" is a new technology where in the trailer of the truck can directly be moved on the rails.

- "Roll-on-Roll-off" (RORO) is a system where in the trucks are carried on ships over long distance

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MODULE – 2

DATA COLLECTION AND INVENTORIES

Nisarga P
Assistant Professor

Lecture - 7

Study Area and Zoning

Planning Surveys

- Travel Movements
- Study Area Delineation
- Transport Planning Surveys

Study Area

- Whole city containing the existing and potential continuously built up areas of city

- Imaginary line representing boundary of the study area is "External Cordon"
  - All built up area and developed during period of study
  - All areas oriented towards city center
  - Continuous and uniform
  - Compatible with previous studies of the area of studies planned for future

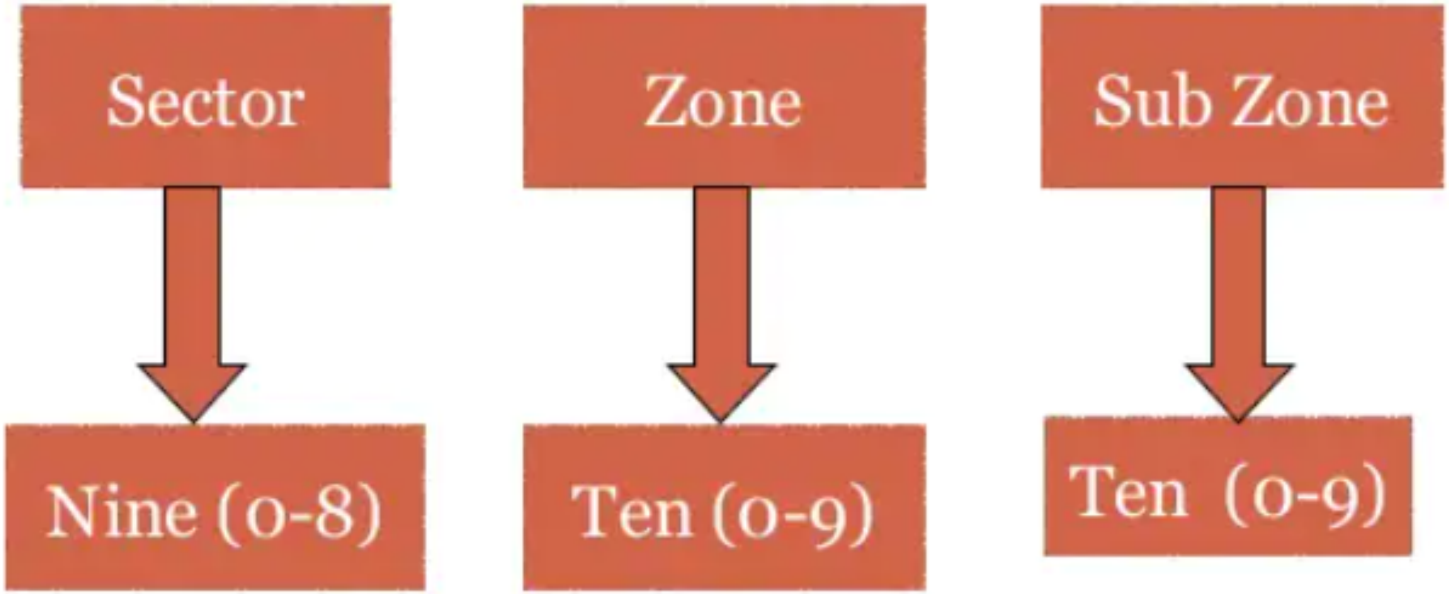
ZONING

- **ZONES:** The defined study areas divided into smaller zones are called as **"Zones."**
- Spatial quantification of land use and economic factors which influence travel pattern
- Internal Zones
- External Zones

Zoning

- To Facilitate the spatial quantification of land use and economic factors influencing the travel Pattern amongst the reasonably homogenous Socio economic conglomerate.

Coding Practice



External Sector : 9

Point should kept in mind while dividing into Zone

- Land use is most important factor
- Homogeneous- Trip making behavior
- Anticipated changes
- Zones should not be too large-Errors
- Sectors should represent the catchment of trips generated on primary route
- Natural barriers should have convenient zone boundaries.

MODULE – 2

DATA COLLECTION AND INVENTORIES

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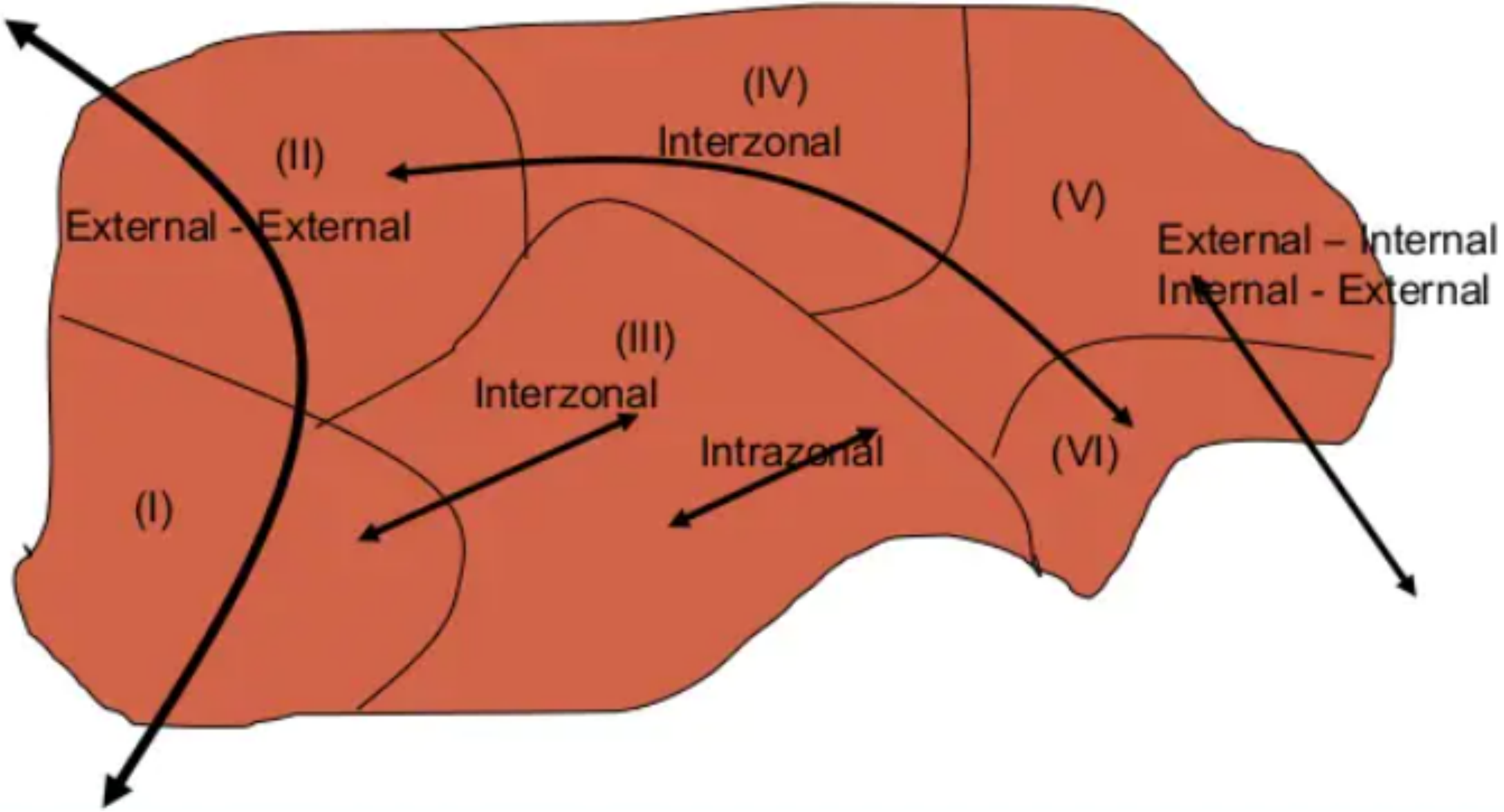
Department of Civil Engineering

Lecture - 8

Types of Survey

Travel Movements



Types of Survey

1. Home Interview surveys
2. Commercial vehicles surveys
3. Taxi surveys
4. Road side interview surveys
5. Post card interview surveys
6. Registration number surveys
7. Tag surveys
8. Public Transport surveys

O & D Study

- An origin-destination study is used to determine travel patterns of traffic on an installation during a typical day. They are useful in assisting long-range traffic planning, especially when there are substantial changes anticipated in the installation mission or strength.

- This is a study to determine and analyze trips. Trips are defined as one-way movement, from where a person starts (origin) to where the person is going (destination).

O & D Study

Trips are further classified as follows:

- Internal--From one point on post to another point on post.
- External--From on-post to off-post or vice versa.
- Through--From off-post to off-post, by going through the installation

Application of O-D Survey

- To judge the adequacy of existing routes and to plan the new road networks
- To plan transportation system and mass transit facilities in cities including routes and schedules of operation.
- To locate the expressway or major routes
- To locate the new bridges as per traffic demands
- To locate the intermediate stops of public transit
- To locate the terminals and to plan the terminal facilities.

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MODULE – 2

DATA COLLECTION AND INVENTORIES

Nisarga P
Assistant Professor

Lecture - 9

Roadside Interview Survey

Home Interview Survey

Conducting Studies

- There are five methods which can be used in conducting these studies

1. Registration Questionnaire
2. Return Post Card method
3. Roadside Interview method
4. Tag on Car method
5. Home Interview method

HOME INTERVIEW SURVEY METHOD

- Collection of origin and destination data
- Survey is essentially intended to yield data on travel pattern of the household influencing trip making
- 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.
- Household characteristics no of residents, age, sex, vehicle ownership, dwelling unit, number of drivers, family income etc.

HOME INTERVIEW SURVEY FORMAT

HOME INTERVIEW SURVEY

Sample No.__________ Date: ____________________

Interviewer________________ Survey Zone: West Zone, Surat Ward No.__________

HOUSEHOLD INFORMATION

1. **Family Size** [ ] Working members [ ] School Going members [ ]

Occupation:

Head	Govt. Serv.	Private Serv.	Self Empl.	Business

2. **Family Income Category (Rs.):**

LIG1	MIG	HIG	VHIG
<10000	10000- 25000	25000-50000	>50000

3. **Vehicle Ownership:**

Vehicle	Car	2W	Cycle	Other	None

TRAVEL INFORMATION

4. **Daily Trips for Work/Education:**

	Mode	Time Slot	Return Time Slot	Work Place Edu.	Work Place/ Edu.	App. Dist.
Head						
Wife						

5. **Weekly Other Trips:**

Purpose	Mode	Place	Place	Time Slot	Return Time Slot	Nos. of Trips
Social						
Shopping/ Recreation						

Roadside Interview

- Roadside Interview--This method requires advance publicity and a greater number of personnel.
- Interview 50 percent of vehicles during non peak hours.
- Interview 25 percent of drivers during peak hours.

Roadside Interview

- Insure stations are visible and safe. One interview should not take more than 40 seconds, and there should not be more than five (5) interviewers in a file (one lane).

- Approximately 300 drivers can be interviewed per hour. Stations do not have to be operated at the same time.

Roadside Interview

MODULE – 2

DATA COLLECTION AND INVENTORIES

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Department of Civil Engineering

Lecture - 10

Registration Number Survey

Post Card Survey

Tags on Vehicle Survey

Registration Questionnaire

Registration Questionnaire--Driver lists are obtained from the vehicle registration form and each is sent a questionnaire at his place of duty with a return date requested.

Post Card

- **Post Card-**-A prepaid post card with the questionnaire on it is distributed to all drivers entering the installation during a given time. A traffic volume count is made at the time the cards are distributed.

Tag on vehicles

- This is a limited study good for studying through trips.
- It is conducted by having all vehicles counted when they enter the installation.
- At stations just inside the entrance gates, Enumerator stop vehicles and affix a piece of colored tape (different for each station) to the car's front bumper. At exit gates of the installation, a tally of vehicles with each colored tape is made.
- It provides a rough estimate of through trips on the installation.
- It's necessary for each installation entrance and exit to be manned during this study.

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MODULE – 2

DATA COLLECTION AND INVENTORIES

Nisarga P
Assistant Professor

Lecture - 11

Inventories

Survey Data Check

INVENTORY OF PUBLIC TRANSPORT BUSES

- Information on total no. of buses, their capacity, schedules, routes, operating speed, terminals, number of passengers carried, economic picture of public transport system and fare structure.

INVENTORY OF RAIL TRANSPORT FACILITIES

- Information on total no. of buses, the length, capacity, schedules, routes, operating speed, terminals, number of passengers carried, economic picture of rail transport system and fare structure.

PARKING INVENTORY

- On street parking and off street parking facilities
- Data on parking charges and the system used for charging should also be collected.

ACCIDENT DATA

- Accident data over the past years will help to understand the nature and extent of the hazards inherent in the present system and the need to improve the situation.
- Inventory of land use and economic activities

INVENTORY OF LAND USE AND ECONOMIC ACTIVITIES

- Travel characteristics are closely related to the land use pattern.
- The zones are land use activity such as residential, industrial, commercial, recreational, open space etc.
    - Data on economic activities should be collected
    - Population of the survey area and various family
    - Age, sex, and composition of the family
    - Employment statistics
    - Income
    - Vehicle Ownership

SURVEY DATA CHECKS

The data collected for transportation planning by any survey can be check out by following methods:

Accuracy Check

- Data accuracy is the foundation dimension of data quality.
  - Accuracy
  - Timeliness
  - Relevance
  - Completeness
  - Understood by users
  - Trusted by users etc.

Screen Line Checks

- Traffic counts taken at selected screen lines are useful for comparing model generated travel pattern with actual volumes of traffic crossing screen line and making adjustments.
- This check is useful for calibration and validation of model
- Check is carried out data collected by home interview survey
- It is line separating study area.

CORDON LINE CHECKS

- Cordon line is the boundary of study area
- The data collected from internal to external, external to internal and external to external
- Cordon line points can be use to compare the trips calculated and observed.
- This check is very useful for data adjustment for study area

TRIP GENERATION MODELS

Module - 3

TRIP GENERATION MODELS

Factors Governing Trip Generation and Attraction Rates

The various factors governing trip generation and attraction rates/ factors affecting travel demand are:

1. Income
2. Car Ownership
3. Family size and Composition
4. Land use characteristics
5. Distance of the zone from the town centre
6. Accessibility to public transport system and its efficiency
7. Employment opportunities, floor space in the industrial and hopping unit and offices, sales figures in shops etc

Methods

- Multiple Linear Regression Analysis
- Category Analysis

Multiple Linear Regression Analysis

- Multiple linear regression analysis is a well-known statistical technique for mathematical relationships between dependent and independent variables
- In trip generation equations, the dependent variables is the number of trips and the independent variables are various factors influencing trip generation like land-use and socio-economic characteristics

Assumptions in Multiple Linear Regression Analysis

- All the variables are independent of each other
- All the variables are normally distributed
- All the variables are continuous
- A linear relationship exit between the dependent and independent variables
- Influence of independent variables is additive that is the inclusion of each variable in the equation contributes a distinct portion of the trip number

The general form of the equation obtained is:

$$\mathbf{Y_p = a_1X_1 + a_2X_2 + a_3X_3 + \ldots\ldots\ldots\ldots. a_nX_n + a_0}$$

Y_p = number of trips for specified purpose p

$X_1, X_{2,} X_{3\ldots\ldots\ldots}$ X_n = independent variables (Ex: land-use and socio-economic characteristics)

$a_{1,} a_{2,} a_{3\ldots\ldots\ldots\ldots}$ a_n = co-efficient of the reprehensive independent variable $X_1, X_{2,} X_{3\ldots\ldots\ldots}$ X_n

a_0 = disturbance term, which is a constant and representing that portion of the value of Y_p not explained by the independent variables

As an example in one of the Indian cities, following relationship was established:

$$\mathbf{Y = 1197.32X_1 + 0.0957X_2}$$

Where, X_1 = number of workers in the zone

X_2 = number of vehicles in the zone

Y = number of trip produced for work purpose in zone

Problem: The following information was obtained from a transportation survey of a town:

Develop a linear regression model for estimating the trips generated from a zone.

If the population in a particular zone increases to 40,000 predict the expected trip generation from that zone.

Traffic zone number	Population in the zone (in thousand)	Total trip generated (in hundreds)
1	26	12
2	28	11
3	31	17
4	33	15
5	22	12
6	30	15
7	20	9
8	25	13

Solution:

Zone	x	y	xy	x^2	y^2
1	26	12			
2	28	11			
3	31	17			
4	33	15			
5	22	12			
6	30	15			
7	20	9			
8	25	13			
n=8					

In this case there is one dependent variable population and problem is to develop linear regression equation of form:

$$\mathbf{Y = b_0 + b_1 X_1}$$

Y = total number of trips in hundred per zone, being the dependent variable

X_1= Population in the zone (in thousand), being independent variable

b_0= regression constant

b_1= regression co-efficient

The equation is calibrated for b_0 and b_1 by the following formulae

$$b_1 = \frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2}$$

$$b_0 = \frac{(\Sigma y - b_1 \Sigma x)}{n}$$

Also, the correlation co-efficient r which tells about goodness of fit, is obtained by:

$$r = b_1 \left[\frac{n\Sigma x^2 - (\Sigma x)^2}{n\Sigma y^2 - (\Sigma y)^2} \right]$$

Here, n= total number of observations

Substituting the values in the above formulae,

$$b_1 = \frac{8 \times 2891 - 215 \times 104}{8 \times 5919 - (215)^2} = 0.469$$

$$b_0 = (104 - 0.469 \times 218)/8 = 0.396$$

Therefore, the trip[generation model is

$$y = 0.396 + 0.469\,x$$

The co-relation coefficient for this mode is

$$r = 0.469 \left[\frac{8 \times 5919 - (215)^2}{8 \times 1398 - (104)^2} \right] = 0.82$$

Zone	x	y	xy	x^2	y^2
1	26	12	312	676	144
2	28	11	308	784	121
3	31	17	527	961	289
4	33	15	495	1089	225
5	22	12	264	484	144
6	30	15	450	900	225
7	20	9	180	400	81
8	25	13	325	625	169
n=8					

The linear regression model is given by:

$$\boldsymbol{y = 0.396 + 0.469\,x,\; r = 0.82}$$

(b) If future population of a zone = 40,000

$$x = 40 \; \textit{for use in model} \text{ (in thousands)}$$

The total trips generated , $y = 0.396 + 0.469 \times 40 = 19.16 \; \textit{in thousands} = 19160$

Limitations

i. The independent variables in the regression equations are not truly independent of each other and some sort of correlation normally exit among them. Ex: Car-ownership, family income, residential density is inter-related etc

ii. Many of the variables are not normally distributed

iii. Some of the variables are not continuous. Ex: being the car ownership, the number of cars owners by the family can only be a discrete variable

With all the above imperfections, the method gain popularity because of its easy adoptability for computer programming when handling voluminous data

Multiple linear regression analysis is of two types:

- Aggregated or Zonal least-square regression
- Disintegrated or Household least-square regression

Disadvantage of Multiple Linear Regression Analysis Technique

1. The equation derived is purely empirical in nature and fails to establish a meaningful relationship between the dependent and independent variables.
2. The technique is based on the premise that the regression co-efficient initially established remain unchanged in the future and can be used in the equation for predicting future travel. How far the prediction is valid is a question.
3. Difficulties arise in evaluating the effect of statistical problems relating to non-linearity of the response surface and high correlation amongst the explanatory variables.

Category Analysis / Cross-Classification Technique

- Category analysis is based on determining the average response or average value of the dependent variable defines categories of independent variables. A multi-dimensional matrix defines categories, each dimension in matrix representing one independent variable. The independent variables themselves are classified into a definite number of discrete class interval

Assumptions:

The technique is based on the following assumption:

1. The household is the fundamental unit in the trip generation process, and most journeys begin and end in response to the requirement of family
2. The trip generated by the household depend upon the characteristics of that household and its location relative to its required facilities such as shops, school and work place
3. Households with one set of characteristics generate different rates of trips from households with other sets of characteristics
4. Only three factors are of prime importance in in affecting the amount of travel a household produces: car-ownership, income and household structure
5. Within the above three factors, a limited number of ranges can be established so as to describe the trip-generating capacity of a household by a limited number of categories
6. Trip generation rates are stable over a time so long as factors external to the household are the same as when the trips were first measured.

Categorization of Households

- Households are classified on the basis of three factors: Car ownership, Income and Household Structures. These are then classified into different ranges as indicated below:
- Car Ownership- 3 levels (0 car, 1 car and more than 1 car)
- Income – 6 Classes:

i) < 500 pa ii) 500-1000 pa iii) 1000-1500 pa

iv) 1500-2000 pa v) 2000-2500 pa vi) >2500 pa

- Household Structure- 6 classes

i) No employed resident and one non-employed adult

ii) No employed resident 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 **3×6×6 = 108 categories**

In addition it is possible to consider 3 modes of travel viz self-driven car, public transport, passenger in a car and 6 trip purpose (work, school, business, shopping, social- recreational and sport others). Thus we have 3X6=18 mode purpose combinations.

Advantages:

1. The whole concept of household trip making is simplified in this technique. The technique categories 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 data from the census can be used directly, it saves considerable effort, time and money spent on home-interview survey
4. The consumptions are relatively simpler
5. Since disaggregate data used, the technique simulates human, behavior more realistically than zonal aggregation process normally employed in regression analysis

Disadvantages:

1. It is difficult to test the statistical significance of various the various explanatory variables
2. The technique normally makes use of studies in the past made else ware, with broad corrections
3. New variables cannot be introduced at the future date
4. Large samples are needed to assign trip rates to any one category

TRIP DISTRIBUTION

UNIFORM GROWTH FACTOR

This method assumes that the growth rate for the whole are a is valid for predicting future inter-zonal trips. A single growth factor, E for entire area is obtained 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 zone i and j is calculated as:

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

Where T_{i-j} = design year(future) number of trips from zone i to zone j

t_{i-j} = observed base year number of trips from zone i to zone j

E = growth factor

Example: The distribution of present trips among zone 1,2, and 3 are given in O-D matrix below. The future trips generated in zone 1, 2 and 3 are expected to be 360, 1260 and 3120 respectively. Distribute the future trips among various zones.

	1	2	3
1	60	100	200
2	100	20	300
3	200	300	20

Solution:

	1	2	3	t_i	T_i
1	60	100	200	360	360
2	100	20	300	420	1250
3	200	300	20	520	3120
Total				1300	4740

$$\text{Growth factor, } E = \frac{ti}{Ti} = \frac{1300}{4740} = \mathbf{3.646}$$

Multiplying the cells in the matrix by the uniform growth factor of E= 3.646, results in following matrix

	1	2	3	T_i (Calculated)	T_i (Given)
1	218	365	729	1312	360
2	365	73	1094	1532	1260
3	729	1094	73	1896	3120
Total				4740	4740

The trips have been distributed among three zones resulting in total trips of 4740, which is same as the total of future trips as per data given. But the total trips generated in each zone is not tally with the values given, this is because of assumption of uniform growth.

Disadvantage of Uniform growth rate method

- The assumption of a uniform growth rate for the entire study area is not correct, because each zone will have its own growth rate and the growth rate of traffic between any two zones will be different
- The method underestimate movements where present-day development is limited and over-estimates movements where present-day development is intensive
- If present trip movement between any two zones is zero, the future trip moment also becomes zero as per this method. This may rarely be the case in reality.

AVERAGE FACTOR METHOD

In this method, a growth factor for each zone is calculated based on the average of the growth factors calculated for the both ends of the trip. The factor thus represents the average growth associated with both with the origin and destination zones.

Thus, $$T_{i\text{-}j} = t_{i\text{-}j} \times \left[\frac{Ei + Ej}{2}\right]$$

Where, $T_{i\text{-}j}$ = design year (future) number of trips from zone i to zone j

$t_{i\text{-}j}$ = observed base year number of trips from zone i to zone j

$E_i = \frac{P_i}{p_i}$ =growth factor for zone i

$E_j = \frac{A_j}{a_j}$ =growth factor for zone j

P_i = future generated trips for zone i

p_i = present generated trips for zone i

A_j = future attracted trips for zone j

a_j = present attracted trips for zone j

- After the distribution is completed on the above basis, the sum of the trips from zone i will probably not agree with the projected trip ends in zone i and the sum of the trips to zone j will not agree with projected trip ends in zone j.
- This is overcome by an iterative process using the new values for E_i and E_j calculated from:

$$E_i' = \frac{P_i}{p_i'} \qquad\qquad E_j' = \frac{A_j}{a_j'}$$

Where p_i' and a_j' are total generations and attraction to zone i and j respectively obtained from first stage of distribution.

The iteration is carried out till the growth factor approaches unity and the values matches within, say plus or minus 1%

Example: The distribution of present trips among zone 1,2, and 3 are given in O-D matrix below. The future trips generated in zone 1, 2 and 3 are expected to be 360, 1260 and 3120 respectively. Distribute the future trips among various zones.

	1	2	3
1	60	100	200
2	100	20	300
3	200	300	20

Solution:

	1	2	3	p_i	P_i	$E_i = P_i / p_i$
1	60	100	200	360	360	1
2	100	20	300	420	1250	3
3	200	300	20	520	3120	6
a_j	360	420	520	1300	4740	
A_j	360	1260	3120			
$E_j = A_j / a_j$	1	3	6			

Average Growth factor, $E = [\frac{E_i + E_j}{2}]$

Future trips generated, $T_{i\text{-}j} = t_{i\text{-}j} \times [\frac{Ei + Ej}{2}]$

$$T_{1\text{-}1} = \frac{1+1}{2} \times 60 = 60$$

$$T_{1\text{-}2} = \frac{1+3}{2} \times 100 = 200$$

$$T_{1\text{-}3} = \frac{1+6}{2} \times 200 = 700$$

$$T_{2\text{-}1} = \frac{3+1}{2} \times 100 = 200$$

$$T_{2\text{-}2} = \frac{3+3}{2} \times 20 = 60$$

$$T_{2\text{-}3} = \frac{3+6}{2} \times 300 = 1350$$

$$T_{3\text{-}1} = \frac{6+1}{2} \times 200 = 700$$

$$T_{3\text{-}2} = \frac{6+3}{2} \times 300 = 1350$$

Thus, the matrix becomes:

	1	2	3	p_i	P_i	$E_i' = P_i / p_i$
1	60	200	700	960	360	0.375
2	200	60	1350	1610	1260	0.783
3	700	1350	120	2170	3120	1.438
a_j	960	1610	2170	4740		
A_j	360	1260	3120		4740	
$E_j' = A_j / a_j$	0.375	0.783	1.438			

For the next iteration the new values of interzonal movements are calculated with the new E, shown as E' in the last column of the above matrix

II Iteration

	1	2	3	p_i	P_i	$E_i' = P_i / p_i$
1					360	
2					1260	
3					3120	
a_j				4740		
A_j	360	1260	3120		4740	
$E_j' = A_j / a_j$						

Example2: The following table gives trip distribution between four zones 1, 2,3 and 4. Estimate the future interzonal trip between the four zones. (upto two iteration)

	1	2	3	4	Future Trips
1	10	20	15	18	140
2	21	16	17	14	150
3	30	21	25	27	200
4	10	9	16	13	100
Future trips	150	120	180	160	

Disadvantages:

- The average factor method has same disadvantages of the uniform factor method. The multiplying factor has no real significance and only a convenient tool to balance the movements.
- If t_{i-j} is zero T_{i-j} also becomes zero a in case the case of uniform factor method
- It has additional disadvantage that a large number of iterations is required

FRATAR METHOD

In this method, the total trips for each zone are distributed to the interzonal movements, as a first approximation, according to the relative attractiveness of each movement. Thus, the future trip estimated for any zone would be distributed to the movement involving that zone in proportion to the expected trips between it and each other zone and in proportion to the expected growth of other zone. It is expressed mathematically as follow:

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

Where T_{i-j} = design year (future) number of trips from zone i to zone j

t_{i-j} = observed base year number of trips from zone i to zone j

P_i = future generated trips for zone i

p_i = present generated trips for zone i

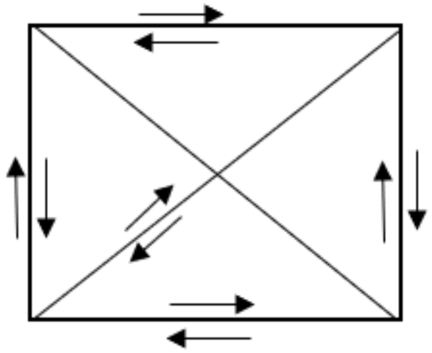
A_j = future attracted trips for zone j

a_j = present attracted trips for zone j

k = Total number of zones

when the future traffic into and out of all zones is similarly distributed, each interzonal trips has been assigned two tentative values.

- The result of distribution for one of the zones involved
- The result of distribution for another zone involved



- As a first approximation those pair of tentative values are averaged and anew growth factor for each zone is then calculated. The process is repeated till the growth factor approaches unity and the values matches within, say plus or minus 1%

Problem: The distribution of present trips among the zone A, B, C and D are given in the O-D matrix below. The future trips generated in zones A, B, C and D are expected to be 80, 114, 48 and 38 respectively. Distribute future trips among the zones.

	A	B	C	D
A	-	10	12	18
B	10	-	14	14
C	12	14	-	6
D	18	14	6	-
Present Total	40	38	32	38
Estimated Future Total	80	114	48	38
Growth Factor	2	3	1.5	1

Solution:

We have

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

$$T_{A-B} = t_{A-B} \times \frac{P_A}{p_A} \times \frac{A_B}{a_B} \times \frac{t_{AB} + t_{AC} + t_{AD}}{t_{AB}E_B + t_{AC}E_C + t_{AD}E_D}$$

$$= 10 \times \frac{80}{40} \times \frac{114}{38} \times \frac{40}{10(3) + 12(1.5) + 18(1)} = 36.4$$

T_{A-C} =

T_{A-D} =

T_{B-A} =

T_{B-C} =

T_{B-D}=

T_{C-A} =

T_{C-B} =

T_{C-D} =

T_{D-A} =

T_{D-B} =

T_{D-C} =

Zone	A	B	C	D	Sum of product of trip ends and growth factors	Desired Trips	Ratio of new total trips to sum of products
Growth factors	2	3	1.5	1			
For zone A							
1	–	10	12	18			
2	–	30	18	18	66		
3	–	36.4	21.8	21.8		80	1.21
For zone B	–						
1	10	–	14	14			
2	20	–	21	14	55		
3	41.5	–	43.5	29		114	2.07
For zone C							
1	18	14	–	6			
2	24	42	–	6	72		
3	16	28	–	4		48	0.667
For zone D							
1	18	14	5	–			
2	36	42	9	–	87		
3	15.8	18.3	8.9	–		38	0.437

The pair of interzonal volumes obtained by the above computation are averaged and shown below to obtain fair approximation for inter zonal trips

	A-B	A-C	A-D	B-C	B-D	C-D
	36.4	21.8	21.8	43.5	29	3.9
	41.5	16	15.8	28	18.3	4
Total	77.9	37.8	37.6	71.5	47.3	7.9
Average	39.9	18.9	18.8	37.5	23.6	40

The average of trips radiating from each zone are summarized to obtain new goth factors

	A	B	C	D
A	–	39.9	18.9	18.8
B	39.9	–	37.5	23.6
C	18.9	35.7	–	7.9
D	18.8	39.9	7.9	–
New totals	77.6	115.5	64.3	50.3
Desired Total	80	114	48	38
New GF	1.04	1.16	0.82	0.82

The procedure is repeated to obtain a second approximation using new growth factor.

FURNESS METHOD

This method to distribute the traffic, an estimate of future traffic originating and terminating at each zone are required, thus yielding origin growth factors and destination growth factors for each zone. The traffic movements are made to agree alternatively with the future traffic originating in each zone and the estimated future terminating in each zone, until both these conditions are roughly satisfies.

Problem: The distribution of present trips among the zones A, B, C and D are given below in the O-D matrix below. Distribute the future trips among zones.

	A	B	C	D	Total present trips	Predicted future trips	Origin Growth factor
A	8	3	16	15	42	147	3.5
B	6	9	8	5	28	42	1.2
C	10	8	3	8	29	32	1.1
D	2	4	7	12	25	30	1.2
Total present trips	26	24	34	40	124		
Predicted future trip	39	24	68	120		251	
Destination Growth factor	1.5	1.0	2.0	3.0			

The values of predicted future origin and destination growth factors are calculated for each zone.

Step:1 Each column is multiplied by destination GF such that column total become equal to predicted future trip totals

	A	B	C	D	Total present trips	Predicted future trips	Origin Growth factor
A	12	3	32	45	92	147	1.6
B	9	9	16	15	49	42	0.86
C	15	8	6	24	53	32	0.60
D	3	4	14	36	57	30	0.5
Total present trips	39	24	68	120	251		
Predicted future trip	39	24	68	120		251	
Destination Growth factor	1	1	1	1			

Step:2 Each … uture trips totals

	A	B	C	D	Total present trips	Predicted future trips	Origin Growth factor
A	19.2	4.8	51.2	72	147.20	147	1
B	7.74	7.74	13.76	12.9	42.14	42	1
C	9.0	4.8	3.6	14.4	31.8	32	1
D	1.59	2.12	7.42	19.08	30.21	30	1
Total present trips	37.57	19.46	75.98	118.38	251.35		
Predicted future trip	39	24	68	120		251	
Destination Growth factor	1.04	1.23	0.89	1.01			

SJB Institute of Technology
Department of Civil Engineering

MODULE – 4
TRIP DISTRIBUTION

Nisarga P, Assistant Professor

Lecture - 20

Synthetic Models- Gravity Model

SYNTHETIC MODEL

In the synthetic models of trip distribution, an attempt is made to discern the underlying cause of movement between places and relationship are established between places and relationship are established between trips measures of attraction, generation and travel distance.

Methods

- Gravity models
- Tanner models
- Intervening opportunities model
- Competing opportunities model

GRAVITY MODEL

Method 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 appropriate function of distance.
- This spatial separation adjusts the relative attraction of each zone for the ability, desire or necessity of the trip maker to overcome the spatial separation.
- **This interchange is directly proportional to the relative attraction between the zones and is inversely proportional to the measure of spatial separation.**

$$T_{i-j} = \frac{K P_i A_j}{d_{i-j}}$$

The following formula was also used in earlier studies dispensing with the proportionality constant.

$$T_{i-j} = P_i \times \frac{\frac{A_j}{(d_{i-j})^n}}{\frac{A_j}{(d_{i-j})^n} + \ldots\ldots \frac{A_k}{(d_{i-j})^n}}$$

In order to simplify the computation requirements, the following formula is used

$$T_{i-j} = \frac{P_i A_{jm} F_{i-j} K_{i-j}}{\sum_{x=1}^{k} A_{km} F_{(i-k)} K_{(i-k)}}$$

T_{i-j} = design year (future) number of trips from zone i to zone

P_i = future generated trips for zone i

A_j = future attracted trips for zone j

d_{j-j} = distance between zone i and zone j, or time or cost of travelling between them

K = a constant, usually dependent on i

n = exponential constant, whose value is usually found to lie between 1 to 3

k = total number of zones

F_{i-j} = Empirically derived travel time factor which expresses the average area wide effect of spatial separation on trip interchange between zone i-j

K_{i-j}= a specific zone to zone adjustment factor

Example: The total trips produced in and attracted to the three zones A,B & C of a survey area in the design year are tabulated as :

Zone	Trips Produced	Trips Attracted
A	2000	3000
B	3000	4000
C	4000	2000

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 20minutes. If the trip interchange between zones B and C is known to be 600, Calculate the trip interchange between zone A&B, A &C, B&A, C&B

Solution:

Given $T_{B\text{-}C}$= 600 P_B= 3000 A_c=2000 n=2 t=20

We have,

$$T_{i-j} = \frac{KP_iA_j}{(t)^n}$$

$$\frac{KP_BA_c}{(t)^n}$$

$$600 = \frac{K \times 3000 \times 2000}{(20)^2}$$

$$K = \frac{1}{25}$$

$$\frac{1}{25} \times \frac{2000 \times 4000}{(20)^2}$$

$$= \mathbf{800}$$

$$\frac{1}{25} \times \frac{2000 \times 2000}{(20)^2}$$

$$= \mathbf{400}$$

$$T_{B-A} = \frac{1}{25} \times \frac{3000 \times 3000}{(20)^2}$$

$$= \mathbf{900}$$

$$T_{C-A} = \frac{1}{25} \times \frac{4000 \times 3000}{(20)^2}$$

$$= \mathbf{900}$$

$$T_{c-B} = \frac{1}{25} \times \frac{4000 \times 4000}{(20)^2}$$

$$= \mathbf{1600}$$

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MODULE – 4

TRIP DISTRIBUTION

Nisarga P, Assistant Professor

Lecture - 21

Synthetic Models- Gravity Model

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

There are 3700 jobs in industrial estate X and 4500 in industrial estate Y. It is well known that 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

A	1000
B	2250
C	1750
D	3200

Zones	X	Y
A	15	20
B	15	10
C	10	10
D	15	20

Calculate and tabulate the inter zonal trips for journey from home to work

Solution: Using Gravity Model, We have

$$T_{i-j} = P_i \times \frac{\frac{A_j}{(d_{i-j})^n}}{\frac{A_j}{(d_{i-j})^n} + \ldots\ldots + \frac{A_k}{(d_{i-j})^n}}$$

Given n=2

$$T_{A-X} = 1000 \times \frac{\frac{3700}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{604}$

$$T_{A-Y} = 1000 \times \frac{\frac{4500}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{396}$

$$T_{B-X} = 2250 \times \frac{\frac{3700}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{604}$

$$\frac{4500}{(15)^2}$$

$$T_{C-X} = 1750 \times \frac{\frac{3700}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{790}$

$$T_{C-Y} = 1750 \times \frac{4500}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{960}$

$$T_{D-X} = 3200 \times \frac{\frac{3700}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{1980}$

$$\frac{4500}{(15)^2}$$

Production	
P_A	1000
P_B	2250
P_C	1750
P_D	3200

Attraction	
A_X	3700
A_Y	4500

Zones	X	Y
A	15	20
B	15	10
C	10	10
D	15	20

The results are tabulated in the matrix below:

Zones	X	Y	Total Production
A	**604**	**396**	1000
B	**604**	**1646**	2250
C	**709**	**960**	1750
D	**1980**	**1220**	3200
Total Calculated attraction, C_j	3978	4222	8200
Total predicted attraction, A_j	3700	4500	8200

Total attraction do not tally with the predicted attraction. Therefore, the attractions are first adjusted as follows:

$$A_{jm} = \frac{A_j}{C_j(m-1)} A_{j(m-1)}$$

Where, A_{jm} = Adjusted attraction function, for iteration 'm'

A_j = Desired attraction

$A_{j(m-1)}$ = Attraction factors, iteration m-1

$C_{j(m-1)}$ = Actual attraction factor, iteration m-1

$$A_{j2}\ for\ zone\ X = \frac{3700}{3978} \times 3700$$

$$= \mathbf{3440}$$

$$A_{j2}\ for\ zone\ Y = \frac{4500}{4222} \times 4500$$

$$= \mathbf{4800}$$

II Iteration:

$$T_{A-X} = 1000 \times \frac{\frac{3440}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$= \mathbf{560}$

$$T_{A-Y} = 1000 \times \frac{\frac{4800}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$= \mathbf{440}$

$$T_{B-X} = 2250 \times \frac{\frac{3440}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$= \mathbf{540}$

$$T_{B-Y} = 2250 \times \frac{\frac{4800}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$$T_{C-X} = 1750 \times \frac{\frac{3440}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$= \mathbf{730}$

$$T_{C-Y} = 1750 \times \frac{\frac{4800}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

$= \mathbf{1020}$

$$T_{D-X} = 3200 \times \frac{\frac{3700}{(15)^2}}{\frac{3700}{(15)^2} + \frac{4500}{(20)^2}}$$

$= \mathbf{1790}$

$$T_{D-Y} = 3200 \times \frac{\frac{4800}{(15)^2}}{\frac{3440}{(15)^2} + \frac{4800}{(20)^2}}$$

Production	
P_A	1000
P_B	2250
P_C	1750
P_D	3200

Attraction	
A_X	3440
A_Y	4800

Zones	X	Y
A	15	20
B	15	10
C	10	10
D	15	20

The results are tabulated in the matrix below

Zones	X	Y	Total Production
A	**560**	**440**	1000
B	**540**	**1710**	2250
C	**730**	**1020**	1750
D	**1790**	**1410**	3200
Total Calculated attraction, C_j	3620	4580	8200
Total predicted attraction, A_j	3700	4500	8200

Further iteration is carried if more accuracy is required using new adjustment factor.

$$A_{j3}\ for\ zone\ X = \frac{3700}{3620} \times 3440$$

$$= \mathbf{3516}$$

$$A_{j3}\ for\ zone\ Y = \frac{4500}{4580} \times 4800$$

$$= \mathbf{4716}$$

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MODULE – 4
TRIP DISTRIBUTION

Nisarga P, Assistant Professor

Lecture - 22

Tanner models

Opportunities model

TANNER MODEL

Tanner has suggested that the inverse of the n[th] power, $1/(d_{i-j})^n$ in the gravity model formula cannot give valid estimates at both very small and very large distances. In this place, tanner model proposes the function $e^{\gamma d} / d^n$, where γ and d are constants.

The model can be represented as follows:

$$t_{i-j} = \frac{mP_iP_je_{i-j}^{-\gamma d}}{d_{i-j}} \left[\frac{1}{C_i} + \frac{1}{C_j} \right]$$

Where t_{i-j} = number of trips per day between zone i and j

m= Constant

P_i and P_j are proportioners or other measures of size of two zone i and j respectively

d_{i-j} = distance between i and j or the time or cost of travelling between them

C_i and C_j = consents, one for each place, C_i being defined by

$$C_i = \sum P_j e^{-d_{i-j}} 3.$$

OPPORTUNITY MODEL

Opportunity models are based on the statistical theory of probability. The two well-known models are:

i) Intervening Opportunity model

ii) Competing opportunity model

The opportunity models can be represented by the general formula:

$$T_{i-j} = O_i P\left(D_j\right)$$

Where, $T_{i-j} =$ Predicted number of trips from zone i to j

O_i = Total number of trips originating in zone i

$P\left(D_j\right)$ = calculated probability of a trip generating in zone j

D_j = total trips destinations attracted to zone j

i) Intervening Opportunity model:

- In the intervening opportunity model, it is assumed that the trip interchange between an origin and destination zone is equal to the total trips emanating from 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:
    a) The size of the destination
    b) The order in which it is encountered as trips proceeds from origin

The probability function may be expressed as follow:

$$T_{i-j} = O_i\left(e^{-LB} - e^{-LA}\right)$$

Where, T_{i-j} = Predicted number of trips from zone i to j

O_i = total number of trips originating in zone i

L = probability density (probability for destination) of destination acceptability at the point of consideration

A = number of destinations between i and j (including j) when arranged in order of closeness

B = number of destinations between i and j (excluding j) when arranged in order of closeness

Example: The number of trips produced and attracted to the three zones 1,2 and 3 are tabulated:

Zones	1	2	3	Total
Trips Produced	14	33	28	75
Trips Attracted	33	28	14	75

The order of closeness of the zones is included in the following matrix:

	1	2	3
1	1	2	3
2	2	1	3
3	2	3	4

The zonal L factor are given below:

Zone	L Factor
1	0.04
2	0.02
3	0.04

Distribute the trips between the zones:

Solution:

We Have

$$T_{i-j} = O_i\left(e^{-LB} - e^{-LA}\right)$$

$$T_{1-1} = 14\left(e^{-0.04\times 0} - e^{-0.04\times(33)}\right)$$

$$= 10.26,\ \text{say } 10$$

$$T_{1-2} = 14\left(e^{-0.04\times 33} - e^{-0.04\times(33+28)}\right)$$

$$= 2.52,\ \text{say } 3$$

$$T_{1-3} = 14\left(e^{-0.04\times(33+28)} - e^{-0.04\times(33+28+14)}\right) = 0.52,\ \text{say } 1$$

$$T_{2-1} = 33\left(e^{-0.02\times 28} - e^{-0.02\times(28+33)}\right) = 9.11,\ \text{say } 9$$

$$T_{2-2} = 33\left(e^{-0.02\times 0} - e^{-0.02\times 28}\right) = 14.15,\ \text{say } 14$$

$$T_{2-3} = 33\left(e^{-0.02\times(33+28)} - e^{-0.02\times(33+28+14)}\right) = 2$$

$$T_{3-1} = 28\left(e^{-0.04\times 14} - e^{-0.04\times(14+33)}\right) = 3$$

$$T_{3-2} = 28\left(e^{-0.04\times(14+33)} - e^{-0.04\times(14+28+33)}\right) = 19$$

$$T_{3-3} = 28\left(e^{-0.04\times 0} - e^{-0.04\times 14}\right) = 15$$

The matrix can be constructed as below:

	1	2	3	Total
1	**10**	**2**	**1**	13
2	**9**	**14**	**2**	25
3	**12**	**19**	**15**	27
Destination total	31	19	15	65

i) Competing Opportunity model:

In the Competing opportunity model, the adjusted probability of a trip ending zone is the product of two independent probabilities, viz., the probability of a trip being attracted to a zone and the probability of a trip finding destination in that zone.

General form of this model is given by:

$$T_{i-j} = \frac{P_i\left(\frac{A_j}{\sum_j A_j}\right)}{\sum\left(\frac{A_j}{\sum_j A_j}\right)}$$

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MODULE – 4

MODAL SPLIT

Nisarga P, Assistant Professor

Lecture - 23

Factors affecting Modal Split

- Modal split is a process of separating person trip by the mode of travel. It is generally expressed as fraction or ratio or percentage of total number of trips.
- The objective of modal split is to analyse people's decision regarding the mode of travel such as auto, bus, train and so on.

Factors affecting Modal Split

1. Characteristics of trip
2. Household Characteristics
3. Zonal Characteristics
4. Network Characteristics

Characteristics of trip

- Trip purpose
- Trip length

Household Characteristics

- Income
- Car ownership
- Family size and composition

Zonal Characteristics

- Residential Density:
- Concentration of workers
- Distance from CBD

Network Characteristics

- Accessibility Ratio: It is the measure of the relative accessibility pf that zone to all other zones by means of mass transit network and highway network.
- Travel time ratio: The ratio of the travel time by public travel time by public transport and travel time by private car give measure of the attractiveness of public transport system
- Travel-cost ratio: The ratio of cost of travel by public transport and cost of travel by car is one of the most important factors influencing modal choice. The importance of travel cost is related to the economic status. People with high income are unmindful of cost and prefer more expensive modes.

Modal Split in Transport Planning Process

Modal split is considered in transport planning at various stages:

a. *Pre-distribution* modal split or *Trip end* modal split

b. *Post-distribution* modal split or *Trip interchange* modal split

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MODULE – 4

MODAL SPLIT

Lecture - 24

Pre-Distribution Modal Split

Nisarga P, Assistant Professor

Pre-distribution modal split / Trip End Modal Split

This process can again be carried out at two different stages:

- At trip generation stage itself
- After trip generation but before trip distribution

At trip generation stage

- If modal split is considered ***at trip generation stage itself***
- The factors normally considered - car ownership, residential density, distance of the origin from CBD and the relative accessibility of the zone of origin to the transport facilities.
- The methods reflect different trip generation patterns for different trip purposes
- Fails to take into account future changes in public transport system, improvement in highway system and the restraint on the use of private car by economic means

After trip generation but before trip distribution

- Modal split is carried out ***after generation but before distribution***
- The trip generation but before distribution, the trip generations are calculated on the assumption that the mode of travel has no influence on the trip generation.

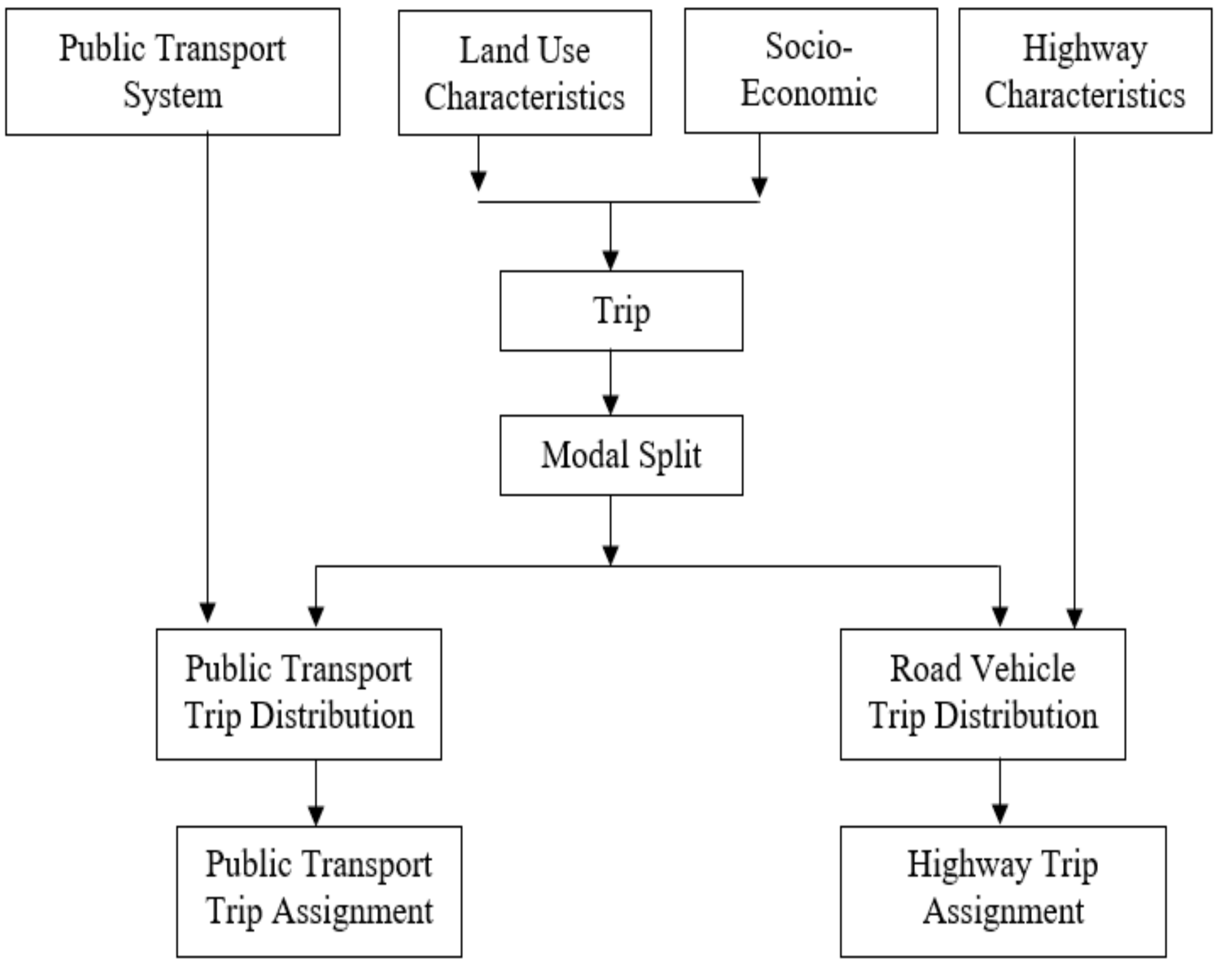

Fig: Modal Split carried out after Trip Generation

ADVANTAGES

1. Less difficult and less costly when compared with trip interchange modal split
2. The possibility of separate public transport and private car distribution afforded by this method is desirable feature because of the differing trip length by car and public transport
3. This method reflects factors such as the income, car ownership, family structure, employment etc. which are the characteristics affecting trip generation

DISADVANTAGES

1. Since the method is reliable on existing and historical levels of public transport service, they are inappropriate to studies involving planning of improvements to public transport system where significantly different levels of service are contemplated.
2. In this method, the characteristics of the transportation system are fed on an average area wide basis. As such, this procedure fails to reflects the particular zone to zone combinations as precisely as trip interchange models.
3. It does not consider the trip generation characteristics fully.
4. It is insensitive to future development in inter-zonal travel.

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MODULE – 4

MODAL SPLIT

Nisarga P, Assistant Professor

Lecture - 25

Post-Distribution Modal Split

Trip Interchange Modal Split / Post-Distribution Model

In post distribution modal split, modal split is carried out after trip generation stage and before trip assignment

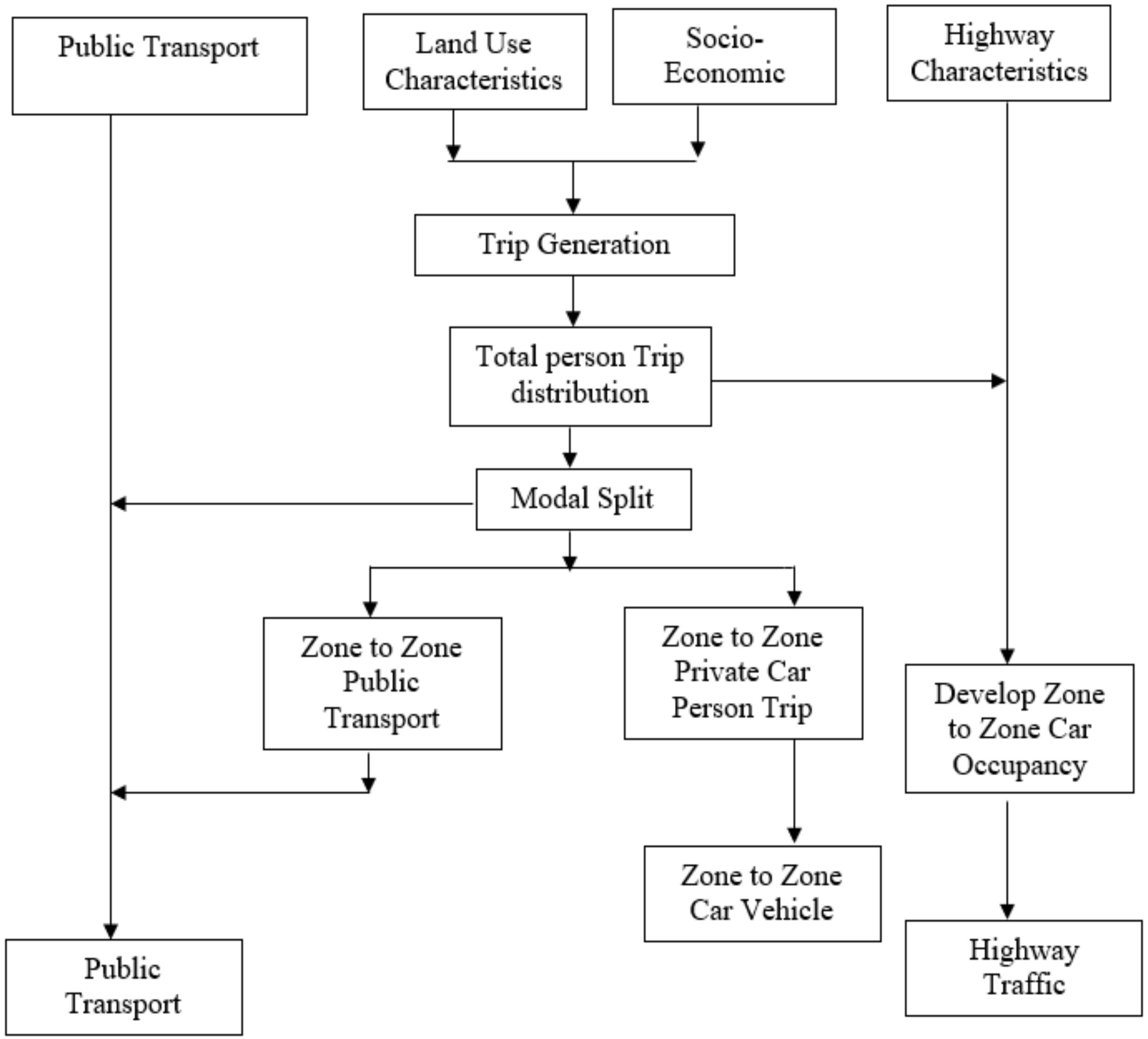

Fig: Post Distribution Model Split

ADVANTAGES

1. It is useful in situations where serious consideration is given in public transport planning
2. The method makes it possible to develop modal split relations based on a wide range of transport system variables influencing modal choice
3. The method considers private car and public transport usage on zone to zone basis instead of a zonal basis as in the pre-distribution methods.

DISADVANTAGES

1. It is very complex, especially if the number of zones is large
2. In this method, total person trip is considered before any modal choice is considered. This ignores the differing lengths by car and public transport

NOTE:

The probability of using a mode of travel is generally given by equation i.e based on logistic model is as follows.

$$P_i = \frac{e^{v(i)}}{\sum_{r=1}^{n} e^{v(r)}}$$

Where $V_{(i)}$ = utility of mode 'I'

$V_{(r)}$= utility of mode 'r'

n = number of modes of consideration

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MODULE – 4

MODAL SPLIT

Nisarga P, Assistant Professor

Lecture - 26

Modal Split - Numerical

Example:1 The calibrated utility functions for auto and bus travel are as follows:

Auto: V_a= - 0.3 - 0.04x - 0.1y - 0.03C

Bus: V_t= - 0.04x - 0.1y - 0.036

Where x = in vehicle travel time

y = out vehicle travel time

C = cost of travel/income

The traffic zone has the following characteristics:

	Auto	Bus
In vehicle time (min)	20	40
Out vehicle time (min)	10	15
Travel cost (Rs)	60	20

What is the probability that a person with an income of 25,000/- will travel by bus.

Solution:

Auto: V_a= - 0.3 - 0.04 (20) - 0.1(10) - 0.03(60/25000)

= **- 2.1**

Bus: V_t= - 0.04(40) - 0.1(15) - 0.036(20/25000)

= **- 3.1**

The probability of trips maker bus trips

$$P_t = \frac{e^{-3.1}}{e^{-3.1} + e^{-2.1}}$$

$$= \frac{0.045}{0.045 + 0.1225}$$

= **0.2687 or 26.87%**

Example:2 The calibrated utility functions for a travel in a medium by automobile, bus and motor-rail is as follows.

$$U = a - 0.002\ x_1 - 0.005x_2$$

Where x_1 = cost of travel(in Rs)

x_2 = Travel time (in min)

Calculate the modal split for the given values

Mode	a		
Automobile		120	30
Bus		20	45
Metrorail		60	35

If parking fee of 5/- per trip is imposed on automobiles, what would be the split to the other two modes?

Solution:

Automobile, $U_a = -0.30 - 0.002\ (120) - 0.005(30)$

$= \mathbf{-1.77}$

Bus, $U_b = -0.305 - 0.002\ (20) - 0.005(45)$

$= \mathbf{-2.64}$

Metrorail, $U_m = -0.40 - 0.002\ (60) - 0.005(35)$

$= \mathbf{-2.27}$

Mode				$P_{in(\%)}$
(a) Automobile		0.1703	0.4936	49.36
(a) Bus		0.0714	0.2069	20.69
(a) Metrorail		0.1033	0.2994	29.94

$$P_a = \frac{e^a}{e^{ua} + e^{ub} + e^{uc}}$$

When additional Rs. 50 is imposed on automobile for parking

Automobile, $U_a = -0.30 - 0.002\,(125) - 0.005(30) = -2.05$

Mode				P (%)
(a) Automobile		0.1287	0.4242	42.42
(a) Bus		0.0714	0.2353	23.53
(a) Metrorail		0.1033	0.3405	34.05

Due to increase in parking charges difference in automobile trips are

= 49.36 - 42.42 = 6.94 = 7%

MODULE – 5

TRIP ASSIGNMENT

Nisarga P, Assistant Professor

SJB Institute of Technology
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Lecture - 27

Trip Assignment – General Principle

TRAFFIC ASSIGNMENT

Traffic assignment is the stage in the transport planning process where in the trip interchange are allotted to different parts of the network forming the transportation system. In this stage,

a) The route to be allotted is determined

b) The inter-zonal flows are assigned to selected routes

APPLICATIONS

1. Determine the deficiencies in the existing transportation system
2. Evaluate the effects of limited improvements and additions to the existing transportation system
3. To develop construction priorities
4. To test alternative transportation system proposals
5. To provide design hour traffic volumes on highway and turning movement at junctions.

GENERAL PRINCIPLE

- All assignment techniques are based on route selection.
- The choice of route is made on the basis of a number of criteria such as journey time, length, cost, comfort, convenience and safety.
- Journey time is often considered as the sole craterisation since length and cost can be considered as function of time in most cases.
- As a first step, the highway network is described by a system of links and nodes.

Moor's Algorithm for Minimum Path Tree

The network is as shown below and consists of a zone centroid 1 and a number of links and nodes

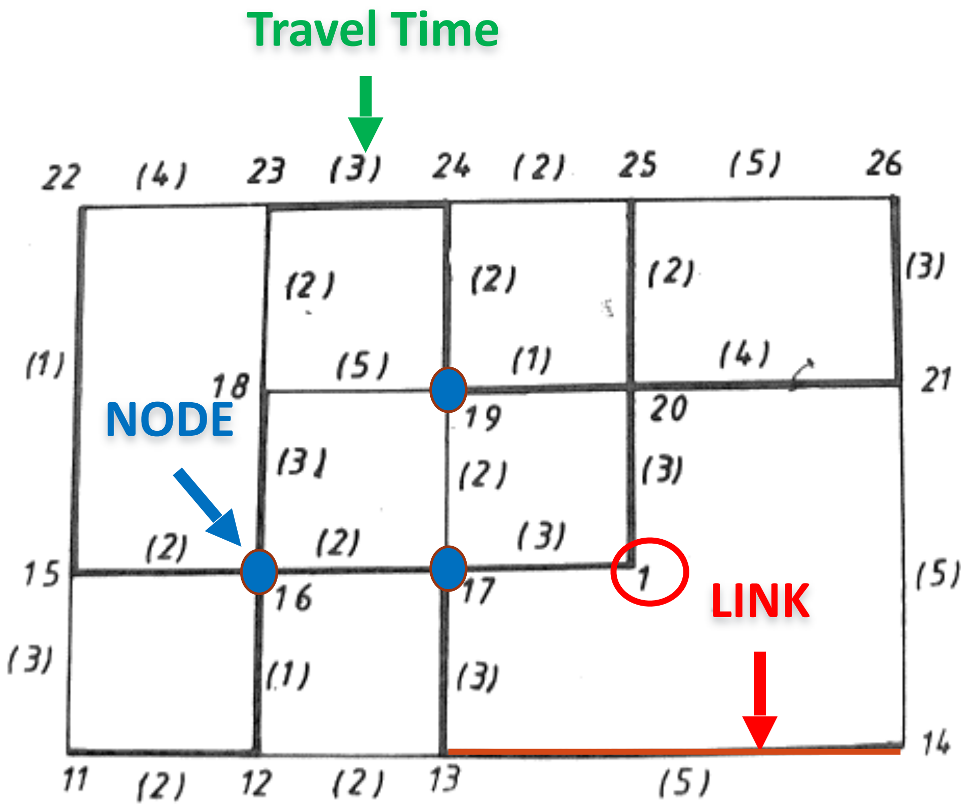
Node: A node is either the centroid of a zone or the intersections of two or more links.

Link: A link is a section of a highway network between two intersection

Minimum path: The route of travel which has least accumulation of time, distance or other parameters.

The travel time on each link is indicated in figures in brackets. It is required to build minimum path tree from zone centroid

Tree: The sequence of nodes which defines the link comprising the minimum path between any two zone centroids



Starting from centroid 1, we go to each connecting node and note the time of travel to the node.

Thus, $T_{1\text{-}20} = 3$

$T_{1\text{-}17} = 3$

The node close to the centroid 1 in time is considered next.

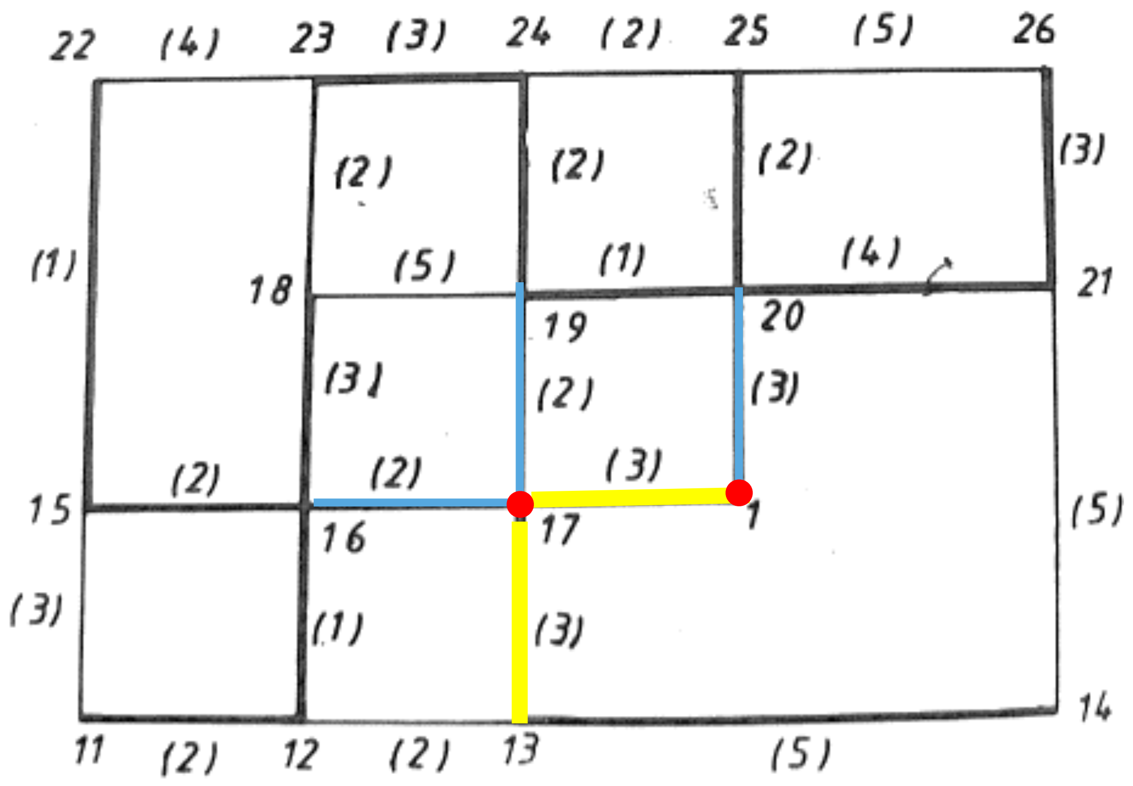
In this example, the time taken to reach both the nodes being the same, the node having lower number, viz node **17** is taken up.

From node 17, the cumulative time to travel from centroid connected directly to note 17 is noted.

$T_{1\text{-}17\text{-}19} = 5 \quad (3+2)$

$T_{1\text{-}17\text{-}16} = 5 \quad (3+2)$

$T_{1\text{-}17\text{-}13} = 6 \quad (3+3)$



From node 20, the cumulative time to travel from centroid connected directly to note 20 is noted.

$T_{1\text{-}20\text{-}19} = 4$

$T_{1\text{-}20\text{-}25} = 6$

$T_{1\text{-}20\text{-}21} = 7$

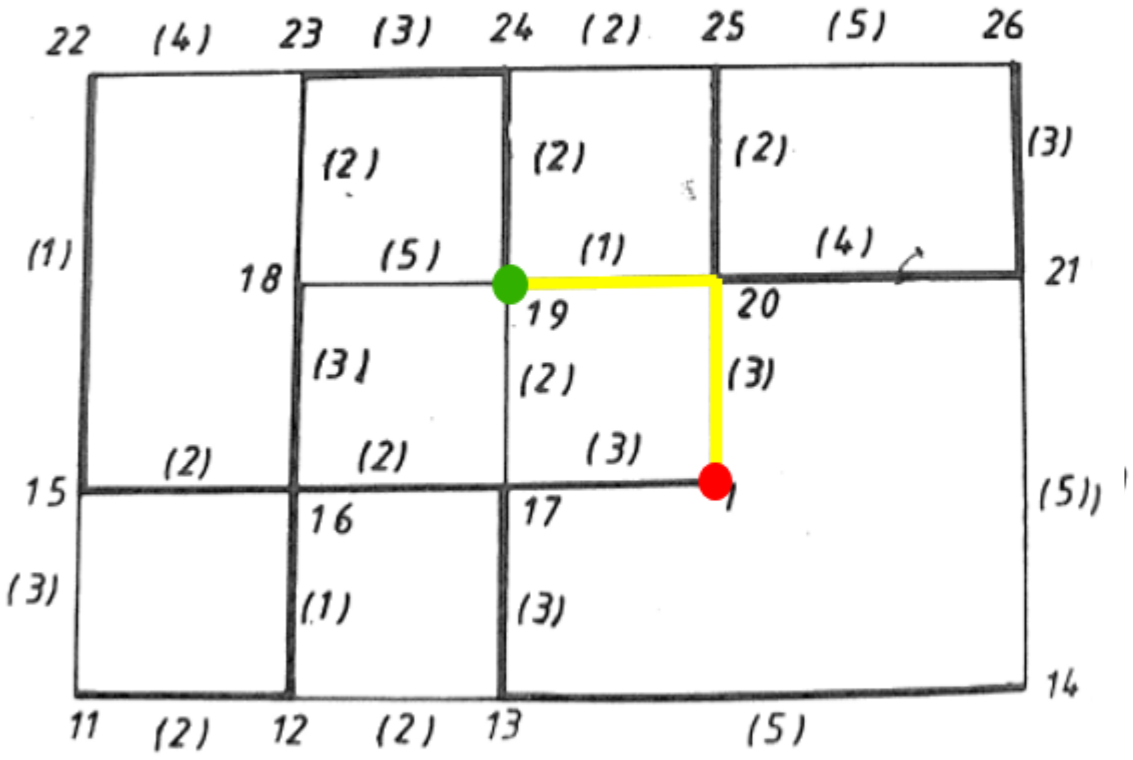
It will be seen from the above that there are two possible routes to reach node 19,

$T_{1\text{-}17\text{-}19} = 5$

$T_{1\text{-}20\text{-}19} = 4$

latter is shorter in time and is therefore chosen former is discarded.

This process is repeated until all nodes have been covered by the shortest path. The minimum path tree is indicated in fig.



ASSIGNMENT TECHNIQUES

The different techniques of traffic assignment are

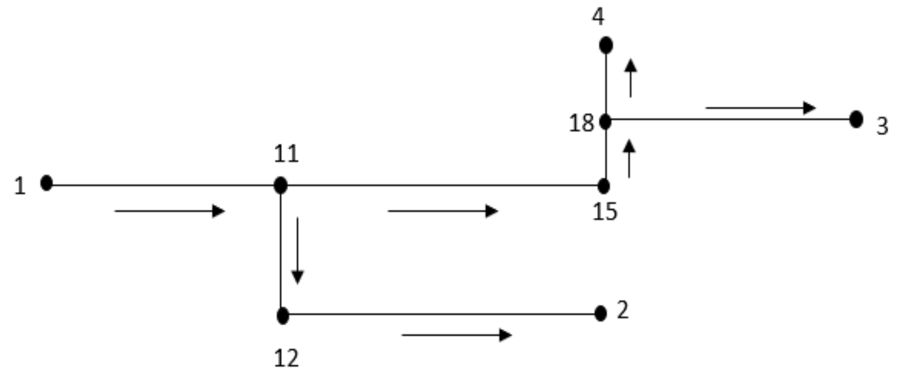
1. All-or-nothing assignment (free assignment or desire assignment)
2. Multiple route assignment
3. Capacity restraints assignment
4. Diversion Curves

All-or-Nothing Assignment

- This is the simplest technique and is based on the premise that the route followed by traffic is one having the least travel resistance.
- The resistance is measured in terms of travel time, distance or a suitable combination of these parameters.
- The procedure of network description and tree building is done considering the minimum travel path. The next stage is to assign the traffic flows to the minimum path tree.

Example: Figure below shows the minimum path tree connecting zone centroid 1 with zone centroid 2, 3, & 4. The traffic volume from zone centroid 1 to zone centroid 2, 3, & 4 are given

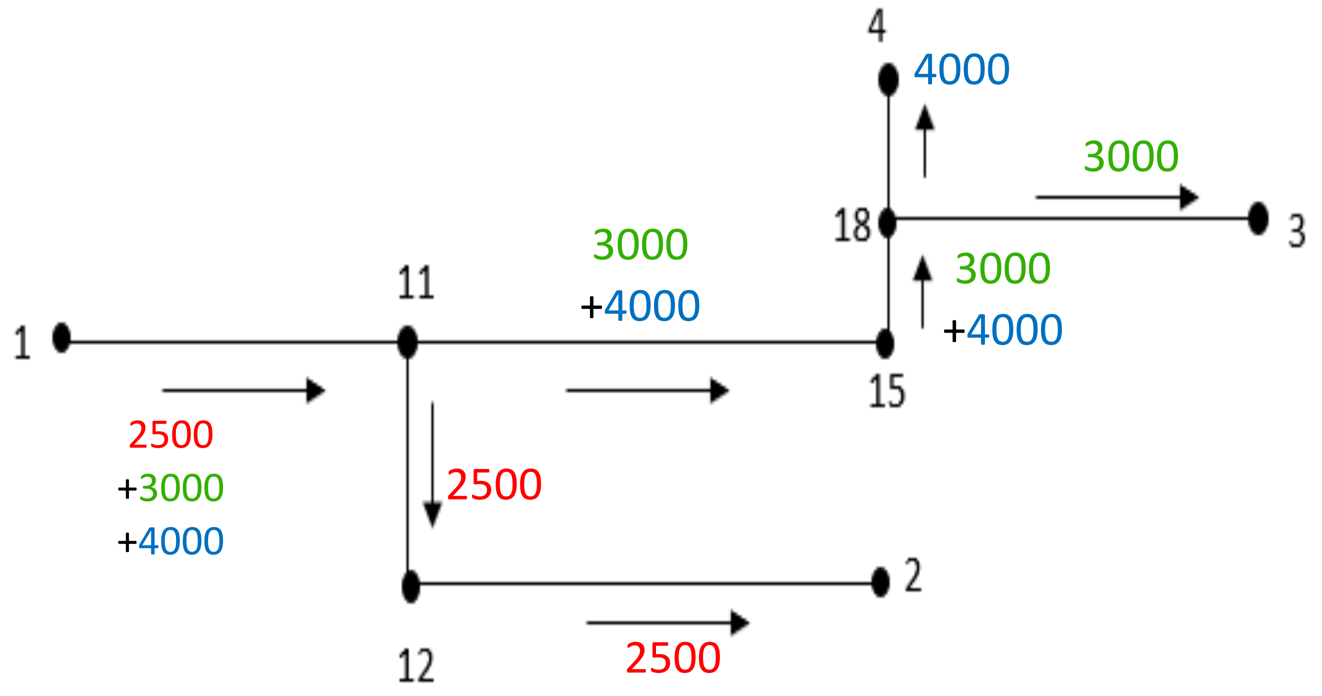
From zone centroid	To zone centroid	Traffic volume (Vehicles/hour)
1	2	2500
1	3	3000
1	4	4000



It is required to assign the flow from zone centroid 1 to zone centroid 2, 3, & 4

Solution:

From zone centroid	To zone centroid	Traffic volume (Vehicles/hour)
1	2	2500
1	3	3000
1	4	4000



It will be seen from the above figure, the traffic volume assigned to the various link are

Link	Traffic Flow (Vehicles/ hour)
1-11	9500
11-12	2500
12-2	2500
11-15	7000
15-18	7000
18-3	3000
18-4	4000

Disadvantages

1. If time alone is used as governing factors for the choice of the minimum path
2. Too many vehicles tend to be assigned to more attractive route which may cause increasing congestion on these routes
3. If superior facility is available, say for example a motorway, people tend to prefer to use this facility for longer journeys. If the travel time or cost is the sole factor, the all-or-nothing assignment might not reflect this tendency.
4. Small difference in journey times by different routes between the same origin and destination can results in unrealistic journey path.

Multiple Route Assignment

- The limitations of the all-or-nothing approach are recognised in the multiple route assignment technique.
- The method consists of assigning the inter-zonal flow to a series of routes, the proportion of the total flow to a series of routes, the proportion of the total flow assigned to each being a function of the length of that route in relation to the shortest route.
- In this approach, it is assumed that a driver does not know the actual travel times, but that he associates with each link a supposed time. The mean of this supposed time gives actual link time.
- The driver is then assumed to select the route which minimises the sum of his supposed time gives actual link time.
- Multiple route models found to yields more accurate assignment than all-or-nothing assignment.

Capacity Restraints Assignment

- Capacity restraint assignment is a process in which the travel resistance of a link is increased according to the relation between the practical capacity of the link and the volumes assigned to the link.

  This technique has been developed to overcome the inherent weakness of all-or-nothing assignment technique which takes no account of the capacity of the system between a pair of zones.

- The capacity restraint system, clearly restrains the number of vehicles that can use any particular corridor. If the assigned volume are beyond the capacity of the network, redistributes the traffic to the realistic alternative paths

Methods of Capacity Restraint Techniques

Smock Method

Bureau of Public Roads (BPR) methods:

1. **Smock Method:** In this method, all-or-nothing assignment is first worked out. In an iterative procedure, the link travel time is modified according to the function

$$T_A = T_0 e^{\left(\frac{V}{C}-1\right)}$$

$$T_A \leq 5T_0$$

Where, T_0 = original travel time or the travel time on a link when volume equals capacity

T_A = adjusted travel time

e = exponential base

V = assigned volume

C = computed link capacity

In the second iteration, the adjusted travel time T_A are used to determine the minimum paths tree.

2. **Bureau of Public Roads (BPR) methods:**

The formula used to update the link volume time is

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

Where, T_N = link travel time at assigned volume

T_o = base travel time art assigned volume

(equals 0.81times travel time at particular capacity)

V = Volume

C = Capacity

Diversion Curves

a) One of the frequently used assignment techniques is the diversion curves. These curves represent empirically derived relationship showing the proportion of the traffic that is likely to be diverted on a new facility (by pass, new expressway, new arterial streets etc.)

b) The equations for diversion curves used in India for estimating the traffic that get diverted to expressway are as follow

Item	Cost Ratio Interval	Equation
Cars	≤ 0.634	
	0.634< CR<1.464	
	1.465 to 2,000	
Trucks & Buses	≤ 0.750	
	00750<CR<1.250	
	1.250 to 2,000	

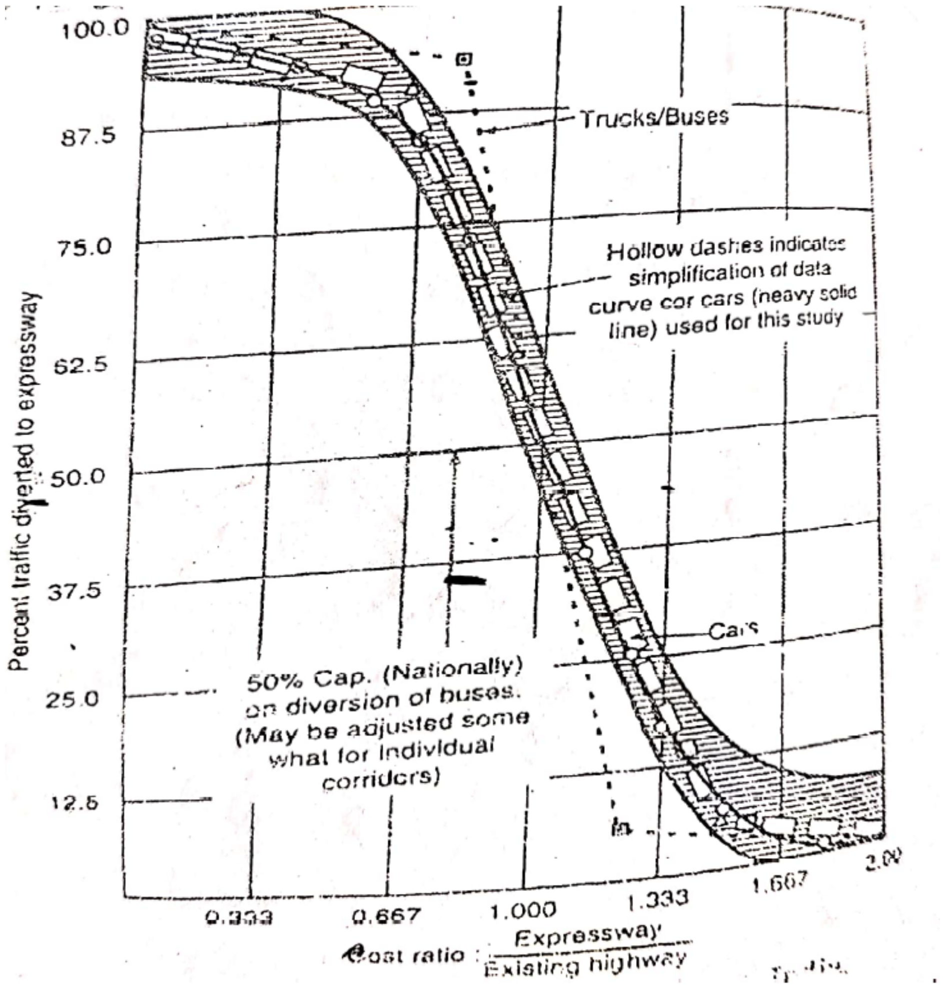


Fig: Diversion curves for Expressway in India

(C) A well known examples of diversion curves using travel time ration to determine the traffic diverted to expressway is the Bureau of Public Road Curves. The curve is 'S' shaped as given in fig below

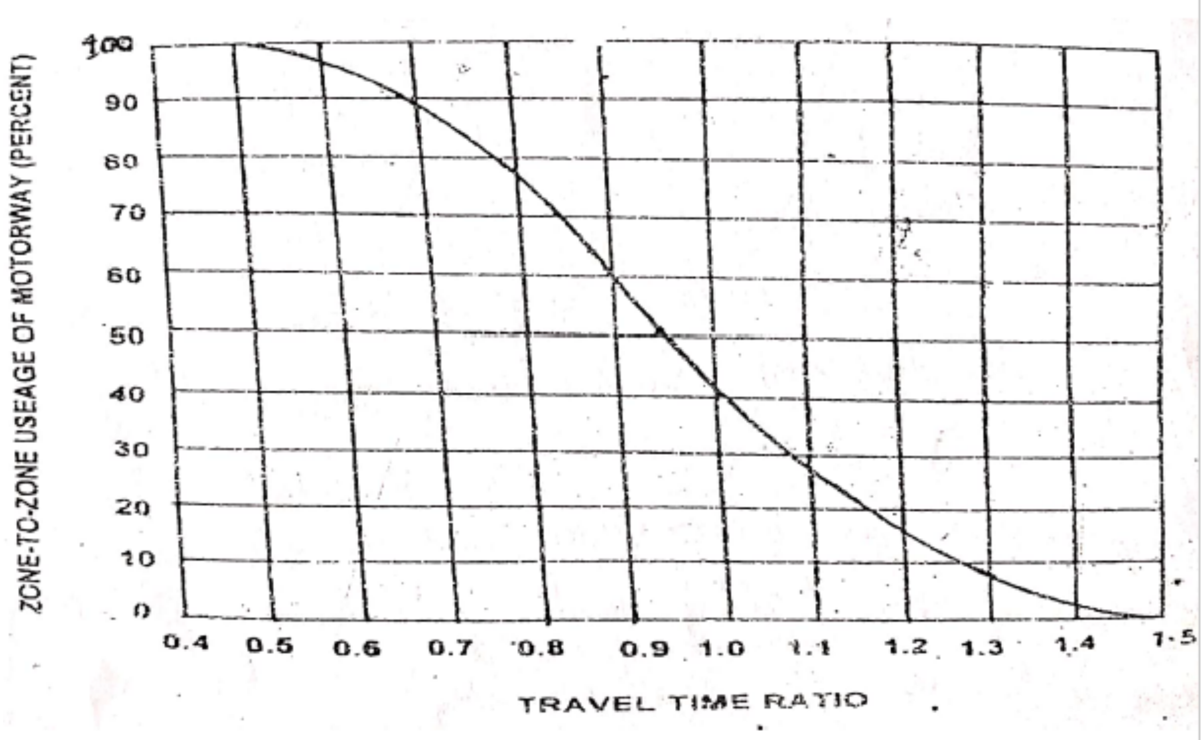


Fig: Bureau of Public Roads Diversion Curves

The following formula has been fitted to this type of curves.

$$P = \frac{100}{1 + t_R^6}$$

Where, P= percentage of traffic diverted to new system

$$T_R = \text{Travel time ratio} = \frac{\textit{Time on new system}}{\textit{Time on old system}}$$

Problems: In order to relieve congestion on the urban street network a motorway is proposed to be constructed. The travel time from zone centroid to another via the proposed motorway is estimated to be 10 min whereas the time for same travel via the existing street is 18min. min. The flow between the two zone centroid is 1000vehicles/hour. Assign flow between the new motorway and existing street.

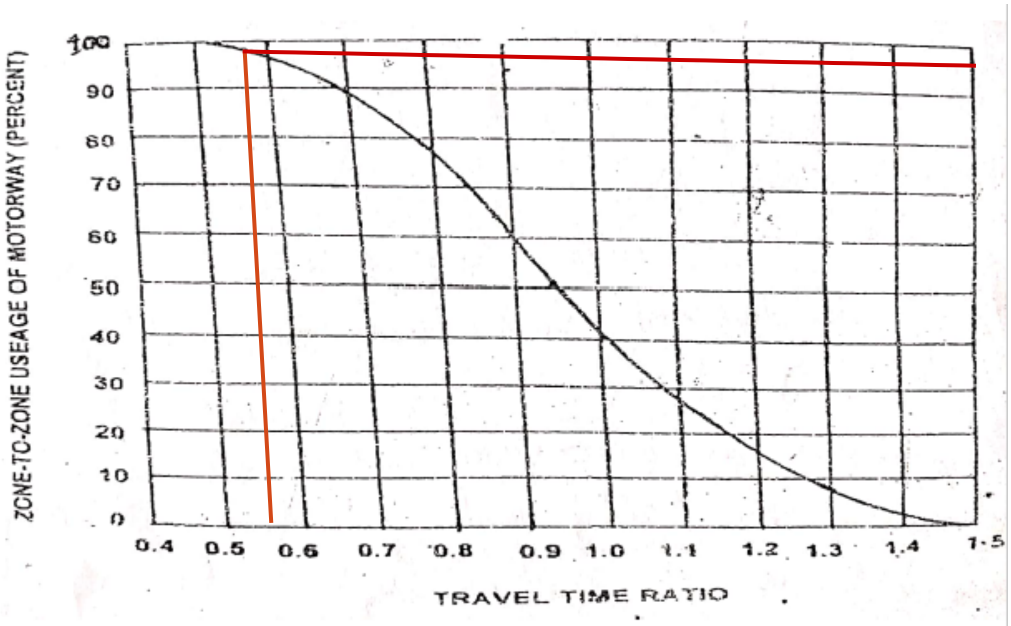
Solution:

We have , $P = \dfrac{100}{1+t_R^6}$

T_R = Travel time ratio $= \dfrac{\textit{Time on new system}}{\textit{Time on old system}} = \dfrac{10}{18} == 0.56$

Percentage motorway usage, $P = \dfrac{100}{1+t_R^6} = \dfrac{100}{1+0.56} = 96.5\%$

Traffic diverted to new motorway = 1000 x 96.5 = 35vehicles/hour



<u>Alternatively:</u>

Using graph, percentage of traffic using motorway corresponding to travel-time ratio 0.56 = 97%

(d) Another well known example using two variables, distance and travel time saved usina a motorway, is the **California Diversion Curve**. Figure shows family of curves, the following has been developed to fit the above curve

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

Where, P = percentage of motor way usage

d = distance saved in miles via the motorway

t = time saved via the motorway