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سلايدات

# مواصلات

د. حمزة العلكومي

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# *Transportation Engineering and Planning*

Module | 0 | Introduction

0.0 | Introduction + Course Syllabus

*Dr. Hamza Mohammad Alkuime*

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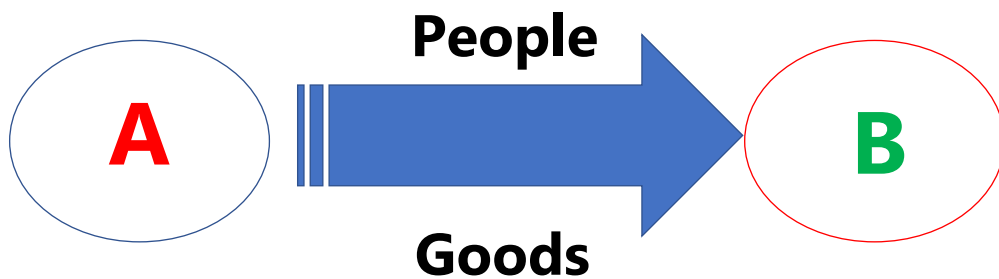
Definitions

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## Transportation

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- ❑ The movement of people and goods from one location to another.



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## Transportation System

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- ❑ A Transportation System encompasses all the components involved in the movement of people and goods from one place to another efficiently, safely, and sustainably.



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## Components of a Transportation System:

- ❑ Infrastructure: Roads, railways, airports, ports, bridges.
- ❑ Vehicles: Cars, trucks, buses, trains, airplanes, ships.
- ❑ Users: Drivers, passengers, pedestrians, cyclists.
- ❑ Traffic Control Devices: Signals, signs, markings, automated systems.
- ❑ Operations and Management: Traffic monitoring, congestion control, ITS.



5

## Functions of a Transportation System

- ❑ Mobility: Enables efficient movement of people and goods.
- ❑ Connectivity: Links urban, rural, and remote locations.
- ❑ Economic Growth: Supports trade, industry, and tourism.
- ❑ Sustainability: Promotes green and energy-efficient transportation.
- ❑ Safety: Reduces accidents and enhances security in transi

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## Modes of Transportation in a System

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- Roadways: Cars, buses, trucks.
- Railways: Passenger and freight trains.
- Airways: Domestic and international flights.
- Waterways: Cargo ships, ferries.
- Non-Motorized: Bicycles, pedestrians



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## Transportation Engineering

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- Transportation Engineering is a branch of the engineering that deals with planning, design, construction, operation, and management of *various transportation systems and their components*, to achieve a safe, efficient, convenient and economical movement of passengers and goods.

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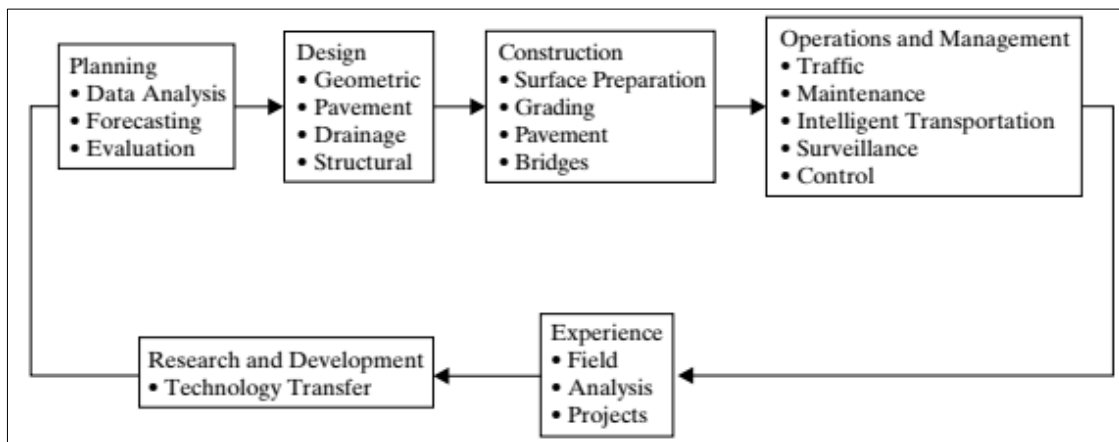
## Transportation Engineer

- The professional who is concerned with the planning, design, construction, operations, and management of a transportation system



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## Key Tasks in Transportation Engineering



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# Transportation Engineering and Planning

## Course Syllabus

14

### Course Overview

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- **Course Title:** Transportation Engineering and Planning
- **Course Number:** 110 401367
- **Institution:** The Hashemite University
- **Department:** Civil Engineering
- **Instructor:** Dr. Hamza Mohammad Alkuime

15

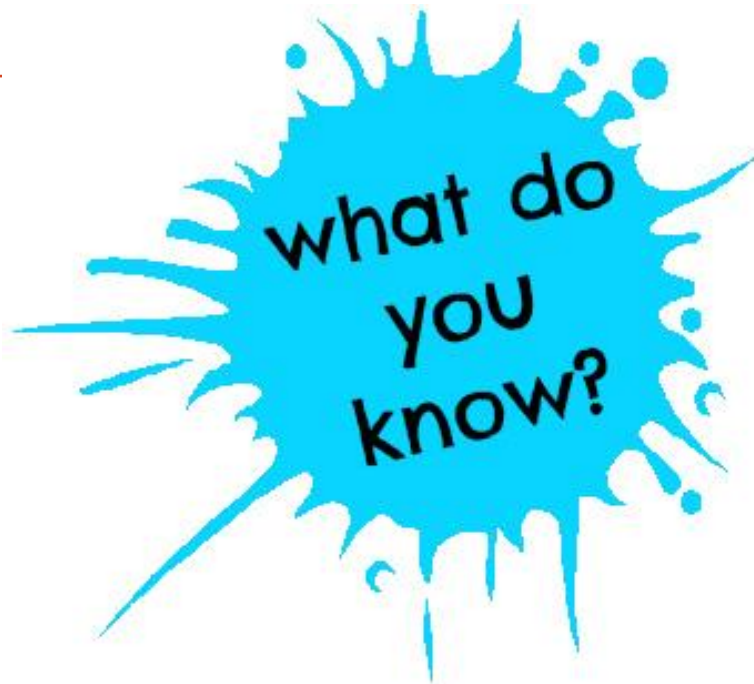
## Getting to know me

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- Dr. Hamza Mohammad Alkuime**
- Office** : E 3029
- Email** : [Alkuime@hu.edu.jo](mailto:Alkuime@hu.edu.jo)
- Office Hour** :
  - **Sun, Tue, Thurs** (10:30 - 11:00 a.m.)
  - **Sun, Tue, Thurs** (10:00 - 11:10 p.m.) during Ramadan

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# What do you expect from this course ?

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## Course Description

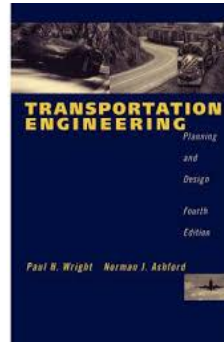
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- Study of **transportation systems** including urban planning and land use.
- **Understanding demand forecasting** and transportation modeling.
- **Engineering economic principles** in transportation.
- **Evaluation of transportation alternatives** and urban mass transit systems.
- **Airport design fundamentals** and operations.

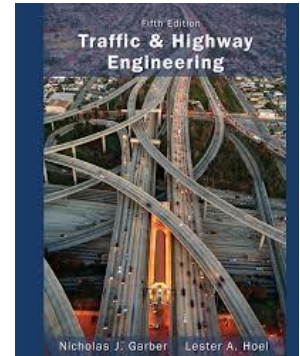
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## Textbook

- ❑ Paul H. Wright, Norman J. Ashford and Robert J. Stammer, ***Transportation Engineering Planning and Design***, Fourth Edition, John Wiley and Sons, 1998



- ❑ Nicholas Garber and Lester Hoel, ***Traffic & Highway Engineering***, 5<sup>th</sup> Edition.. Cengage Learning, 2015



21

21

## Other Supplementary Materials

- ❑ Ashford, N. J., Mumayiz, S., & Wright, P. H. (2011). Airport Engineering: Planning, Design, and Development of 21st Century Airports (4th ed.). Wiley. [Wiley](#)
- ❑ Prassas, E. S., & Roess, R. P. (2013). Engineering Economics and Finance for Transportation Infrastructure. Springer. [Springer Link](#)
- ❑ O'Flaherty, C. A. (1997). Transport Planning and Traffic Engineering. Butterworth-Heinemann. [Amazon](#)
- ❑ Fricker, J. D., & Whitford, R. K. (2004). Fundamentals of Transportation Engineering: A Multimodal Systems Approach. Pearson Prentice Hall. [Amazon](#)
- ❑ Findley, D. J., Schroeder, B. J., Cunningham, C. M., & Brown Jr., T. H. (2015). Highway Engineering: Planning, Design, and Operations. Elsevier. [Amazon](#)
- ❑ Federal Highway Administration (FHWA), Highway Functional Classification Concepts, Criteria and Procedures, 2013, ([https://www.fhwa.dot.gov/planning/processes/statewide/related/highway\\_functional\\_classifications/](https://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/))

22

## Other Supplementary Materials

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- ❑ Thagesen, B. (Ed.). (1996). Highway and Traffic Engineering in Developing Countries. E & FN Spon. [SearchWorks](#)
- ❑ Findley, D. J., Cunningham, C. M., Brown Jr., T. H., Cahill, L. M., Yang, G., & Huntsinger, L. F. (2015). Highway Engineering: Planning, Design, and Operations. CRC Press. [Amazon](#)
- ❑ Rogers, M., & Enright, B. (2023). Highway Engineering (4th ed.). Wiley-Blackwell. [Wiley](#)
- ❑ Ahuja, T. D. (2009). Highway Engineering. CBS Publishers & Distributors. [Google Books](#)
- ❑ Garber, N. J., & Hoel, L. A. (2014). Traffic and Highway Engineering (5th ed.). Cengage Learning. [Cengage](#)
- ❑ Federal Highway Administration (FHWA), Highway Functional Classification Concepts, Criteria and Procedures, 2013, ([https://www.fhwa.dot.gov/planning/processes/statewide/related/highway\\_functional\\_classifications/](https://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/))
- ❑ <https://www.faa.gov/>
- ❑ Research articles

23

## Other Supplementary Materials

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- ❑ Tang, C. K., & Zhang, L. (2021). Principles and Practices of Transportation Planning and Engineering. CRC Press. [Amazon](#)
- ❑ Mannering, F. L., & Washburn, S. S. (2019). Principles of Highway Engineering and Traffic Analysis (7th ed.). Wiley. [Wiley](#)
- ❑ Chakroborty, P., & Das, A. (2003). Principles of Transportation Engineering. PHI Learning. [Amazon](#)
- ❑ McNally, M. G. (2000). The Four Step Model. In Handbook of Transport Modelling (pp. 35-52). Pergamon. [TRID](#)
- ❑ Miller, E. J. (2003). Transportation Models. In Handbook of Transport Modelling (pp. 53-77). Pergamon. [Taylor & Francis Online](#)
- ❑ Hoel, L. A., Garber, N. J., & Sadek, A. W. (2010). Transportation Infrastructure Engineering: A Multimodal Integration (4th ed.). Cengage Learning. [Amazon](#)
- ❑ Teodorović, D., & Janic, M. (2016). Transportation Engineering: Theory, Practice, and Modeling. Elsevier.

24

## Course Materials

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### ☐ Access to Course Materials

- All course materials will be available on the **Moodle/Teams Platforms**.
  - Lecture slides.
  - Assignments and handouts.
  - Reference materials and additional resources.



25

## Session Recordings

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- **Each session** will be **recorded** and made available on **YouTube**:
- Accessible anytime for review.
- Helps students who miss a session or need additional clarification.
- Recordings will also be available on the **Moodle platform**

26

## Major Topics Covered

Topics	No. of Weeks	Contact hours*
1. Introduction to transportation systems	1/3	1
2. Transportation planning	1	3
3. Demand forecasting using 4 steps modeling	4	12
Quiz 1	TBD	
4. Engineering economy in transportation	3	9
Quiz 2	TBD	
5. Evaluation of transportation alternatives	2	6
Quiz 3	TBD	
6. Urban mass transit systems	3 2/3	11
7. Airports	1	3
<b>Total</b>	<b>15</b>	<b>45</b>

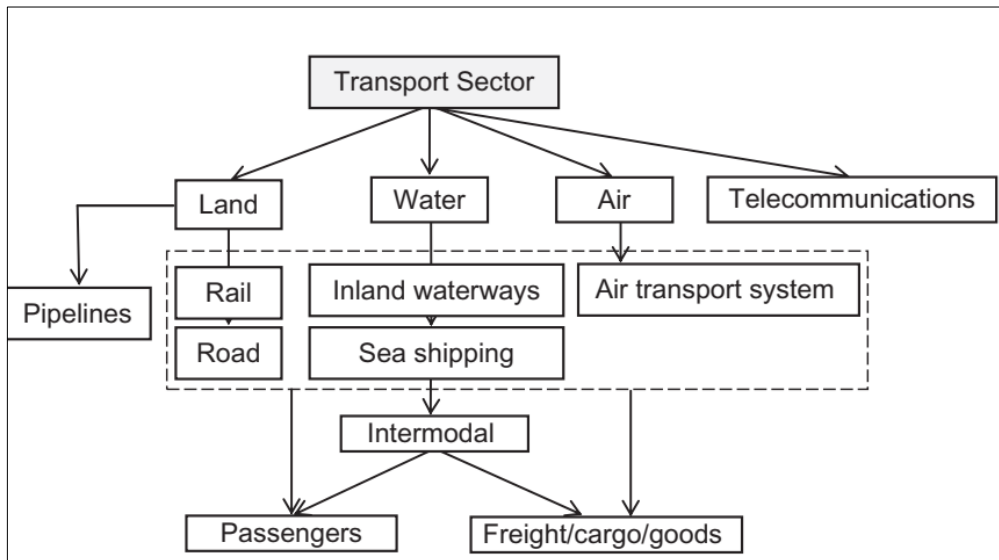
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## Transportation Engineering and Planning

What you will learn

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## What you will learn

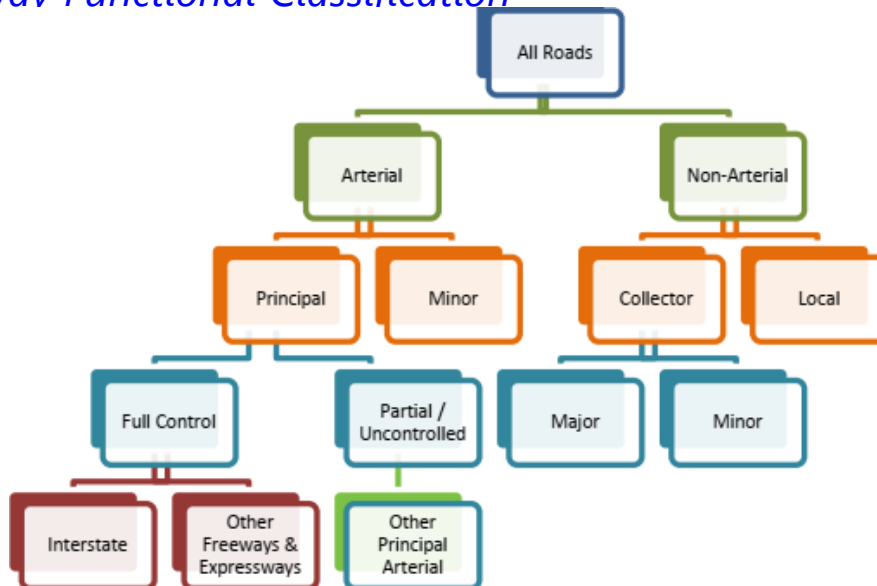


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## What you will learn

### Highway Functional Classification

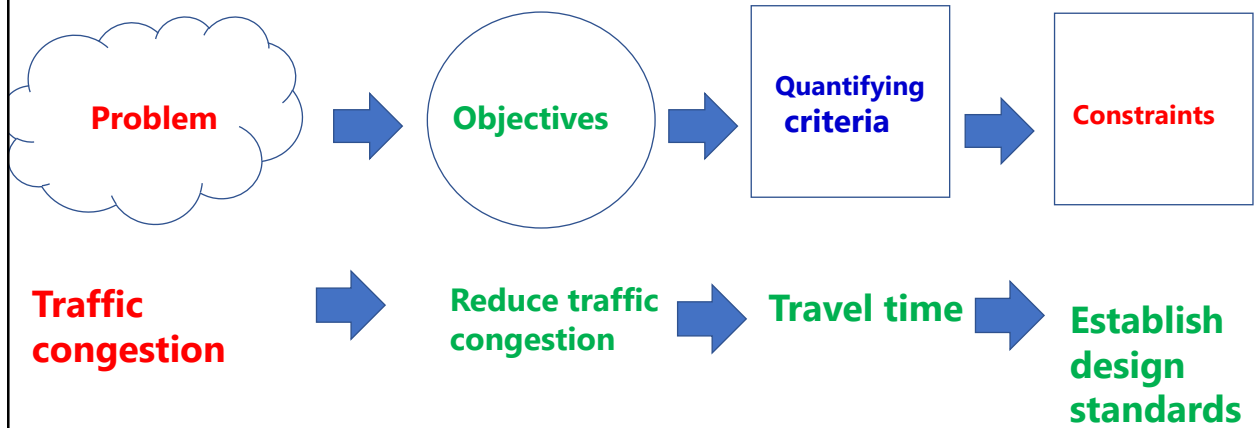


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## What you will learn

### *Transportation Planning*

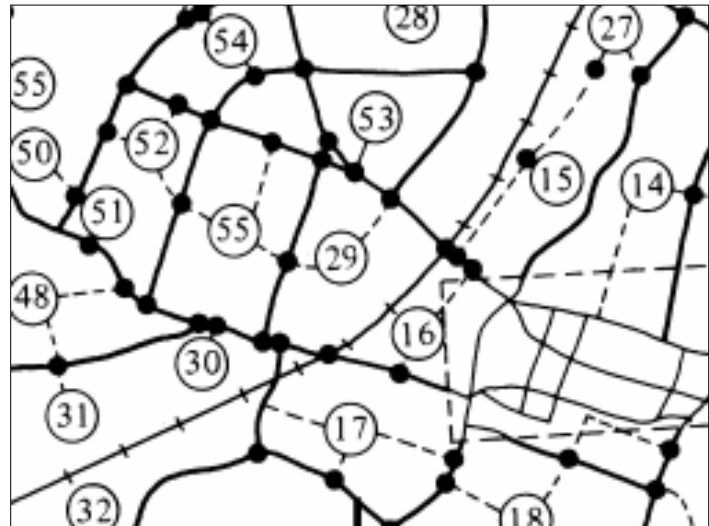
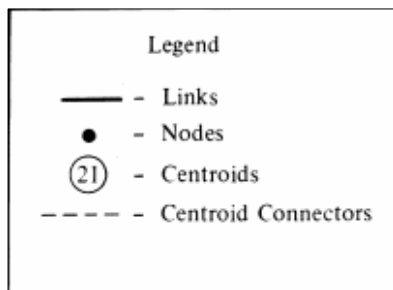
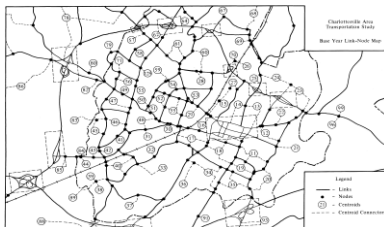


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## What you will learn

### *Urban Transportation Forecasting Process*

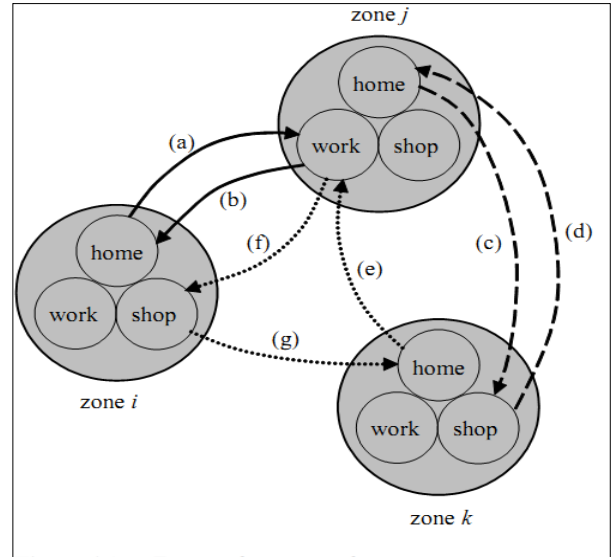
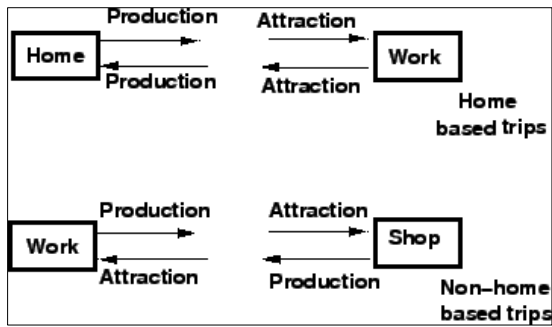


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## What you will learn

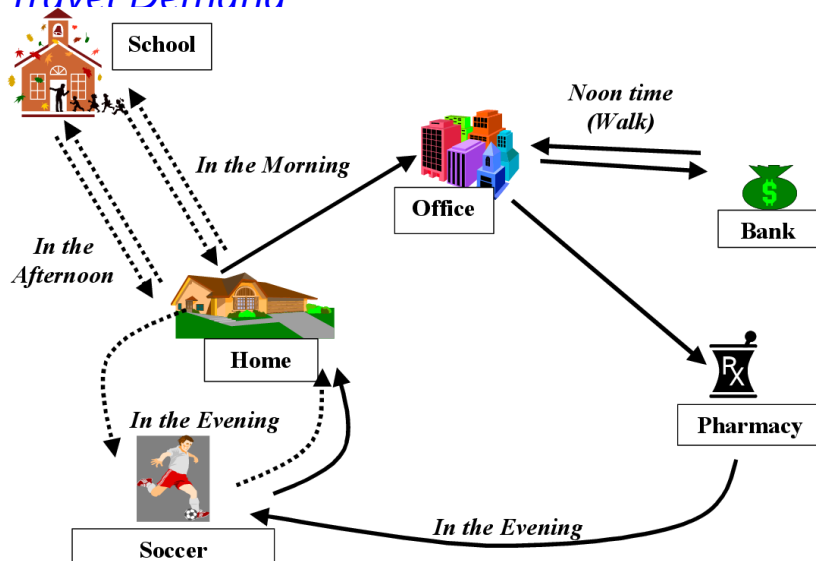
### Nature and Analysis of Transportation Demand



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## What you will learn

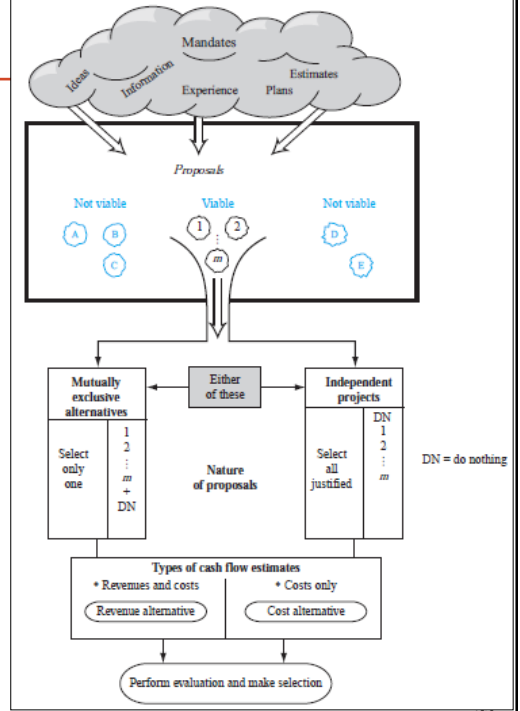
### Forecasting Travel Demand



34

## What you will learn

### Common Economic Analysis Methods



35

## What you will learn

### Evaluation of Transportation Alternatives



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## What you will learn

### Highway Transit



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## What you will learn

### Amman Rapid Bus



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## What you will learn

### *Rail Transit*

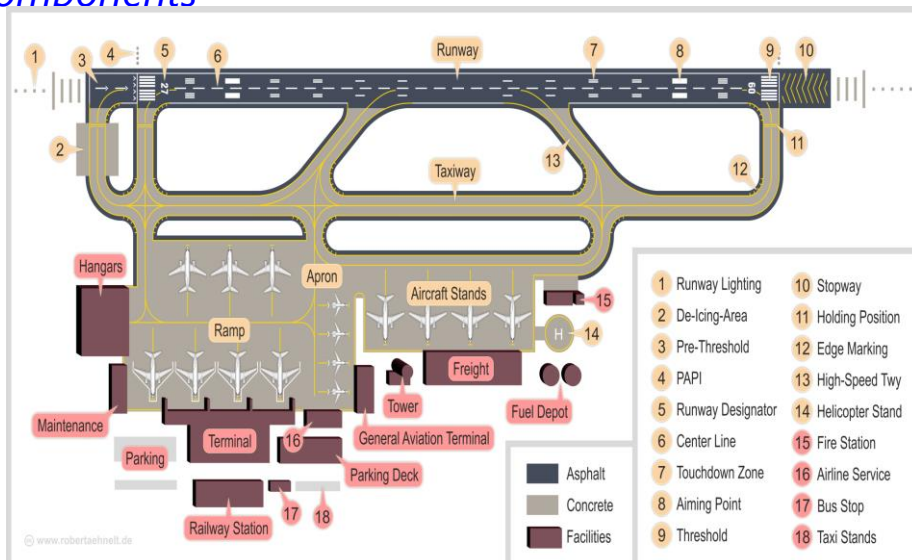


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## What you will learn

### *Airport Components*

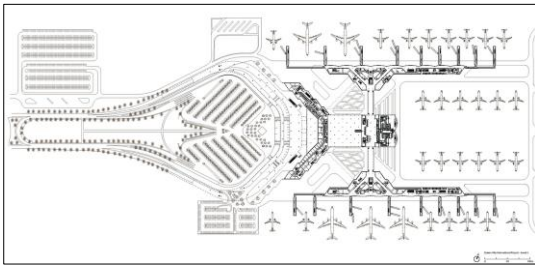


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## What you will learn

### Airport Terminals



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## Course Policies & Guidelines

42

## Course Grading:

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### 📌 Assessment Breakdown:

- **First Exam:** 25 Points
- **Second Exam:** 25 Points
- **Quizzes:** 10 Points
- **Final Exam:** 40 Point

43

43

## General Notes

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The maximum allowed number of absentees from the course is **6** classes.

➤ Exceeding these limits will lead to prevention from attending the final exam.

Beware of ***Plagiarism***:

➤ Copying and handing in for credit someone else's work.

➤ Any plagiarism (cheating) case will result in an automatic '**F**' for the course

**No MAKE-UP EXAMS**

44

44

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45



Transportation Engineering

47

47

# *Transportation Engineering and Planning*

## Module | 1 | Introduction

### 1.1 | Introduction of Transportation systems

*Dr. Hamza Mohammad Alkuime*

1

## Overview of transportation

2

## Transportation

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- **Definition**
  - Movement of people and goods to meet societal needs
- **Daily Examples**
  - Patient transported to a hospital
  - Goods delivered to supermarkets
  - Business travel for management meetings

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# The Role of Transportation

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## The Role of Transportation

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- **Transportation is essential for economic and social activities.**
- It connects **people, goods, and services** across regions.
- Supports **urban development, trade, and industrial growth.**
- **Improves accessibility** and enhances the quality of life.

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## Transportation & Economic Growth

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## Transportation & Economic Growth

- ❑ **Facilitates trade and commerce** by moving goods efficiently.
- ❑ *Example:*
- ❑ **Port of Shanghai, China**  
– The world's busiest container port enables large-scale global trade.



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## Transportation & Economic Growth

- ❑ **Creates jobs in logistics, infrastructure, and operations.**
- *Example: Dubai International Airport* – Supports over 400,000 jobs in aviation and logistics sectors.



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## Transportation & Economic Growth

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- ❑ **Contributes to Gross Domestic Product (GDP) growth** and national development.

➤ *Example: U.S. Interstate Highway System* – Boosted economic growth by enhancing nationwide connectivity.



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## Transportation & Social Connectivity

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## Transportation & Social Connectivity

- ❑ Enables commuting for work, education, and healthcare.

➤ Example: **New York City Subway** – Millions rely on it daily for work and education.

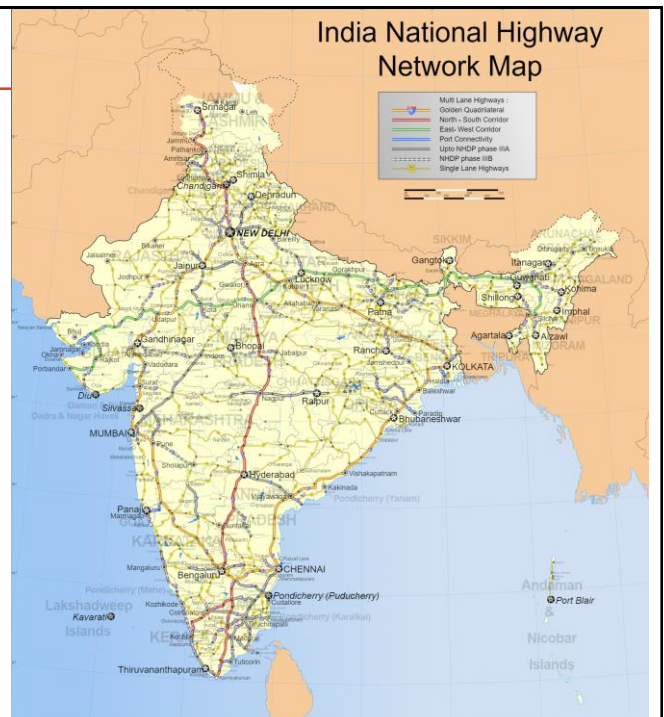


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## Transportation & Social Connectivity

- ❑ Enhances mobility and access to essential services

• Example: *India's Rural Roads Program*

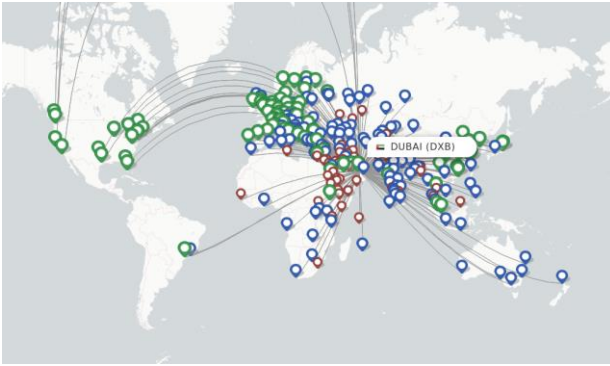


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## Transportation & Social Connectivity

### □ Promotes cultural exchange and tourism.

- *Example: Eurail in Europe* – Facilitates cross-border travel, boosting tourism.
- *Example: Dubai International Airport* – A global hub connecting diverse cultures.



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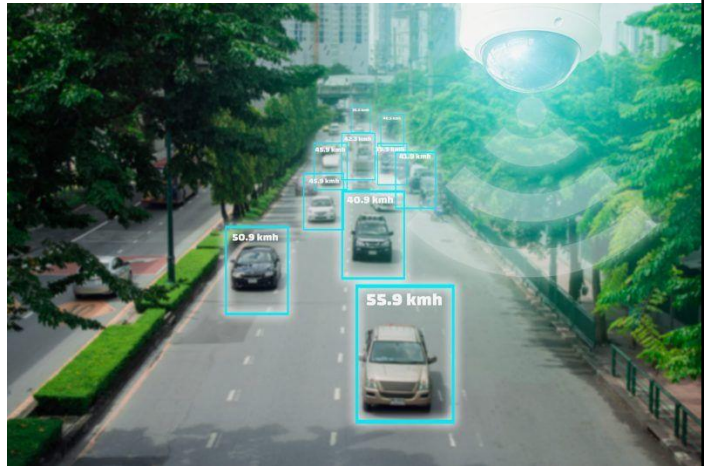
## Transportation & Urban Development

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## Transportation & Urban Development

- ❑ **Reduces traffic congestion with smart infrastructure.**

➤ *Example: Singapore's Smart Traffic Management System* – Uses AI to optimize traffic flow.



18

## Transportation & Urban Development

- ❑ **Promotes sustainable mobility solutions** like cycling and walking.

➤ *Example: Amsterdam's Bicycle Infrastructure* – 60% of commutes done by bike.



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# Transportation & Environmental Impact

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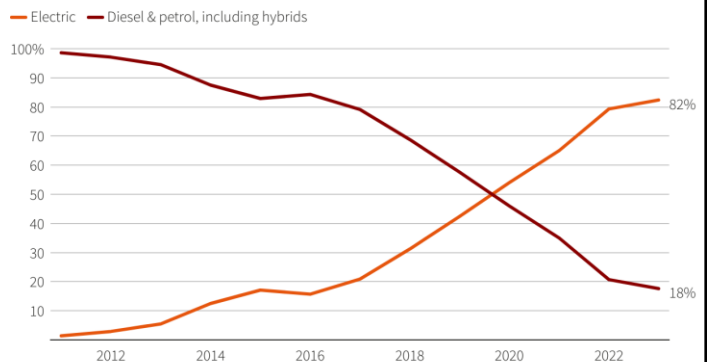
## Transportation & Environmental Impact

- ❑ **Shift towards sustainable transport** (EVs, public transit, cycling).

➤ *Example: Norway's EV Adoption* – Over 80% of new cars sold are electric.

### Norway new car sales

Years 2011-2023, percentage of market



Source: Norwegian Road Federation (OFV) | Reuters, Jan 2, 2024 | By Victoria Klesty

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## Transportation & Environmental Impact

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- ❑ Encourages eco-friendly solutions like green logistics.

➤ *Example:* **UPS Smart Logistics** – Uses AI to reduce unnecessary fuel consumption.



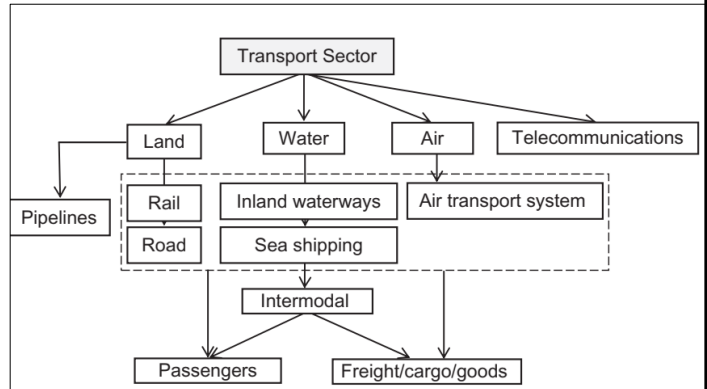
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## Transportation Modes

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## Transportation Modes

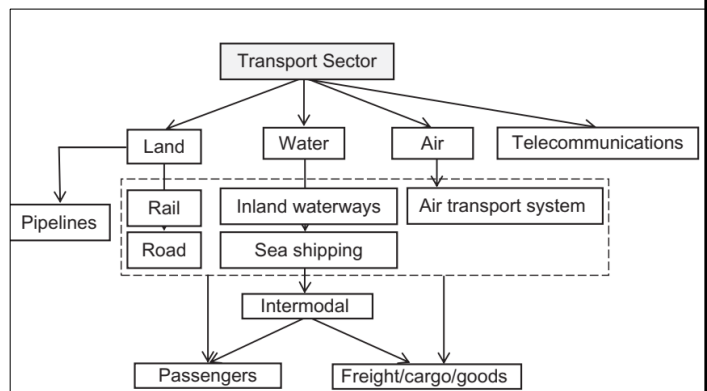
- **Land-based transport:**
  - **Road transport:** Cars, buses, trucks.
  - **Rail transport:** Passenger and freight trains.
  - **Pipelines:** Oil, gas, and other fluid transport.
- **Water-based transport:**
  - **Sea shipping:** Cargo ships and tankers.
  - **Inland waterways:** River and canal transport.



25

## Transportation Modes

- **Air-based transport:**
  - Passenger and cargo aviation.
- **Intermodal transport:**
  - **Combines multiple modes** (e.g., rail + road + sea).
- **Telecommunications:**
  - Transmits information **without physical movement**.



26

# Transportation Modes

## Components of Transport Modes

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## Components of Transport Modes

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- Each transport mode consists of:
  - **Transport Infrastructure** (roads, railways, ports, airports).
  - **Vehicles** (cars, trains, ships, airplanes).
  - **Supporting Facilities** (stations, terminals, maintenance depots).
  - **Equipment** (navigation, signaling, safety systems).
  - **Staff** (drivers, pilots, controllers, maintenance crews).

28

# Road Transport Mode

29

## Road Transport Infrastructure

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- **Key Components:**
  - **Roads** (highways, urban streets, rural roads)
  - **Bridges** (crossing rivers, valleys)
  - **Tunnels** (underground or underwater passages)
- **Terminals/Stations:**
  - **Passenger terminals** (bus stations)
  - **Freight/Cargo terminals** (truck depots,)



30

## Truck depots



<https://truckall.ca/index.shtml>

31

## Road Transport Vehicles

- **Fuel-Powered Vehicles:**
  - **Passenger Cars & Buses** (diesel, petrol)
  - **Freight Trucks** (various sizes and capacities)
- **Electric-Powered Vehicles:**
  - **Trolleybuses** (connected to overhead wires)
  - **BEVs (Battery Electric Vehicles)** (cars, electric buses)



32

## Road Transport – Supporting Facilities & Equipment

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- **Traffic Signaling & Control:**
  - Traffic lights, pedestrian crossings.
- **Management Systems:**
  - highway surveillance cameras.
- **Power Supply Systems:**
  - EV charging stations, trolleybus overhead power lines.
- **Customer Facilities & Administration:**
  - Bus stops, highway service stations, rest areas.



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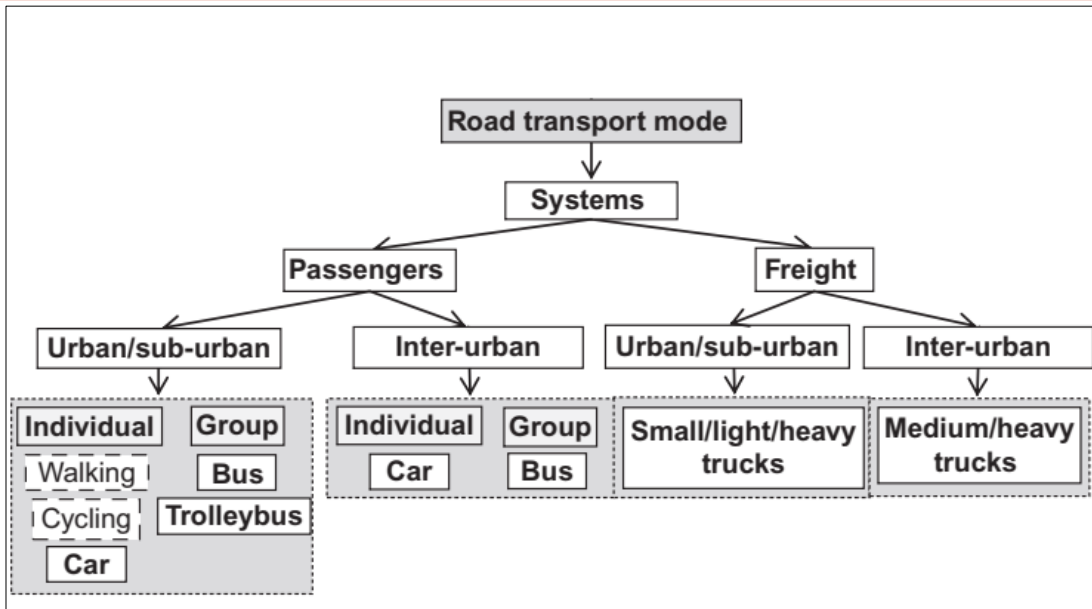
## Road Transport – Staff Roles

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- **Drivers:**
  - Bus drivers, truck drivers, taxi/rideshare drivers.
- **Traffic Controllers:**
  - Highway patrol officers, traffic police.
- **Maintenance Crew:**
  - Road construction workers, mechanics.
- **Management & Administration:**
  - Fleet managers, logistics coordinators.
- **Customer Support:**
  - Ticket agents, service desk personnel, roadside assistance providers.

34

## Structure of road transport mode



35

## Rail Transport Mode

36

## Rail Transport Infrastructure

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- **Main Elements:**

- **Rail Lines** (mainline)
- **Shunting Yards** (railcar sorting and storage)
- **Passenger Stations** (urban and regional transit hubs)
- **Freight/Cargo Terminals** (rail freight yards,



37

## Shunting Yards

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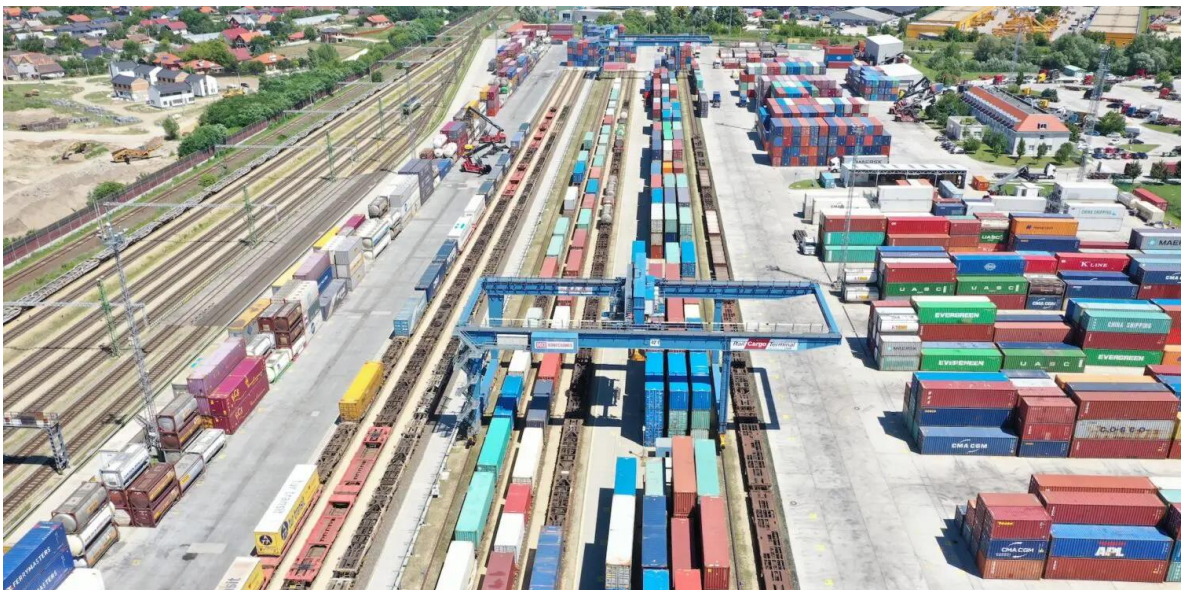
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## Passenger Stations



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## Freight/Cargo Terminals



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## Rail Transport Vehicles

- **Passenger Rail Vehicles:**
  - **Urban/Suburban Rail:**
    - Streetcars (Tramways)
    - LRT (Light Rail Transit)
    - Subway (Metro) Systems
  - **Interurban Rail:**
    - Conventional & High-Speed Trains
- **Freight Rail Vehicles:**
  - Electric or Diesel-Powered Trains
  - Cars/Wagons pulled by locomotives



41

## Light Rail Transit



[https://www.google.com/url?sa=i&url=https://3A%2F%2Fen.wikipedia.org%2Fwik%2F/Light\\_rail&imgsig=42NvKv0pK0W1u0VHw](https://www.google.com/url?sa=i&url=https://3A%2F%2Fen.wikipedia.org%2Fwik%2F/Light_rail&imgsig=42NvKv0pK0W1u0VHw)  
 All rights reserved. Source: images&cd=vfe&opi=89978449&ved=0CBECQwefwTCKDh-E3seDFQMAAAAdAAAAABAE

42



Tramway



High speed train



Bulk train

43

43

## Rail Transport – Supporting Facilities & Equipment

- **Traffic Signaling & Control:**
  - Track signals
- **Management Systems:**
  - Rail network monitoring, scheduling systems.
  - Passenger information display systems (PIDS).
- **Power Supply Systems:**
  - Electrified rail networks (catenary systems).
  - Diesel refueling stations for non-electric trains.
- **Customer Facilities & Administration:**
  - Railway stations, ticketing offices.
  - Cargo terminals, logistics hubs.



44

## Catenary systems

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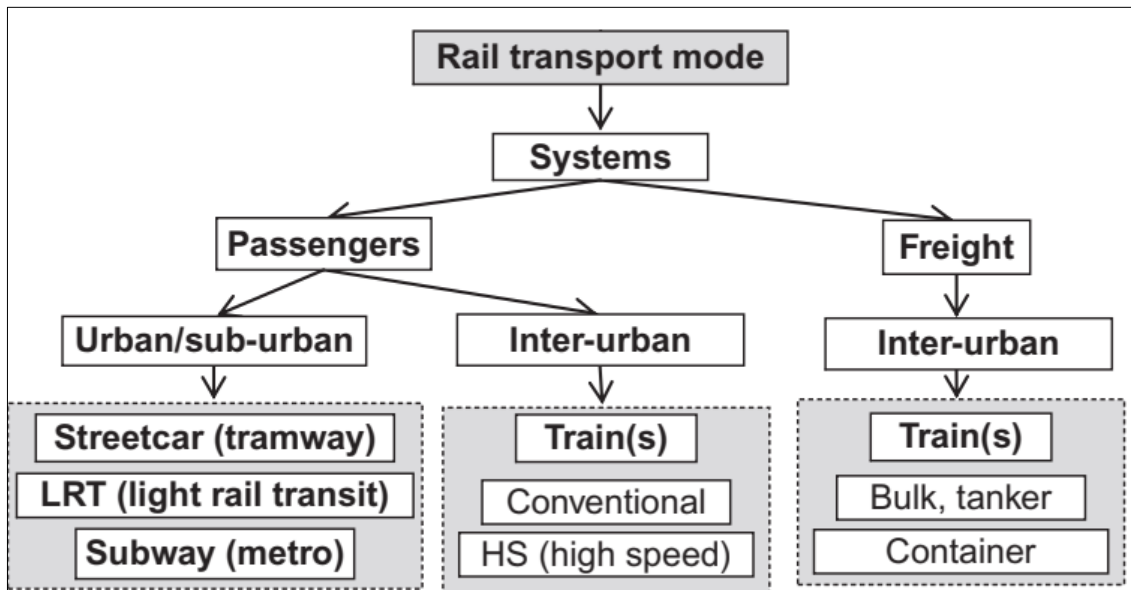
## Rail Transport – Staff Roles

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- **Train Crew:**
  - Train drivers (locomotive engineers), rail guards.
- **Station & Passenger Services:**
  - security staff.
- **Operations & Control:**
  - Rail traffic controllers.
- **Maintenance Team:**
  - Rail track inspectors, train mechanics.
- **Administrative & Logistics:**
  - Railway operations managers, scheduling coordinators,

46

## Structure of rail transport mode



47

## Air Transport Mode

48

## Air Transport Infrastructure

- **Essential Components:**

- **Airports:**

- **Runways and Taxiways**  
(aircraft movement areas)
- **Terminals**  
(passenger and cargo handling)

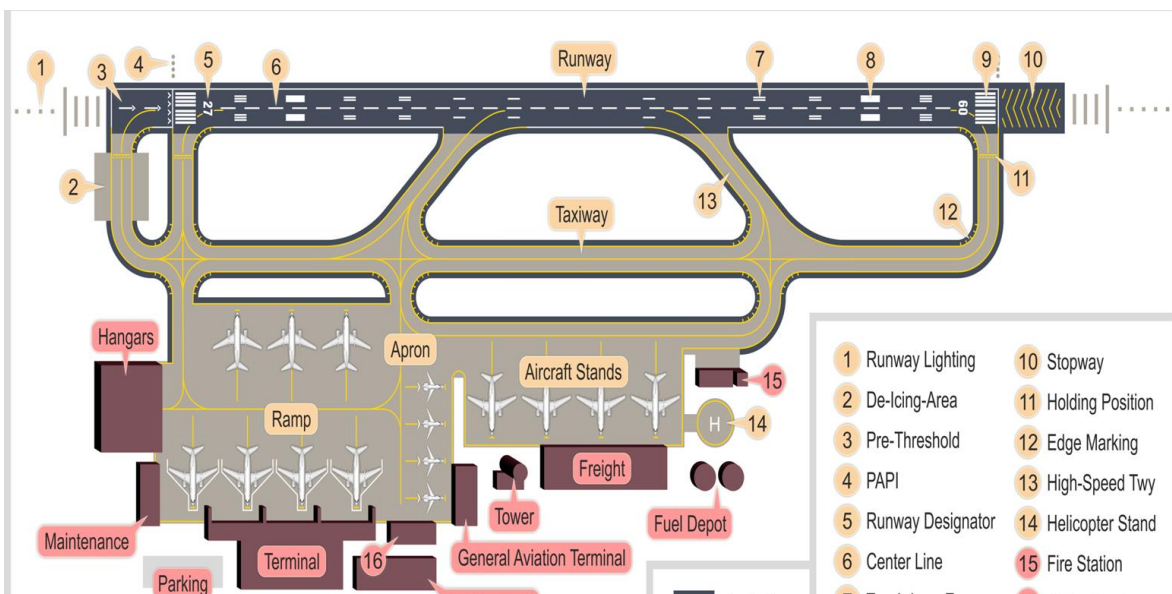
- **Ground Access Systems:**

- **Road and Rail Links**  
(connections to cities and logistics hubs)



49

## Air Transport Infrastructure



50

## Runway



<https://www.vecteezy.com/free-photos/airplane-runway>

51

## Taxiway



52

## Airport hub



<https://www.foxnews.com/travel/dubai-airport-closed-for-drone-activity-temporarily>

53

## Queen Alia International Airport



54

## Queen Alia International Airport

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## Air Transport Vehicles

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- **Passenger Aircraft:**
  - **Regional Jets** (short-haul flights)
  - **Commercial Airliners** (medium/long-haul)
- **Cargo Aircraft:**
  - **Dedicated Freight Planes** (express shipping)

56

## Regional Jets



57

## Commercial Airliners



58

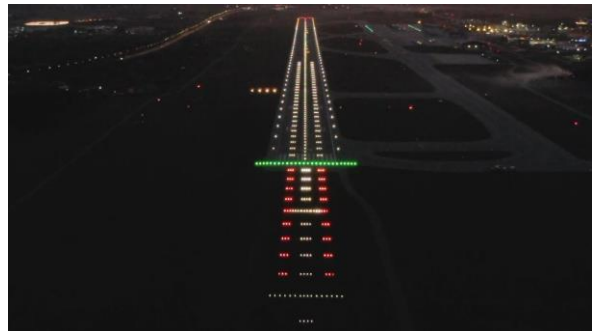
## Cargo Aircraft



59

## Air Transport – Supporting Facilities & Equipment

- **Traffic Signaling & Control:**
  - Runway lighting systems
- **Management Systems:**
  - Flight scheduling.
- **Power Supply Systems:**
  - Fuel stations for jet refueling.
- **Customer Facilities & Administration:**
  - Airport terminals, check-in counters,



60

## Air Transport – Staff Roles

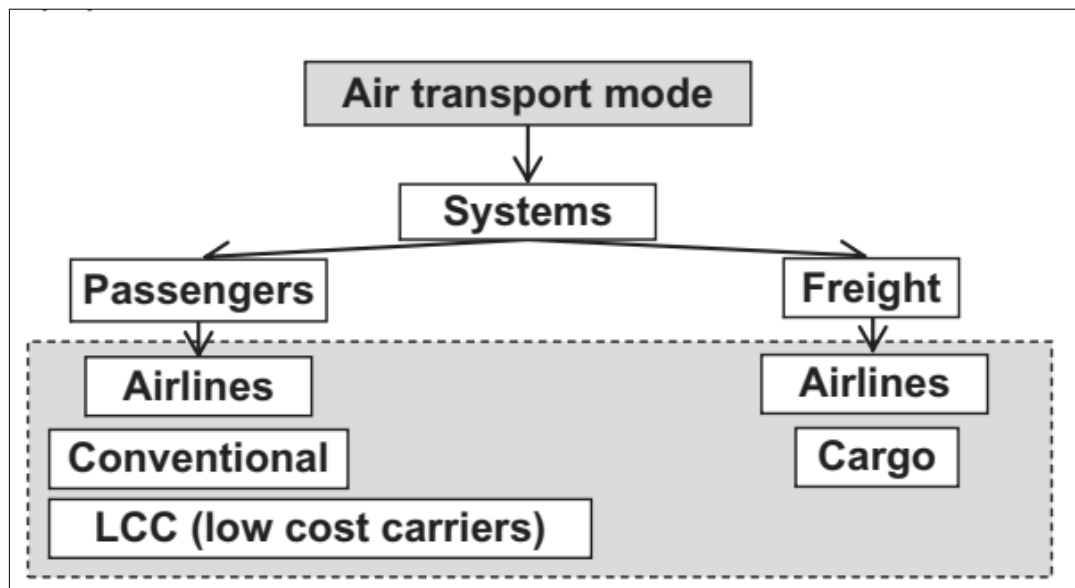
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- **Flight Crew:**
  - Pilots, co-pilots,
- **Ground Operations:**
  - Baggage handlers, aircraft refueling crew.
- **Air Traffic Control:**
  - Air traffic controllers, radar operators.
- **Maintenance & Technical Staff:**
  - Aircraft mechanics, safety inspectors.
- **Airport Administration & Customer Service:**
  - Ticketing agents, customs officers.

61

## Structure of air transport mode

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62

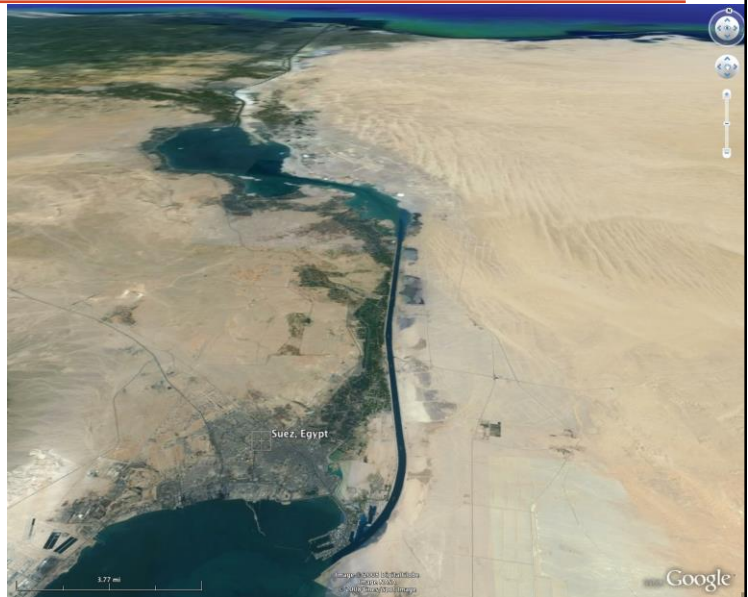
# Inland Waterways Transport Mode

63

## Inland Waterways Infrastructure

- **Core Features:**

- **Waterways** (rivers, canals)
- **Ports and Harbors:**
  - **Passenger Terminals** (ferries, water taxis)
  - **Freight/Cargo Terminals** (bulk handling, container facilities)



64

## Suez Canal

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65

## Ferries

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66

## Water taxis



[https://www.google.com/url?sa=i&url=https%3A%2F%2Fen.wikipedia.org%2Fwik%2FNew\\_York\\_Water\\_Taxi&psig=AOvWaw0eNMe6Awte-1H6v0SkAy8kAuaa-1729948549346000&source=images&cd=r&ved=0C80QQRqFwTCNjU3zCzGzDFQAAAAAAdMAAABAA](https://www.google.com/url?sa=i&url=https%3A%2F%2Fen.wikipedia.org%2Fwik%2FNew_York_Water_Taxi&psig=AOvWaw0eNMe6Awte-1H6v0SkAy8kAuaa-1729948549346000&source=images&cd=r&ved=0C80QQRqFwTCNjU3zCzGzDFQAAAAAAdMAAABAA)

67

## Inland Waterways Transport Vehicles

- **Types of Vessels:**
  - **Self-Propelled Barges** (diesel-powered)
  - **Towboats & Pushes Barges** (diesel-powered)

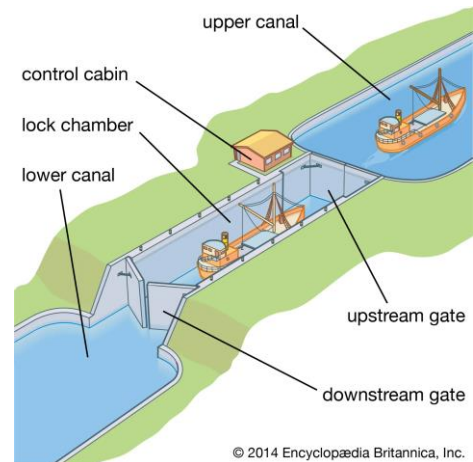


[https://en.wikipedia.org/wiki/Pusher\\_%28boat%29](https://en.wikipedia.org/wiki/Pusher_%28boat%29)

68

## Inland Waterways – Supporting Facilities & Equipment

- **Traffic Signaling & Control:**
  - River navigation lights, depth markers.
- **Management Systems:**
  - Lock operation systems.
- **Power Supply Systems:**
  - Diesel fueling stations.
- **Customer Facilities & Administration:**
  - Passenger terminals, cargo loading docks.



69

## Sea Shipping Transport Mode

70

## Sea Shipping (Maritime) Transport Infrastructure

---

- **Land and Water-Based Infrastructure:**
  - **Land-based:** Roads, railways for port access
  - **Water-based:** Access channels,
  - **Seaports:**
    - **Passenger Terminals** (cruise ship docks)
    - **Freight/Cargo Terminals** (container ports, bulk cargo facilities)

71

### Aqaba container terminal

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72

## Sea Shipping (Maritime) Transport Vehicles

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- **Passenger Vessels:**
  - **Cruise Ships** (for tourism and long-distance passenger travel)
- **Cargo Vessels:**
  - **Bulk Carriers** (coal, grain, ores)
  - **Oil & Gas Tankers** (petroleum, Liquefied Natural Gas (LNG))
  - **Container Ships** (global trade logistics)
- **Powered by:** Diesel engines.
- **Used for:** International freight transport and oceanic travel.

73

### Cruise ship docks

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74

## Oil & Gas Tankers

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75

## Bulk Carriers

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76

## Sea Shipping – Supporting Facilities & Equipment

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- **Traffic Signaling & Control:**
  - Lighthouses,.
- **Management Systems:**
  - Port logistics and container handling systems.
- **Power Supply Systems:**
  - Shore power for docked ships.
- **Customer Facilities & Administration:**
  - Passenger terminals
  - Cargo terminals, customs processing centers.



77

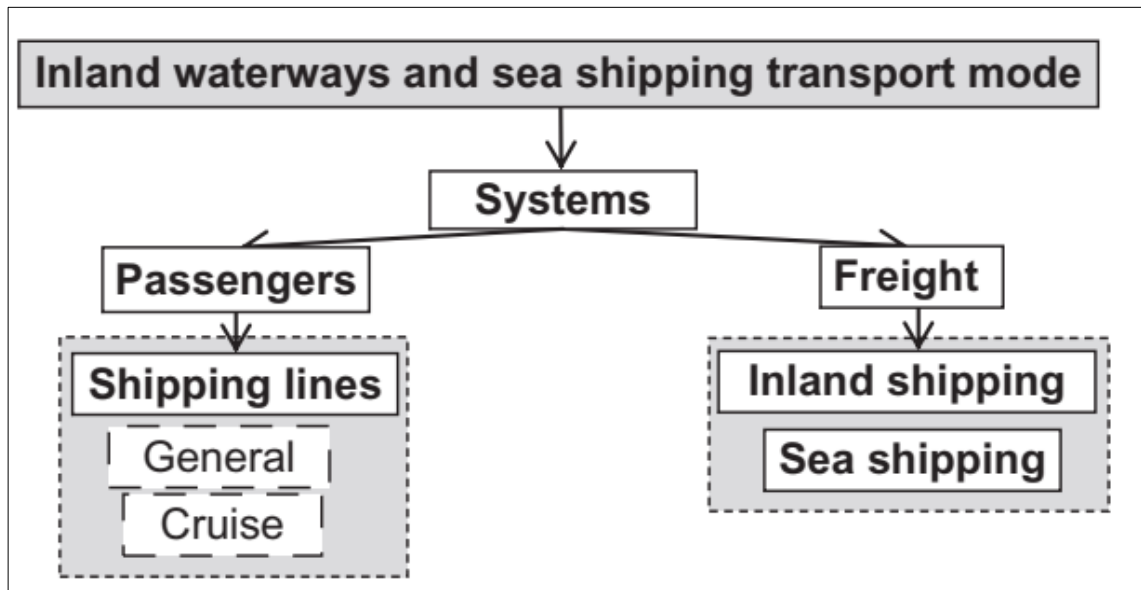
## Sea Shipping (Maritime) Transport – Staff Roles

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- **Ship Crew:**
  - Captains, navigators.
- **Engineers & Technicians:**
  - ship electricians, maintenance personnel.
- **Port & Terminal Operations:**
  - cargo loaders, crane operators.
- **Maritime Traffic Control:**
  - coast guards
- **Administrative & Customer Support:**
  - Cruise ship hospitality staff, ticket agents, customs clearance officers.

78

## Structure of inland waterways transport mode



79

## Relationships Between Transport Modes

80

## Relationships Between Transport Modes



**Competition:** Transport modes compete for passengers and freight.



**Cooperation:** Modes collaborate to provide integrated transport services.



**Goal:** Optimize efficiency, market share, and customer satisfaction.

81

## Competition Between Transport Modes

- **Objective:** Maximize passenger and freight volumes over time.
- **Competitive Factors:**
  - **Service Quality** (speed, reliability, comfort).
  - **Cost (Price)** (fares, freight charges).
- **Examples:**
  - **Urban transit:**
    - Buses vs. Streetcars (Trams) vs. Subways (Metro).
  - **Intercity travel:**
    - High-Speed Rail (HSR) vs. Air Travel.
  - **Freight transport:**
    - Rail vs. Road vs. Sea shipping.



82

## Cooperation Between Transport Modes

**Objective:** Provide smooth, integrated transport services.

### Methods of Cooperation:

- **Intermodal Transfer Locations:**
  - Common **bus/streetcar stops** near **metro stations**.
  - **Integrated bus/LRT connections** for urban & suburban travel.
- **Coordinated Schedules** for smooth passenger transitions.
- **Common Ticketing & Pricing Systems** for ease of travel.

### Examples:

- **Urban Transit:** Bus-Tram-Metro integration.
- **Regional Transit:** Bus and Light Rail Transit (LRT) coordination.
- **Freight:** Rail-sea, air-road multimodal logistics hubs.

83

### Urban Transit: Bus-Tram-Metro integration.

### Example: Dijon, France



84

Regional Transit: Bus and Light Rail Transit  
(LRT) coordination.

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85

Transportation Challenges and problems

86

## Transportation Challenges and Problems

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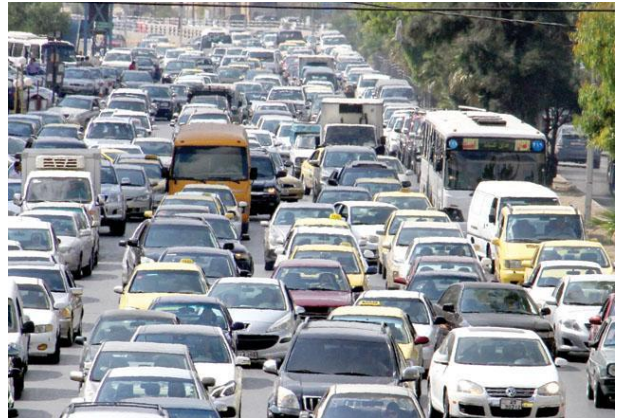
- Transportation systems **face multiple challenges** that impact efficiency, sustainability, and safety.
- Key **challenges and problems** include:
  - Traffic Congestion
  - Inadequate Public Transportation
  - Environmental Pollution
  - Road Safety Issues
  - Aging Infrastructure
  - Sustainability and Energy Consumption

87

## 1. Traffic Congestion

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- **Overcrowded roads lead to longer travel times, delays, and economic losses.**
- **Major causes:**
  - Increase in vehicle ownership.
  - Poor urban planning and road network design.
  - Inefficient traffic management and public transport systems.



88

## 2. Inadequate Public Transportation

- **Many cities lack reliable, accessible, and efficient public transport options.**
- **Challenges include:**
  - Limited routes and irregular bus schedules.
  - High dependence on private vehicles due to lack of alternatives.
  - Poor integration between different transport modes.



89

## 3. Environmental Pollution

- **Transport sector contributes significantly to air pollution and climate change.**
- **Issues include:**
  - High CO<sub>2</sub> emissions from fossil fuel vehicles.
  - Increased urban air pollution affecting health.
  - Lack of investment in electric and hybrid transportation.



عوادم السيارات من أهم أسباب التلوث البيئي

91

## 4. Road Safety Issues

- **Traffic accidents result in injuries, fatalities, and economic losses.**
- **Common causes:**
  - Speeding and reckless driving.
  - Poor road conditions and lack of pedestrian safety measures.
  - Weak enforcement of traffic regulations.
- **Statistics:**
  - In 2023, Jordan recorded **over 170,000 traffic accidents**, causing **560+ fatalities**.
  - The economic cost of road crashes in Jordan is estimated at **\$400 million annually**.

<https://www.jsf.org/ar/infographic/traffic-accidents-in-jordan>



92

# Transportation Development

## Trends

93

## Trends in Transportation Development

---

- **The transportation industry is evolving rapidly** due to technological advancements and sustainability goals.
- Key trends shaping the future of transportation:
  - Smart and Connected Transportation
  - Electrification and Alternative Fuels
  - Autonomous Vehicles (AVs)
  - High-Speed Rail and Urban Transit Innovations
  - Sustainable and Green Transport Solutions
  - Integration of AI and Big Data in Transportation

94

## 1. Smart and Connected Transportation

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- **Advancements in intelligent transport systems (ITS)** are transforming mobility.
- **Key developments:**
  - **Smart traffic management** using AI-based signal control.
- **Example:**
  - **Dubai's Smart Traffic Systems** reduced congestion by **20%**.



95

## 2. Electrification and Alternative Fuels

---

- **Shift towards electric vehicles (EVs) and alternative energy sources.**
- **Key trends:**
  - Expansion of **EV charging networks.**
  - Government incentives for **electric public transportation.**



96

## 3. Autonomous Vehicles (AVs)

---

- **Self-driving technology is reshaping personal and commercial mobility.**
- **Key applications:**
  - **Autonomous taxis and ride-sharing services.**
  - **Self-driving freight trucks** for efficient logistics.
  - **AI-powered delivery robots and drones.**



97

## 4. High-Speed Rail and Urban Transit Innovations

---

- **Rail and transit developments focus on speed, efficiency, and sustainability.**
- **Key trends:**
  - Expansion of **high-speed rail networks** to replace short-haul flights.



98

# Transportation in Jordan

## Roles

101

## Roles of Transportation in Jordan

---



Transportation plays a **critical role in Jordan's economy and daily life.**



Key roles include:

**Economic Growth & Trade**  
**Tourism & Cultural Exchange**  
**Urban Mobility & Public Transit**

102

## Economic Growth & Trade

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- **Boosts national and regional trade** with neighboring countries.
- **Major trade corridors:**
  - **Aqaba Port:** Jordan's primary seaport for imports/exports.
  - **Highway & Rail Links:** Facilitates land trade with Saudi Arabia, Iraq, and Syria.

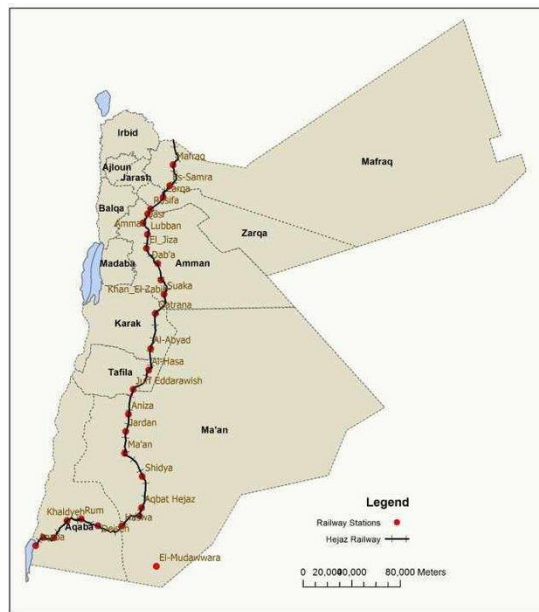
103

# Aqaba Port



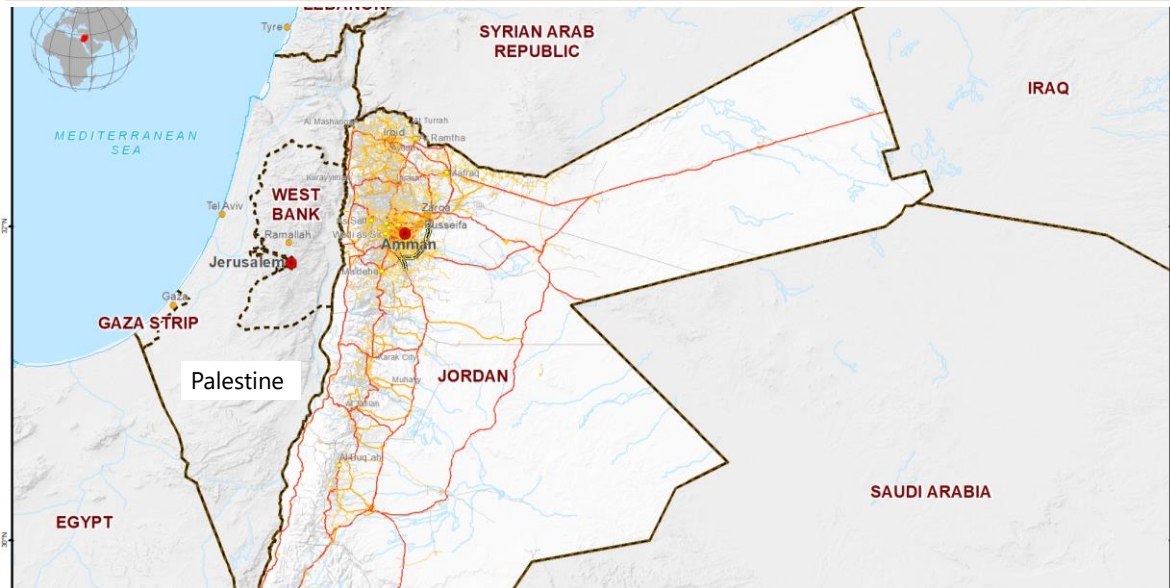
104

# Jordan Existing Railway Network and Stations Map



105

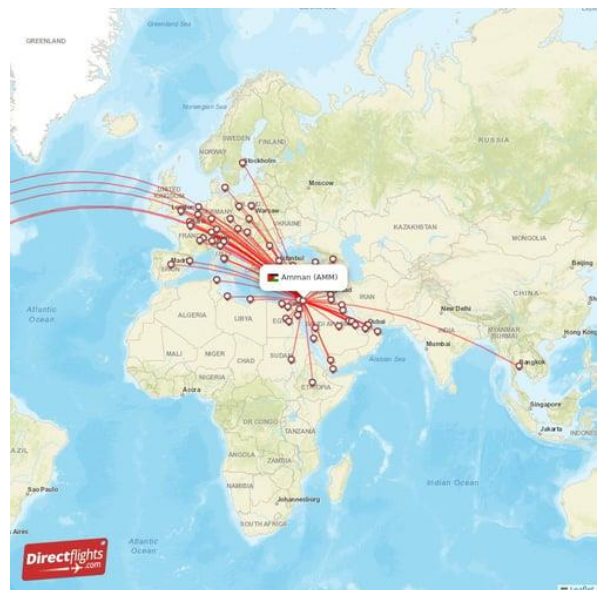
## Jordan Road Network



106

## 2. Tourism & Cultural Exchange

- **Vital for Jordan's tourism industry,** connecting key destinations:
  - **Petra, Wadi Rum, Dead Sea,**



107

# Queen Alia International Airport

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108

# *Transportation Engineering and Planning*

## Module | 1 | Introduction

### 1.2| Introduction of Transportation engineering

*Dr. Hamza Mohammad Alkuime*

1

# What is Transportation Engineering

2

## What is Transport Engineering

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Transportation Engineering is a branch of the engineering that deals with planning, design, construction, operation, and management of *various transportation systems and their components*, to achieve a safe, efficient, convenient and economical movement of passengers and goods.

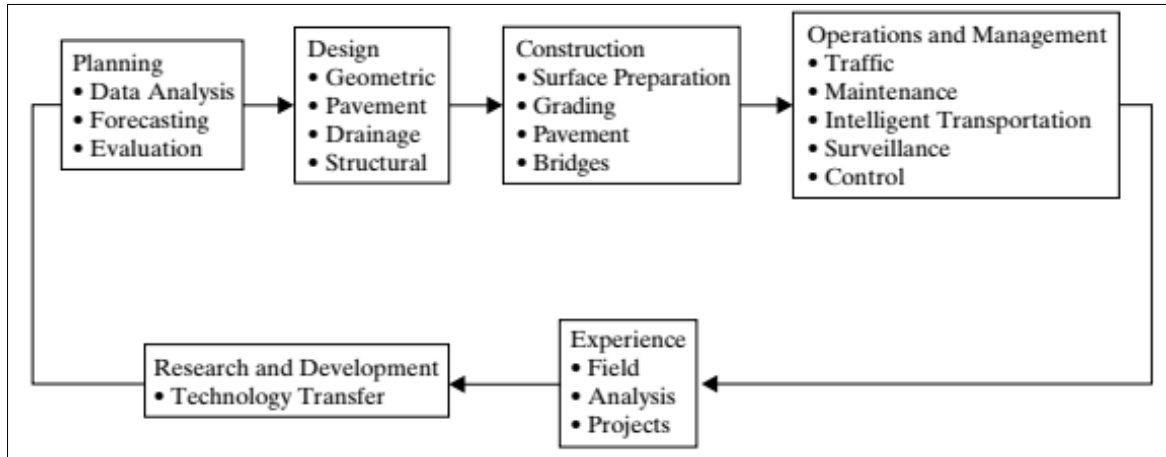
3

## Role of Transportation Engineers

5

## Transportation Engineer

↻ The professional who is concerned with the planning, design, construction, operations, and management of a transportation system



6

6

# Transportation Engineering

## Classifications

7

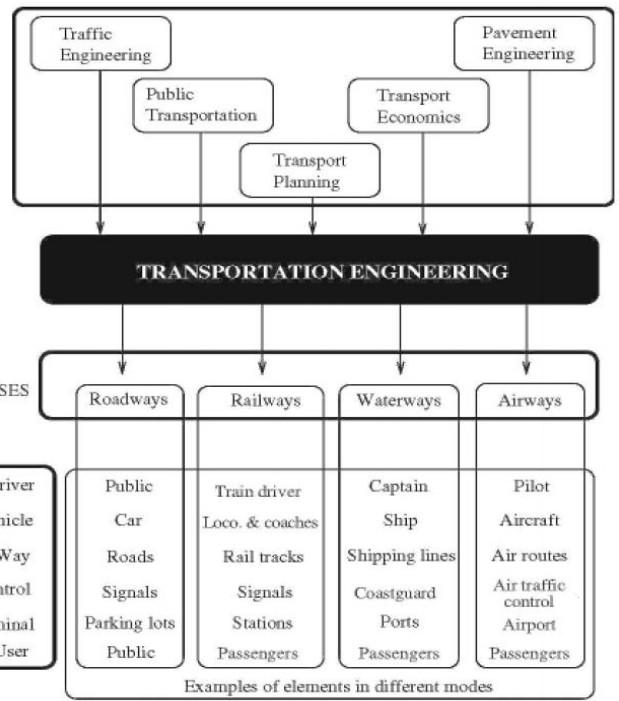
## Classification approaches

- **Transportation systems consist of various modes of travel.**
- Focuses on **mode-specific design, operations, and policies**
- Classification helps in the **systematic study and analysis** of transportation.
- Three main classification approaches:
  - **Modal Classification**
  - **Elemental Classification**
  - **Functional Classification**

### FUNCTIONAL CLASSES

### MODAL CLASSES

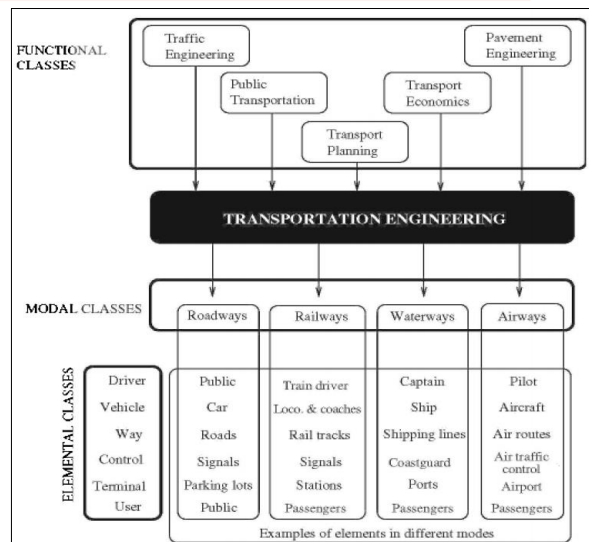
### ELEMENTAL CLASSES



8

## Modal Classification

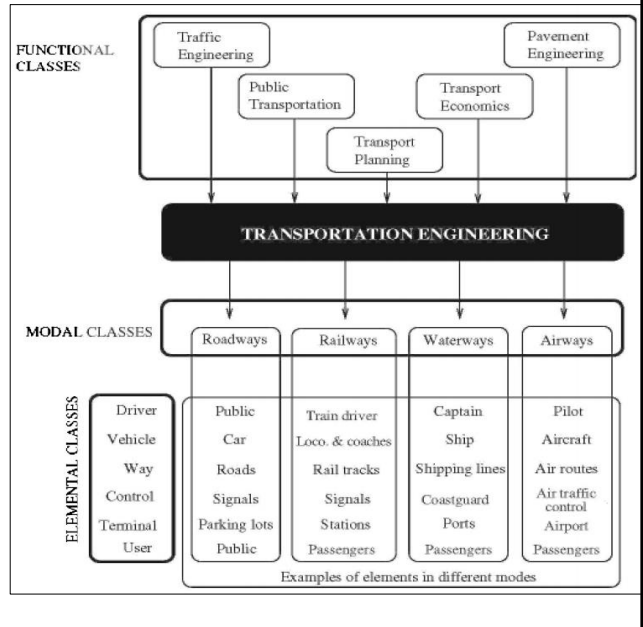
- Based on **different modes of transport.**
- Categorizes transport into **broad classes of travel:**
  - **Walking & Non-Motorized Transport**
  - **Road Transport (Cars, Buses, Motorcycles)**
  - **Rail Transport (Trains, Metros, Light Rail)**
  - **Air Transport (Aircraft, Helicopters)**
  - **Water Transport (Ships, Ferries, Boats)**



9

## Elemental Classification

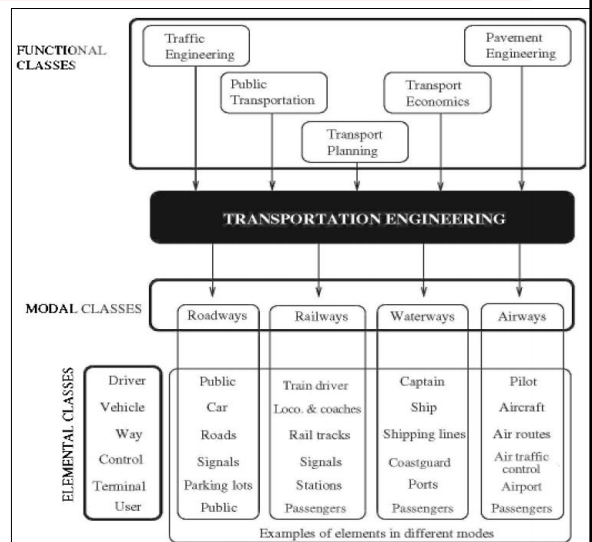
- ❑ Looks at a transportation system's core elements.
- ❑ Focuses on how individual elements interact in a transport system.
- ❑ The six key elements:
  - Driver
  - Vehicle
  - Travel Way
  - Control
  - Terminal
  - User



10

## Functional Classification

- Based on the **functions of transportation engineering**.
- Focuses on **how engineering expertise is applied in transportation systems**.
- Transportation engineers perform various tasks, such as:
  - **Facility Design & Planning** (Roadways, Terminals, Rail Networks)
  - **Traffic Management** (Bus Routes, Highway Operations, Control Systems)
  - **Pavement Engineering** (Road Surface Design, Maintenance)
  - **Transport Policy & Planning** (Urban Mobility, Logistics Strategies)



11

# What is Transport Engineering

## Functional classifications

12

## Functional Divisions of Transportation Engineering

---

- Transportation engineering can be **functionally categorized** based on its applications.
- The main functional divisions include:
  - Planning & Policy
  - Transport economics
  - Geometric Design
  - Traffic Engineering & Operations
  - Pavement Engineering
  - Public Transit & Intermodal Systems
  - Safety & Environmental Impact

13

## Transportation Planning & Policy

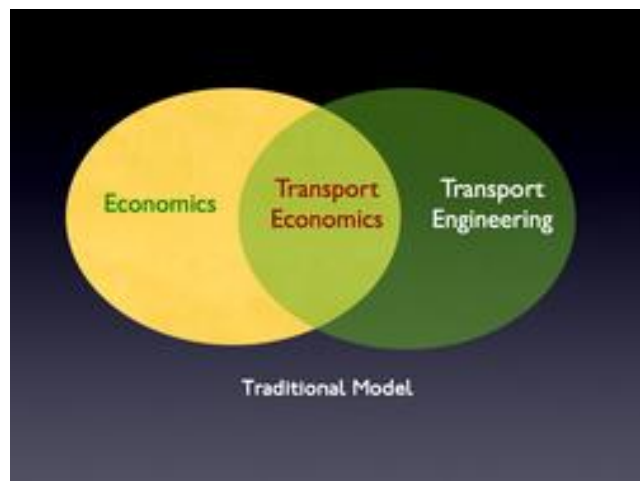
- Involves **forecasting future transportat needs.**



14

## Transport economics

- Deals with various **economic costs and benefits** of building and operating **different** transportation facilities



15

## Geometric Design of Transport Facilities

- Focuses on the **physical design of transportation infrastructure**.
- Ensures **safety, efficiency, and comfort** for transport users.
- Key aspects:
  - **Roadway alignments (horizontal & vertical curves).**
  - **Intersections, roundabouts, and interchange design.**
  - **Rail track layout and platform configurations.**
  - **Runway & taxiway design in aviation.**



16

## Traffic Engineering & Operations

- Deals with **movement control and traffic flow efficiency**.
- Key areas:
  - **Traffic signal design & control systems.**
  - **Traffic flow analysis & congestion management.**
  - **Parking facility design & management.**
  - **Intelligent Transport Systems (ITS)** for real-time traffic monitoring.



17

## Pavement Engineering

- Focuses on **road and runway surface design & maintenance**.
- Ensures **safe, long-lasting, and cost-effective transport surfaces**.
- Key aspects:
  - **Material selection (asphalt, concrete, composites)**.
  - **Pavement structural design** for durability.
  - **Maintenance strategies (resurfacing, rehabilitation)**.
  - **Load-bearing capacity for heavy transport vehicles**.



18

## Public Transit & Intermodal Systems

- Involves **designing and optimizing public transport networks**.
- Aims to **reduce congestion, emissions, and enhance accessibility**.
- Key areas:
  - **Bus Rapid Transit (BRT) & rail transit planning**.
  - **Integration of multiple transport modes (bus-rail-airport links)**.
  - **Passenger flow management & fare collection systems**.
  - **Sustainable transit solutions (electric buses, high-speed rail)**.



19

# *Transportation Engineering and Planning*

## Module | 2 | Transportation Planning

### 2.1 | Transportation Planning and Its Elements

*Dr. Hamza Mohammad Alkuime*

1

## Transportation Planning

Definition and purpose

2

## Transportation Planning - Definition

---

- **A systematic process** for designing, evaluating, and implementing transportation systems.
- **Aims to meet mobility needs** by ensuring the efficient movement of people and goods.
- **Analyze travel demand** and identify necessary infrastructure improvements.
- **Considers economic, environmental, and social impacts** for long-term viability.
- **Supports data-driven decision-making** for both short-term solutions and long-term planning of Transportation infrastructure

3

## Purpose of Transportation Planning

---

- **Forecasting future transportation needs** using data analysis.
- Determines:
  - **How much traffic** will exist in future years.
  - **Where the traffic** will go.
  - **What routes** travelers will take.
  - **Which transport modes** will be most utilized.

5

# Transportation Planning

## Importance

6

## Importance of Transportation Planning

---

- **Transportation planning is essential** to ensure efficient, sustainable, and cost-effective mobility solutions.
- It helps in addressing **future transportation demands** while balancing economic, environmental, and social factors.
- **Key reasons why transportation planning is needed:**
  - Increased Demand for New Facilities and Services
  - Huge Investments in Transportation Projects
  - Land Use Development
  - Multiple Alternatives for Transportation Projects

7

## 1. Increased Demand for New Facilities and Services

---

- **Growing population and urbanization** increase pressure on existing transportation infrastructure.
- **Rising vehicle ownership** leads to traffic congestion and travel delays.
- **Public transit expansion** is needed to meet the mobility needs of urban and rural populations.
- **Example:**
  - **Global road traffic expected to double by 2050**, requiring better planning and expansion.

8

## 2. Huge Investments in Transportation Projects

---

- **Transport projects require significant financial investments** in infrastructure and maintenance.
- Planning ensures:
  - **Efficient allocation of resources** to high-priority areas.
  - **Cost-benefit analysis** to justify large expenditures.
  - **Long-term sustainability** of transportation networks.

9

### 3. Land Use Development

---

- Transportation and land use are **interdependent**
- **Poor planning can lead to:**
  - **increased travel times.**
  - **Inefficient public transport accessibility.**
  - **Traffic congestion due to unplanned road networks.**

10

### 4. Multiple Alternatives for Transportation Projects

---

- Every transportation project has **multiple design and implementation options.**
- Planning helps in:
  - **Evaluating different alternatives** based on cost, efficiency, and environmental impact.
  - **Choosing the most sustainable and effective solution.**
  - **Balancing short-term costs with long-term benefits.**
- **Example:**
  - **High-Speed Rail vs. Expanding Highway Networks**—each has different costs, benefits, and environmental impacts.

11

# Transportation Planning

## Basic Elements

12

## Basic Elements of Transportation Planning

---

- **Transportation planning** consists of **seven interrelated elements**, forming a continuous decision-making process.
- These elements do **not always occur sequentially**—information from one phase can influence earlier or later steps.
- **Key elements of transportation planning:**
  1. **Situation Definition**
  2. **Problem Definition**
  3. **Search for Solutions**
  4. **Analysis of Performance**
  5. **Evaluation of Alternatives**
  6. **Choice of Project**
  7. **Specification and Construction**

13

# Step 1: Situation Definition

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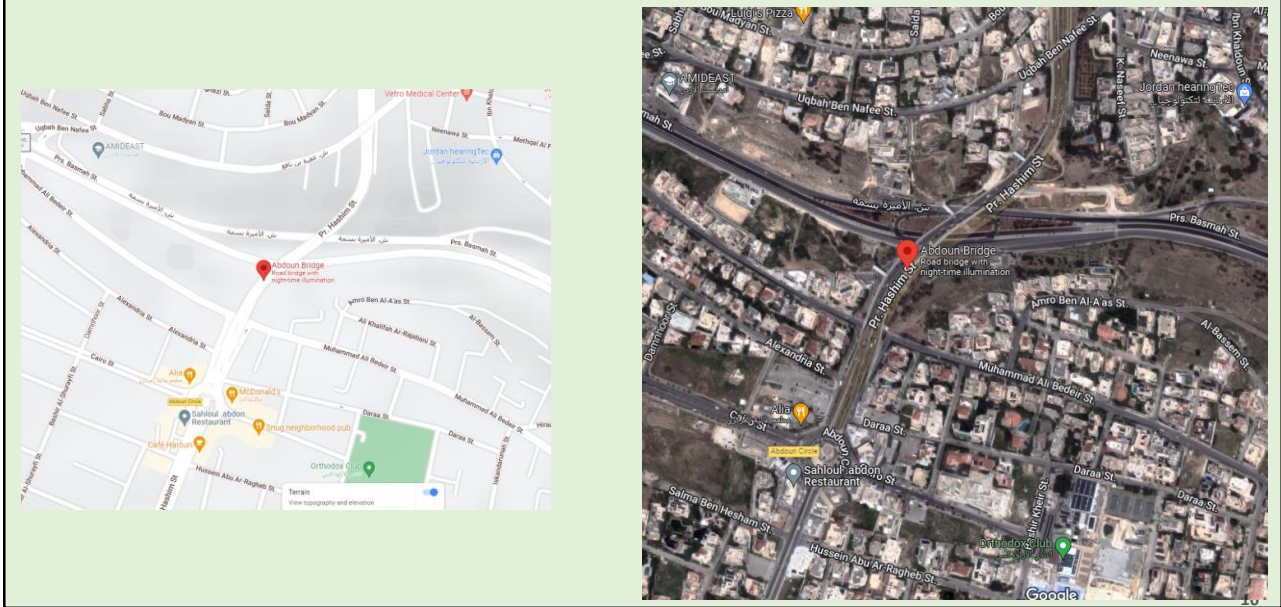
## Situation Definition in Transportation Planning

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- It involves **analyzing the current system**, identifying deficiencies, and determining the **scope of study**.
- Helps in **understanding the factors** that created the need for a transportation improvement project.
- **Key components of situation definition:**
  1. Assessing the Existing Transportation System
  2. Collecting Data on Travel Patterns and Traffic Volumes
  3. Reviewing Previous Studies and Reports
  4. Defining the Study Area and Scope
  5. Engaging Public and Stakeholders

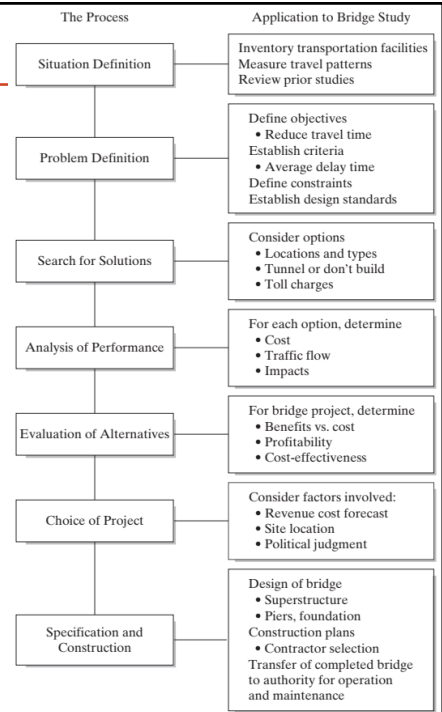
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## Case Study: Feasibility of a New Bridge in Amman



16

## Case Study: Feasibility of a New Bridge in Amman



17

## Situation Definition - 1. Assessing the Existing Transportation System

---

- **Understanding current infrastructure and services** to identify gaps or inefficiencies.
- Includes:
  - Analyzing **road networks, bridges, railways, transit systems, and traffic conditions**
  - Identifying **congestion points, and safety concerns**.
- **Example:**
  - **A city considers a new bridge** due to increasing congestion on existing roadways.

18

## Situation Definition - 2. Collecting Data on **Travel Patterns** and Traffic Volumes

---

- **Understanding how people move** and **where the highest demand exists**.
- Data sources include:
  - **Traffic surveys, automatic vehicle counters, GPS tracking.**
  - **Peak-hour traffic flow analysis** for congestion hotspots.

19

### Situation Definition - 3. Reviewing Previous Studies and Reports

---

- **Examining prior research, geological maps, and environmental reports.**
- Helps in **understanding past findings and recommendations** for similar projects.
- **Example:**
  - **A previous study may have analyzed soil conditions**, helping determine feasibility for a new bridge.

20

### Situation Definition - 4. Defining the Study Area and Scope

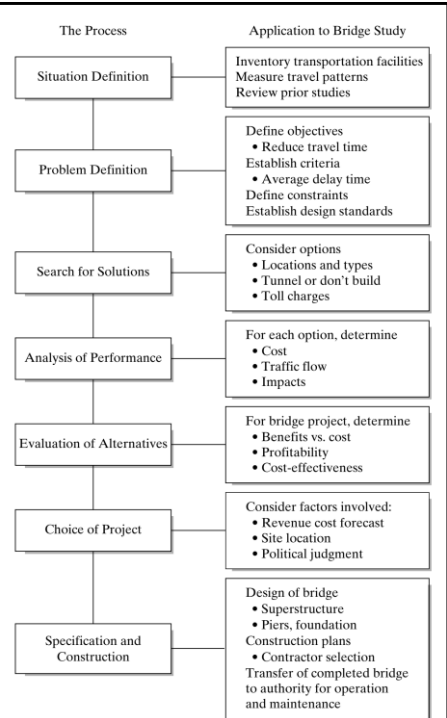
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- Establishing **the geographic area that will be affected by the proposed project**
- Includes:
  - Defining **boundaries for analysis**.
  - Identifying **affected communities and businesses**.
- **Example:**
  - If a bridge is planned, the study area includes **existing roads, alternative routes, and surrounding developments**.

21

### Example: Applying Situation Definition to a New Bridge Project

- **Project Idea:** Building a new bridge to reduce congestion.
- **Steps in Situation Definition:**
  - **Analyze the current highway system** (existing bridges, traffic flow).
  - **Collect data on travel patterns** (commuters, freight movement).
  - **Review prior studies** (environmental impact, feasibility reports).
  - **Define the affected study area** (nearby communities, businesses).
  - **Conduct public hearings** to get input from citizens and stakeholders.



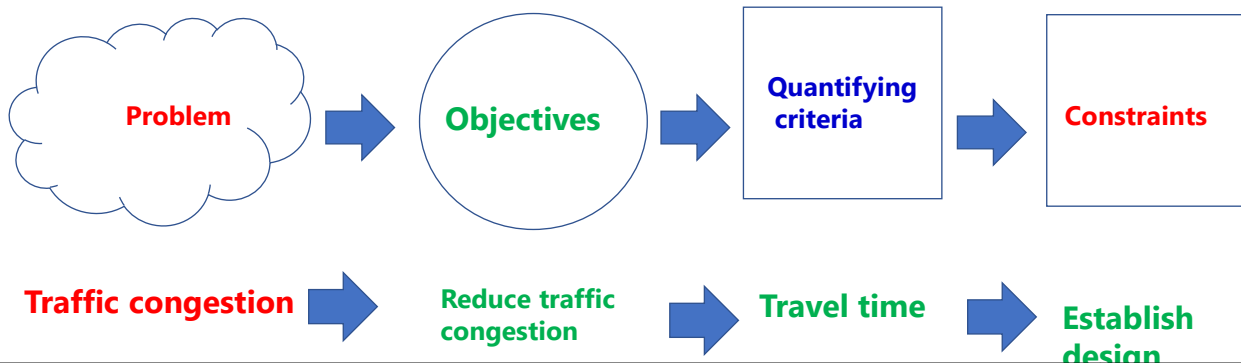
22

## Step 2: Problem Definition

23

## Problem Definition in Transportation Planning

- **Problem definition** is a crucial step in the planning process where the issue is clearly identified.
- It involves:
  - **Setting objectives** to be achieved by the project.
  - **Establishing quantifiable criteria** to measure success.
  - **Identifying constraints and limitations** affecting the project.



24

## Problem Definition -1. Setting Objectives

- Objectives define the **intended purpose** of the transportation project.
- Examples of common objectives include:
  - **Reduce traffic congestion.**
  - **Improve road safety.**
  - **Enhance economic connectivity.**
  - **Minimize environmental impact.**
- **Example:** A bridge project might aim to **reduce traffic congestion on alternative routes.**

25

## Problem Definition -2. Establishing Quantifiable Criteria

---

- **Criteria are used to measure the success of meeting objectives.**
  - These are often called **Measures of Effectiveness (MOEs)**.
- **Examples of quantifiable criteria:**
  - **For reducing congestion:** Measure **average travel time** or **vehicle delay**.
  - **For improving safety:** Measure **accident rates per mile**.
  - **For maximizing user benefits:** Analyze **cost-benefit ratios**.
- **Example:** If the objective is to **reduce travel time**, the criterion could be **reducing average delays at key intersections**.

26

## Problem Definition -3. Identifying Constraints and Limitations

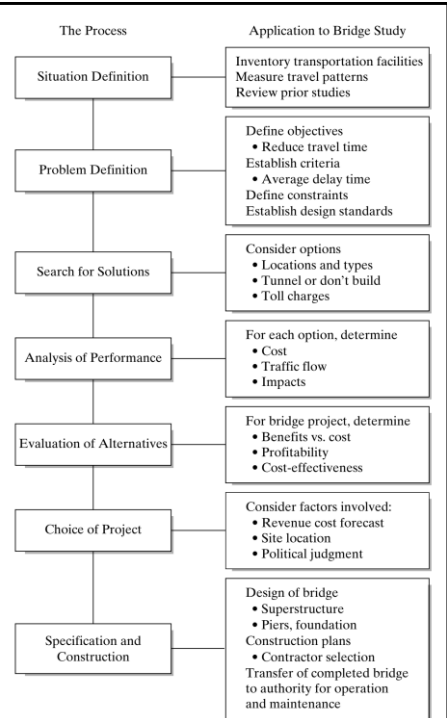
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- Every transportation project faces **physical, regulatory, and environmental constraints**.
- **Common constraints include:**
  - **Physical limitations** (e.g., existing buildings, terrain).
  - **Regulatory constraints** (e.g., environmental laws, historic preservation).
  - **Engineering standards** (e.g., bridge width, clearance heights).
- **Example:** A bridge project may have **design constraints due to nearby historic buildings or difficult soil conditions**.

27

Example: Problem Definition for a New Bridge Project

- **Objective:** Reduce congestion on alternative routes.
- **Criteria:** Measure **average delay and travel time.**
- **Constraints:**
  - **Physical:** Nearby rivers, existing infrastructure, historic districts.
  - **Regulatory:** Environmental approvals required.
  - **Engineering:** Must meet **bridge width and load-bearing standards.**
- **Outcome:** A well-defined problem statement that helps in decision-making



28

## Step 3: Search for Solutions

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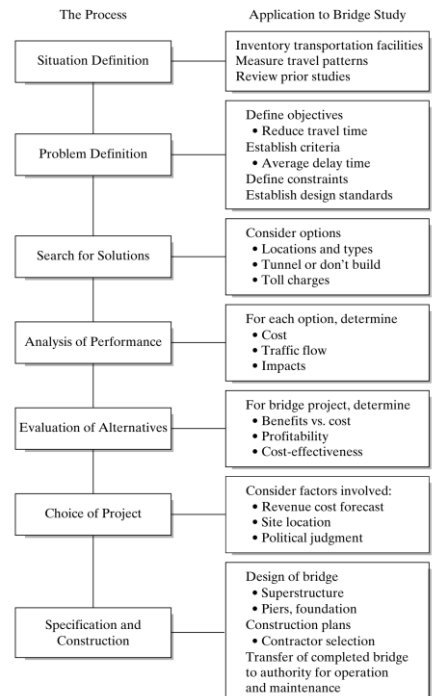
## Search for Solutions in Transportation Planning

- This phase focuses on **generating multiple possible solutions** to the identified transportation problem.
- It is a **brainstorming stage** where different **ideas, designs, locations, and system configurations** are explored.
- **Solutions may be proposed by various stakeholders, including:**
  - Government agencies
  - Urban planners
  - Engineers and researchers
  - Community groups
- **Common alternative solutions include:**
  - **New transportation technologies** (electric buses, autonomous vehicles).
  - **Infrastructure changes** (new bridges, tunnels, road expansions).
  - **System or network modifications** (traffic signal adjustments, public transit improvements).
  - **Policy and operational changes** (congestion pricing, tolls, dedicated lanes).

30

### Example: Bridge Project Alternatives

- For a proposed bridge, multiple options should be considered:
  - **Location alternatives:** Different placement points for minimal disruption.
  - **Structural alternatives:** Suspension bridge vs. cable-stayed bridge.
  - **Alternative transportation modes:** Tunnel instead of a bridge.
  - **Operational policies:** Toll-based funding vs. government funding.
- A **“No Build” option** should also be evaluated to determine if **alternative solutions** (e.g., road widening, ferry service) might be better.



31

## Step 4: Analysis of Performance

32

### Analysis of Performance in Transportation Planning

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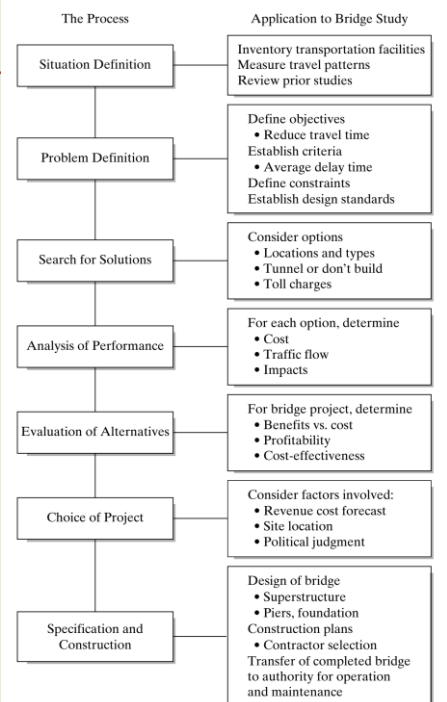
- The goal of **performance analysis** is to estimate how each proposed alternative would function **under current and future conditions**.
- This involves:
  - **Evaluating investment, maintenance, and operational costs.**
  - **Using mathematical models to forecast travel demand.**
  - **Determining system performance metrics** (e.g., travel time, trip length, congestion levels).
  - **Assessing environmental and community impacts.**
- Helps in selecting the **most effective and sustainable transportation option**.

33

## Example: Bridge Project Performance Analysis

### • **Steps for performance evaluation of a new bridge:**

- **Estimate construction costs** for different locations.
- **Forecast traffic demand** based on bridge width and toll charges.
- **Compare average trip length and travel time** before and after the bridge.
- **Assess environmental impacts** (air pollution, noise, land use changes).
- **Evaluate user benefits** (faster commutes, reduced congestion).



38

## Step 5: Evaluation of Alternatives

39

## Evaluation of Alternatives in Transportation Planning

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- The **evaluation phase** assesses how well each proposed alternative meets project objectives.
- It **compares benefits, costs, and overall effectiveness** to determine the best solution.
- **Key components of the evaluation process:**
  - **Comparing Performance Against Objectives**
    - Evaluates each alternative based on predefined criteria (e.g., congestion reduction, safety improvement, cost-effectiveness).
  - **Benefit-Cost Analysis (BCA)**
  - **Weighted Ranking of Alternatives**
  - **Cost-Effectiveness Analysis**
  - **Environmental and Social Impact Considerations**

40

## Evaluation of Alternatives- Comparing Performance Against Objectives

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- **Uses performance data from the previous analysis phase** to measure success.
- Evaluates each alternative based on predefined **criteria** (e.g., congestion reduction, safety improvement, cost-effectiveness).
- **Example:**
  - A proposed **bridge project** is assessed based on:
    - **Traffic flow improvements.**
    - **Reduction in travel time.**
    - **Environmental impact.**

41

## Evaluation of Alternatives-2. Benefit-Cost Analysis (BCA)

---

- **Determines whether a transportation project is a sound investment.**

- **Formula:**

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\text{Total Expected Benefits}}{\text{Total Project Costs}}$$

- 
- If **BCR > 1**, the project is financially viable.
- **Example:**
  - A highway expansion project is expected to generate **\$200 million in benefits** over its lifespan with **\$150 million in costs**, leading to a **BCR of 1.33 (favorable investment)**.

42

## Evaluation of Alternatives-Weighted Ranking of Alternatives

---

- Some project impacts **cannot be directly converted into monetary values.**
- **A weighted ranking system assigns scores to different criteria** based on importance.
- **Example:**
  - A transit project is ranked on:
    - **Efficiency (40%)**
    - **Environmental impact (30%)**
    - **Construction feasibility (20%)**
    - **Community acceptance (10%)**

43

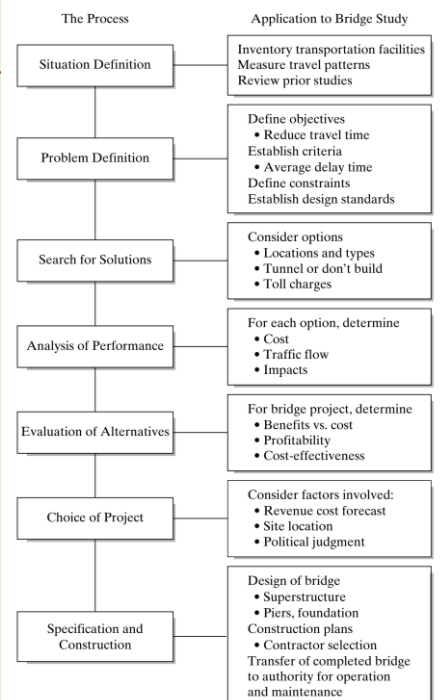
## Evaluation of Alternatives-4. Cost-Effectiveness Analysis

- Used when benefits **cannot be expressed in direct monetary terms.**
- **Example: Evaluating two alternatives for a new bridge:**
  - **Alternative A:** Costs **\$300M**, displaces **100 homes.**
  - **Alternative B:** Costs **\$280M**, displaces **50 homes.**
  - A **cost-effectiveness matrix** visually compares **cost vs. impact** to guide decision-making.

44

### Example: Application to a Bridge Project

- **Steps for Evaluating a Bridge Alternative:**
  - Calculate the **benefits and costs** for different locations.
  - Compute the **benefit-cost ratio (BCR)** to assess investment viability.
  - Compare factors like **traffic efficiency, environmental impact, and engineering feasibility.**
  - Use a **cost-effectiveness matrix** to compare construction costs vs. benefits.
  - Identify the **alternative with the best trade-off between cost, performance, and social impact.**



45

## Step 6: Choice of Project

46

### Choice of Project in Transportation Planning

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- The **project selection phase** determines which transportation project will move forward.
- **Key considerations in project selection:**
  - Cost and financial feasibility
  - Technical and engineering feasibility
  - Community and public approval
  - Environmental and social impacts
  - Political and policy considerations
- **In some cases, additional investigations or public hearings may be needed before making a final decision.**

47

## Choice of Project-1. Simple vs. Complex Project Selection

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- **Simple projects** may be selected based on a **single criterion, such as cost**.
- **Complex projects** require a **multi-criteria approach**, involving:
  - Economic analysis
  - Public input
  - Environmental regulations
  - Engineering feasibility studies
- **Example:**
  - A **road-widening project** may be chosen **solely based on cost**, while a **new metro system** would require extensive community involvement.

48

## Choice of Project-2. Public and Stakeholder Involvement

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- **Community feedback can influence project selection.**
- **Methods of public participation include:**
  - **Public hearings** for stakeholder input.
  - **Surveys and workshops** to gather opinions.
- **Example:**
  - A **proposed highway expansion may be adjusted** due to environmental concerns raised by the public.

49

### Choice of Project-3. Role of Transportation Engineers in Project Selection

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- Engineers provide **data-driven insights** to support decision-makers.
- **Ethical considerations:**
  - Avoid **bias** in selecting or eliminating alternatives.
  - Ensure **all feasible options are fairly assessed**.
  - Present **accurate cost-benefit analyses and performance metrics**.
- **Example:**
  - **A transportation engineer should objectively evaluate a bridge location**, even if a preferred site exists.

50

### Choice of Project-5. Finalizing the Project Location and Design

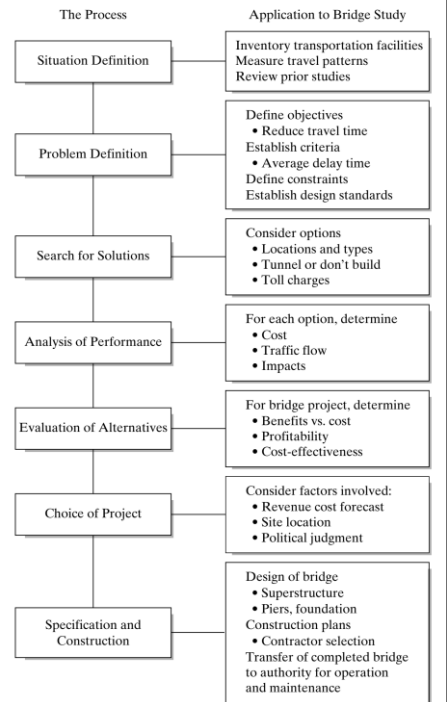
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- The **site location is carefully selected** after evaluating:
  - Land availability and environmental constraints.
  - Traffic impact and connectivity with existing infrastructure.
  - Engineering feasibility and safety considerations.
- **Example:**
  - A **bridge project's location is determined based on soil conditions, traffic flow, and environmental impact studies**.

52

Example: Bridge Project Selection

- **Steps in selecting a bridge project:**
  - **Evaluate economic feasibility** using benefit-cost analysis.
  - **Compare alternative locations** based on environmental and engineering studies.
  - **Consider public input and government policies.**
  - **Make a final decision based on financial and social viability.**
- **Example Outcome:**
  - A **cable-stayed bridge is chosen over a suspension bridge** due to lower costs and better structural stability.



54

# Step 7: Specification and Construction

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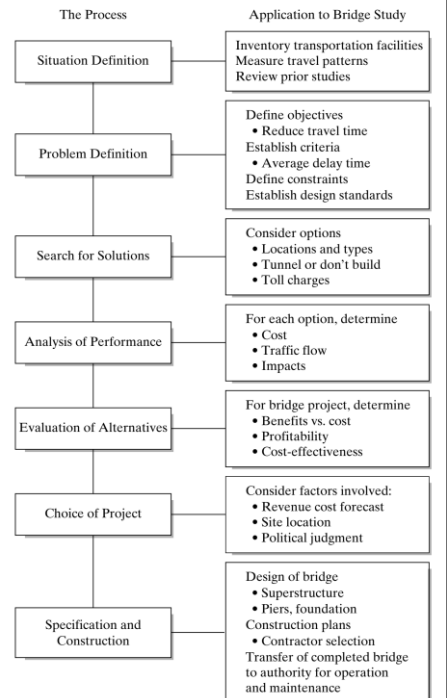
## Specification and Construction in Transportation Planning

- After selecting a transportation project, the **detailed design and construction phases** begin.
- **Key steps in this phase include:**
  - Finalizing Design Specifications
  - Preparing Detailed Plans and Cost Estimates
  - Selecting a Construction Contractor
  - Executing the Construction Process
  - Transitioning to Operation and Maintenance

56

### Example: Problem Definition for a New Bridge Project

- **Final Design Includes:**
  - Superstructure type, pier and foundation details.
  - Roadway width, pedestrian access, lighting, and signals.
- **Bidding & Contractor Selection:**
  - Bids are evaluated based on **cost and expertise**.
- **Construction Phase:**
  - **Site preparation, material sourcing, and structural assembly.**
- **Post-Construction:**
  - Handover to **transportation authority for operation and long-term maintenance.**



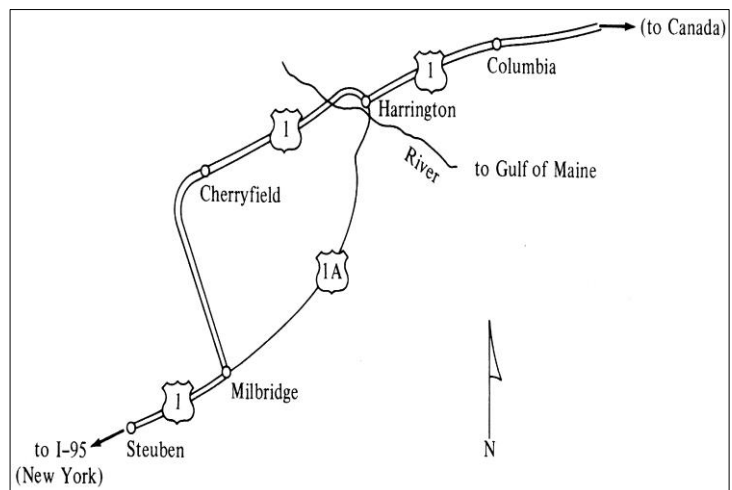
62

# Case Study : Relocation of Rural Road

63

- ☐ This example is based on a study completed by the engineering firm **Edwards and Kelsey**

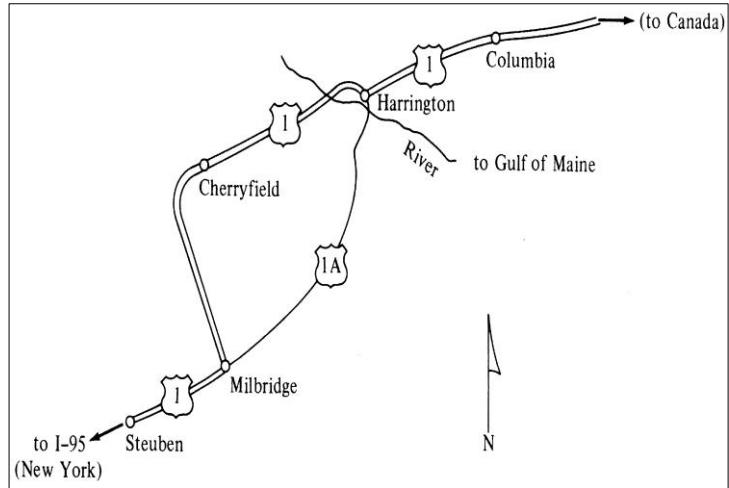
<b>Feature</b>	<b>US 1</b>	<b>US 1A</b>
<b>Purpose</b>	Major <b>north-south</b> highway	<b>Alternate routes</b> , scenic byways, or business routes
<b>Length</b>	2,370 miles (3,810 km)	Varies by state (several disconnected segments)
<b>Access</b>	<b>Major intersections, highways</b>	<b>Local roads, business districts, and bypasses</b>
<b>Existence</b>	A <b>single continuous highway</b>	<b>Multiple separate routes</b> in different states



64

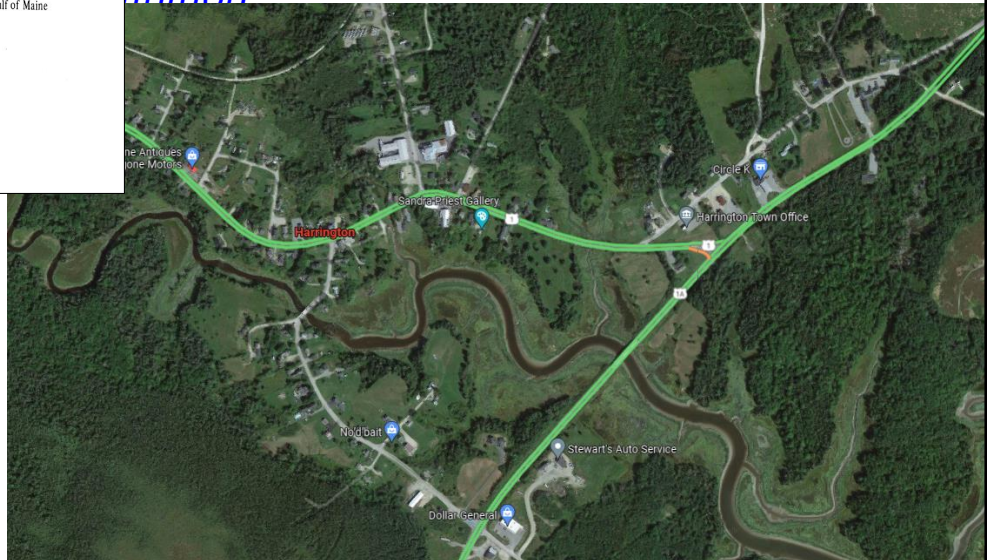
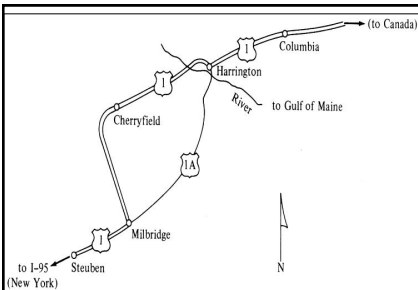
- ❑ This example is based on a study completed by the engineering firm **Edwards and Kelsey**

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## Defining the relocation of a rural road



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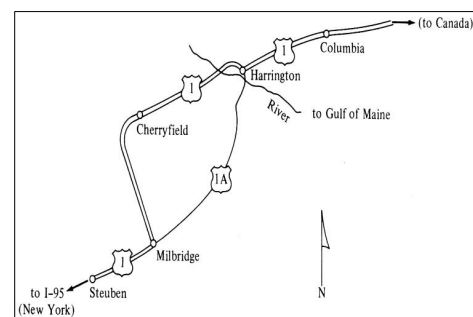
# Case Study : Relocation of Rural Road

## Step 1: Situation Definition

67

### Step 1: Situation Definition – Harrington, Maine Road Relocation Project

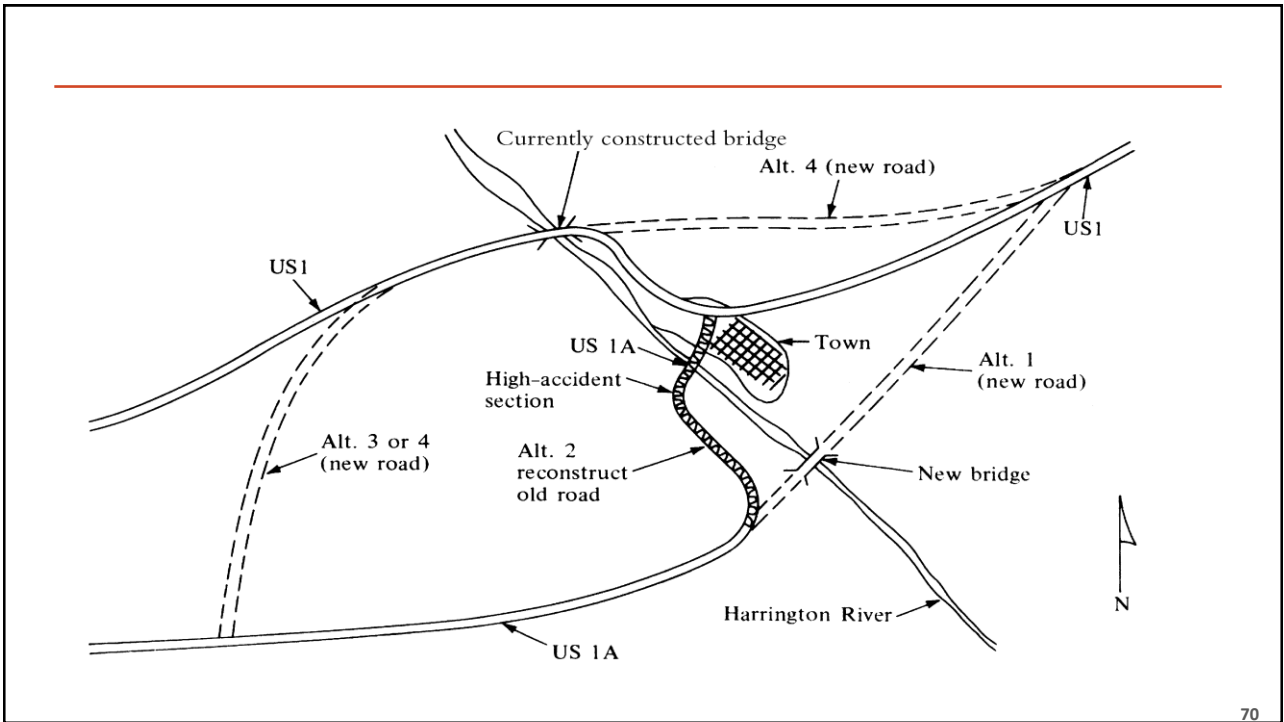
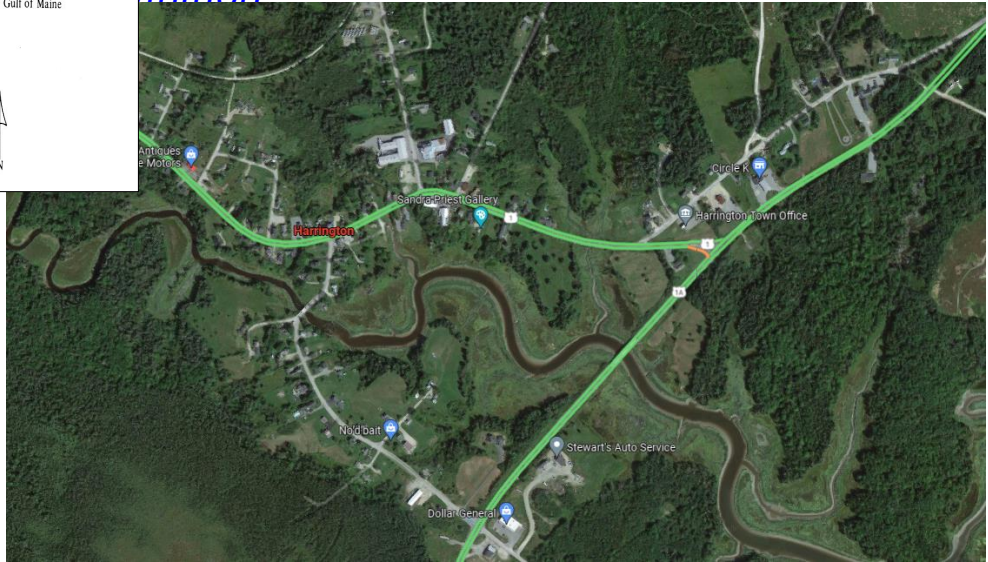
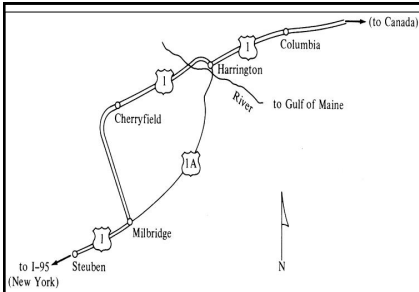
- **Project Overview:**
  - The project involves the **relocation or reconstruction of 3.3 miles of U.S. 1A** in **Harrington, Maine**.
  - The town center is located at the **intersection of U.S. 1 and U.S. 1A**, near the **Harrington River**.
- **Purpose of Situation Definition:**
  - To understand the **existing conditions** that led to the need for a transportation improvement.
  - To analyze the **physical, social, and economic factors** affecting the project are



68

# Planning the relocation of a rural road

Definition



## Town Profile and Population Trends

---

- **Harrington, Maine – Study Area Overview:**
  - Total **population: 553 residents**.
  - **420 residents live within the study area**, including **350 in the town center**.
  - Population **declining** due to **lack of employment opportunities**.
- **Economic Considerations:**
  - Primary industries: **Agriculture and fishing**.
  - **Road realignment could affect the local economy** if it impacts natural resources.
  - **10 business establishments** in the study area, with **20% of retail sales tied to tourism**.

71

## Traffic and Transportation Characteristics

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- **Average Daily Traffic (ADT): 2,620 vehicles/day.**
  - **69% of traffic is through-traffic** (not stopping in town).
  - **31% of traffic is local** (residents and businesses).
- **Existing Issues:**
  - High proportion of **non-local vehicles** affecting congestion.
  - Possible **negative impacts on tourism and businesses** if the new alignment diverts local traffic away from the town center.
  - Potential **environmental concerns** due to the town's reliance on **fishing and agriculture**.

72

## Key Considerations for Situation Definition

---

- **Social Impact:**
  - Population decline and **economic struggles of small businesses**.
  - The need to maintain **access to essential services and businesses**.
- **Environmental Impact:**
  - Road realignment could **affect the estuary and fishing industry**.
  - Potential for **habitat disruption and water pollution**.
- **Economic Impact:**
  - The project must **balance traffic efficiency with economic sustainability**.
  - **Tourism and local business accessibility** should be maintained.
- **Traffic Flow Considerations:**
  - Reducing congestion while **preserving the town's connectivity**.
  - Evaluating the **impact of diverting traffic from U.S. 1A**.

73

## Case Study : Relocation of Rural Road

### Step 2: Problem Definition

74

## Step 2: Problem Definition – Harrington, Maine Road Relocation Project

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- **The Maine Department of Transportation (MDOT) aims to improve U.S. 1A** by addressing safety and traffic flow issues.
- **Primary issue:** High accident rate in the **town center area**.
- **Causes of the problem:**
  - **Narrow bridge** leading into the town center.
  - **Poor horizontal and vertical alignment** of U.S. 1A within the town.
  - **Dangerous intersection** at U.S. 1A and U.S. 1.
- **Accident rate:** Four times the **statewide average**, making it a priority for improvement.

75

## 1. Objectives of the Road Relocation Project

---

- **Primary Objective:**
  - **Reduce the accident rate** by improving road alignment and intersection safety.
- **Secondary Objective:**
  - **Improve traffic flow for through traffic** by increasing the average speed.
- **Key transportation issues:**
  - The **existing bridge is too narrow** for current traffic demands.
  - **Poor road geometry** makes driving hazardous.
  - The **town center intersection is a high-risk crash location**.

76

## 2. Measures of Effectiveness (MOEs)

---

- **The success of the project will be measured using:**
  - **Accident Rate:** Reduction in crashes after improvements.
  - **Travel Time:** Increased average speed for through traffic.
  - **Construction Cost:** Ensuring the project remains financially feasible.
  - Changes in Noise Levels and Air Quality
  - Number of Businesses and Residences Displaced

77

## 3. Additional Considerations in Problem Definition

---

- The **impact on local businesses and residences** will be considered:
  - **Number of businesses and homes displaced** due to construction.
- **Environmental impacts:**
  - Changes in noise levels and air quality.
  - Effects on natural habitats, including salt marshes and tree cover.

78

# Case Study : Relocation of Rural Road

## Step 3: Search for Solutions

79

### Step 3: Search for Solutions – Harrington, Maine Road Relocation Project

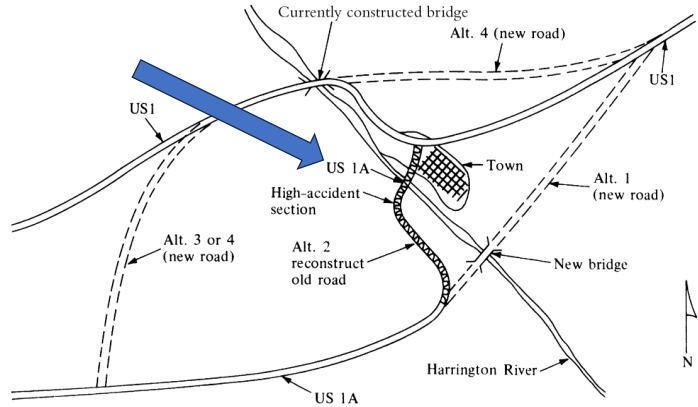
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- The **Maine Department of Transportation (MDOT)** has identified **four alternative routes** along with a "Do-Nothing" option.
- **All alternatives start and end at the same location:**
  - **3 miles southwest of Harrington town center → Northeast of the town center.**
- The goal is to **find the most effective and feasible solution** based on safety, efficiency, and environmental impact.

80

## 1. Alternative 0 – The “Do-Nothing” Option

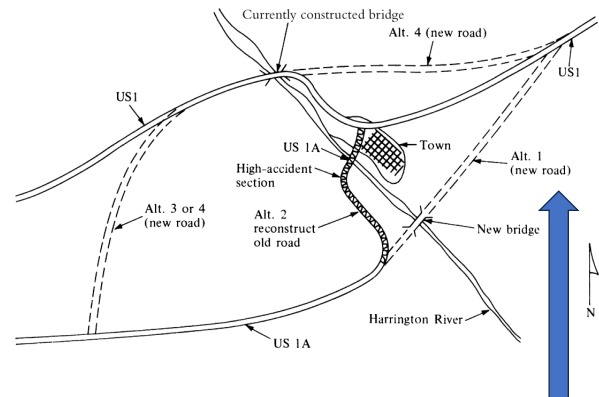
- Also known as the **Null Alternative**.
- **Current Issues with Existing U.S. 1A Route:**
  - Narrow bridge causing traffic bottlenecks.
  - Poor horizontal and vertical alignment increasing accident risk.
  - Dangerous intersection at U.S. 1 and U.S. 1A.
- **Considerations:**
  - Maintains existing traffic patterns but does not address safety issues.
  - Lowest initial cost but high long-term accident and congestion costs



81

## 2. Alternative 1 – Southern Bypass with New Bridge

- **Key Features:**
  - Bypasses the town center to the south.
  - A new bridge over the Harrington River, about 0.5 miles downstream from the existing bridge.
  - Two-lane road, each lane 12-ft wide, with 8-ft shoulders.
- **Potential Benefits:**
  - Reduces congestion in town.
  - Minimizes impact on local businesses.
  - Provides a direct, faster route for through traffic.
- **Potential Drawbacks:**
  - Requires new right-of-way and land acquisition.
  - Environmental concerns related to river crossing.



82

### 3. Alternative 2 – Existing U.S. 1A Route Improvement

- **Key Features:**

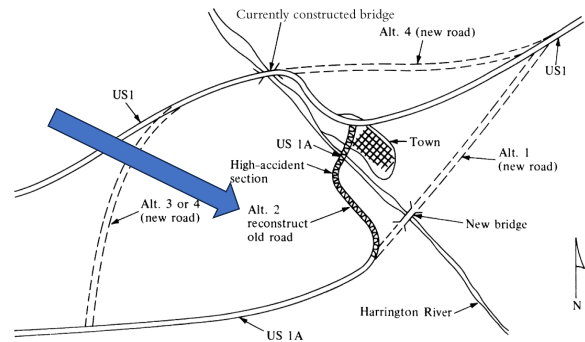
- Uses the **existing U.S. 1A alignment** but with **horizontal and vertical realignment**.
- Includes **construction of a new bridge**.
- **Same geometric design as Alternative 1** (12-ft lanes, 8-ft shoulders).

- **Potential Benefits:**

- Maintains access to local businesses and tourism traffic.
- Requires less new land acquisition than Alternative 1.

- **Potential Drawbacks:**

- Construction delays may affect local businesses.
- Less effective in reducing congestion than a full bypass.



83

### 4. Alternative 3 – Partial Bypass Using Existing Route 1 Bridge

- **Key Features:**

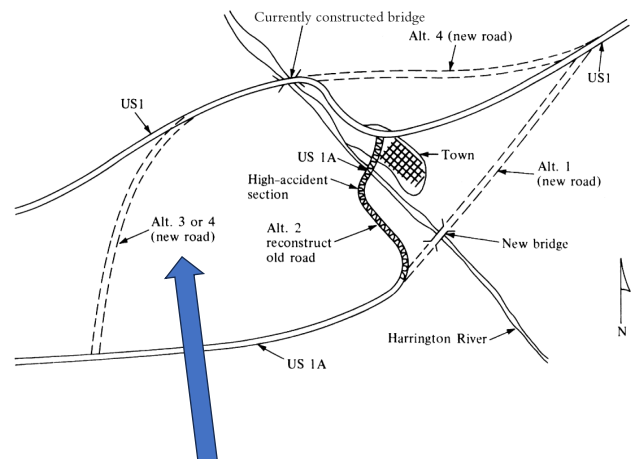
- **Merges with U.S. 1 west of Harrington** and continues through town.
- Uses the **recently constructed Route 1 Bridge**.
- **Same geometric specifications as other alternatives.**

- **Potential Benefits:**

- Leverages existing infrastructure (Route 1 Bridge), reducing costs.
- Improves connectivity with U.S. 1.

- **Potential Drawbacks:**

- Does not fully eliminate town center congestion.
- May still impact businesses along U.S. 1A.



84

## 5. Alternative 4 – Full Bypass Using Route 1 Bridge

- **Key Features:**

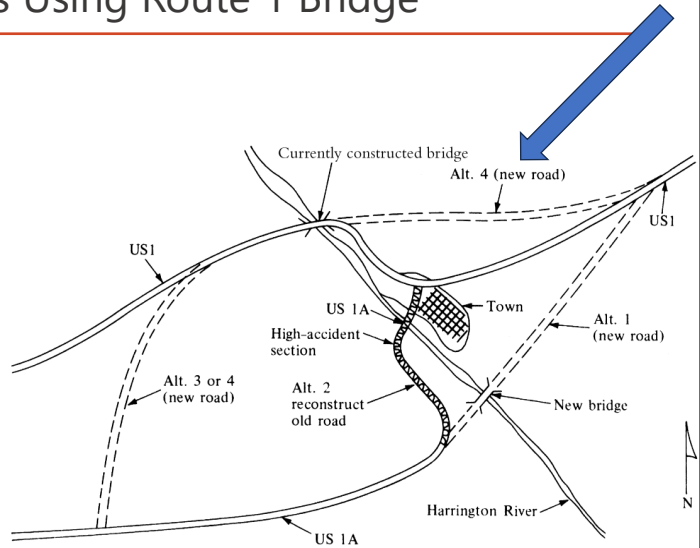
- Similar to Alternative 3, but instead of passing through town, it **bypasses the town center on a new alignment**.
- Uses **Route 1 Bridge** instead of constructing a new one.

- **Potential Benefits:**

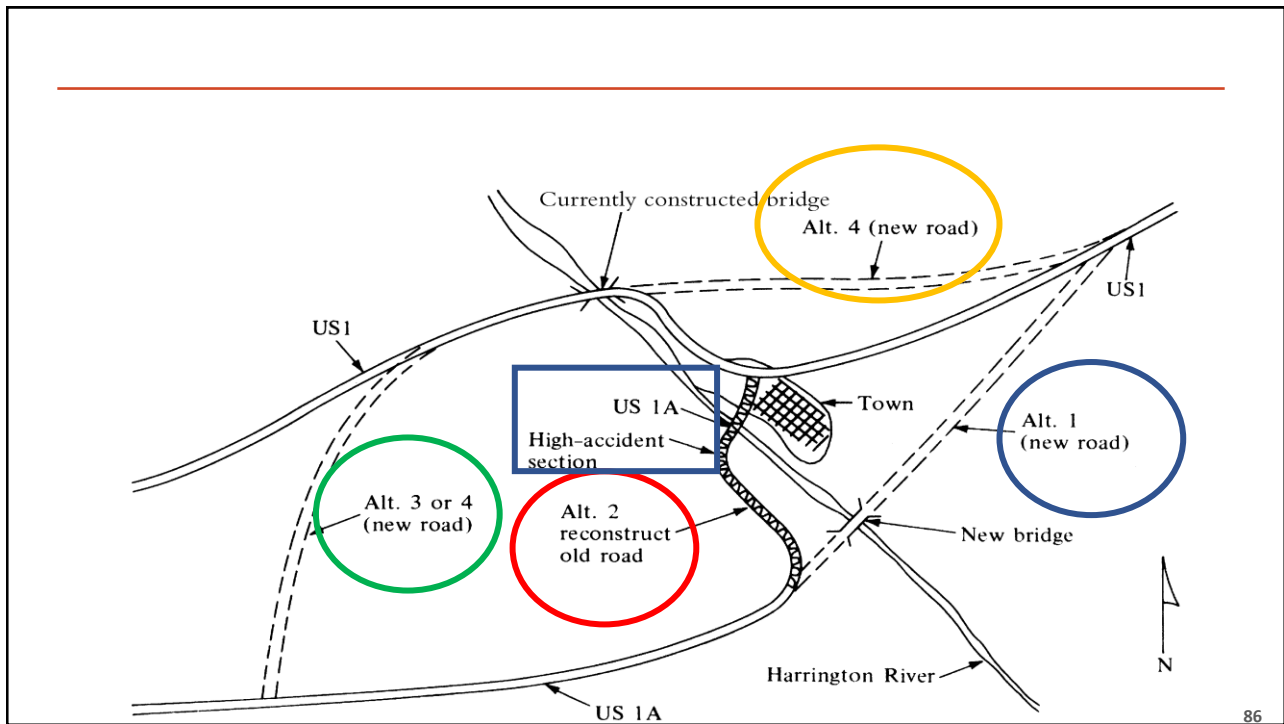
- Removes through traffic from the town center, reducing congestion and improving safety.
- Uses existing infrastructure (Route 1 Bridge), minimizing costs.

- **Potential Drawbacks:**

- Potentially reduces business exposure in the town center.
- Requires new land acquisition for the bypass segment.



85



86

## Comparison of Alternatives

Alternative	New Bridge?	Bypasses Town?	Impacts on Businesses	Safety Improvement	Estimated Cost
<b>Alternative 0 (Do-Nothing)</b>	No	No	High congestion remains	No improvement	No cost
<b>Alternative 1 (Southern Bypass + New Bridge)</b>	Yes	Yes	Minimal impact	High improvement	High
<b>Alternative 2 (Upgrade Existing U.S. 1A)</b>	Yes	No	Some disruption	Moderate improvement	Moderate
<b>Alternative 3 (Partial Bypass + Route 1 Bridge)</b>	No	No	Some impact	Moderate improvement	Low to Moderate
<b>Alternative 4 (Full Bypass + Route 1 Bridge)</b>	No	Yes	Reduces town center traffic	High improvement	Moderate

87

## Case Study : Relocation of Rural Road

### Step 4: Analysis of Performance

88

#### Step 4: Analysis of Performance – Harrington, Maine Road Relocation Project

- This phase **evaluates each alternative** using **measures of effectiveness (MOEs)**.
- The **results of the calculations** determine how well each alternative meets the project objectives.
- **Performance metrics analyzed include:**
  - Average Travel Speed
  - Accident Factor Reduction
  - Project Cost
  - Displacement of Residences
  - Traffic Flow Changes
  - Environmental Impact (Air Quality, Noise, Tree Removal, Lost Taxes)

89

#### Step 4: Analysis of Performance – Measures of effectiveness

**Table 11.1** Measures of Effectiveness for Rural Road

<i>Criteria</i>	<i>Alternatives</i>				
	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
Future (20 years)	4350	2325	4350	4180	2075
Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

90

# 1. Travel Speed Comparison

- **Objective:** Improve traffic flow and efficiency.
- **Current Speed on Existing U.S. 1A: 25 mi/h.**
- **Projected Speeds for Each Alternative:**
  - **Alternative 1 & 4: 55 mi/h** (highest improvement).
  - **Alternative 2 & 3: 30 mi/h** (moderate improvement).
- **Analysis:**
  - **Bypasses (Alternatives 1 & 4) provide the highest speed increases** due to reduced intersections and congestion.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
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Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

91

# 2. Accident Factor Reduction

- **Objective:** Reduce accident rates, which are currently **4 times the statewide average**.
- **Projected Accident Factors for Each Alternative:**
  - **Alternative 4: 0.6 times statewide average** (best improvement).
  - **Alternative 1: 1.2 times statewide average.**
  - **Alternative 2 & 3: Moderate reduction.**
- **Analysis:**
  - **Alternative 4 provides the safest outcome,** likely due to better road alignment and separation of local and through traffic.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
Future (20 years)	4350	2325	4350	4180	2075
Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

92

### 3. Project Cost Comparison

- **Objective:** Ensure the project is cost-effective while achieving transportation goals.
- **Estimated Costs for Each Alternative:**
  - **Alternative 3: \$1.18 million** (lowest cost).
  - **Alternative 2: \$1.58 million** (highest cost).
- **Analysis:**
  - **Alternative 3 is the most cost-effective** but does not offer the best safety or efficiency improvements.
  - Alternative 4 is more expensive but provides superior safety benefits.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
Future (20 years)	4350	2325	4350	4180	2075
Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

93

### 4. Residential Displacement and Land Use Impact

- **Objective:** Minimize the number of people displaced due to road construction.
- **Impacts Considered:**
  - Number of residences displaced.
  - Loss of local businesses and tax revenue.
  - Acreage of trees removed.
- **Analysis:**
  - **Alternative 4 require the most land acquisition.**
  - **Alternative 3 has the least displacement** but provides lower safety benefits.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
Future (20 years)	4350	2325	4350	4180	2075
Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

94

## Environmental Impact

- **Alternative 1 provides the best air quality improvement** (306 µg/m<sup>3</sup> CO, significantly lower than Alternative 2 and 3 at 825).
- **Alternative 4 has the highest tree removal (28 acres), followed by Alternative 3 (25 acres).**
- **Alternatives 3 and 4 also produce the most runoff ("Much"),** while Alternatives 1 and 2 have only "Some" runoff.
- **Noise pollution is lowest in Alternatives 1 and 4 (70 dBA).**

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
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Air quality (µg/m <sup>3</sup> CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

95

## Ranking of alternatives

**Table 11.2** Ranking of Alternatives

Criterion/Alternative	Alternatives				
	0	1	2	3	4
Travel time	4	1	3	3	2
Accident factor	5	2	4	3	1
Cost	1	3	5	2	4
Residences displaced	1	1	3	2	1
Air quality	4	1	4	3	2
Noise	2	1	2	2	1
Tax loss	1	2	4	3	2
Trees removed	1	2	2	3	4
Runoff	1	2	2	3	3

Note: 1 = highest; 5 = lowest

96

96

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
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Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
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Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	

Criterion/Alternative	Alternatives				
	0	1	2	3	4
Travel time	4	1	3	3	2
Accident factor	5	2	4	3	1
Cost	1	3	5	2	4
Residences displaced	1	1	3	2	1
Air quality	4	1	4	3	2
Noise	2	1	2	2	1
Tax loss	1	2	4	3	2
Trees removed	1	2	2	3	4
Runoff	1	2	2	3	3

*Note: 1 = highest; 5 = lowest*

97

# Case Study : Relocation of Rural Road

## Step 5: Evaluation of Alternatives

98

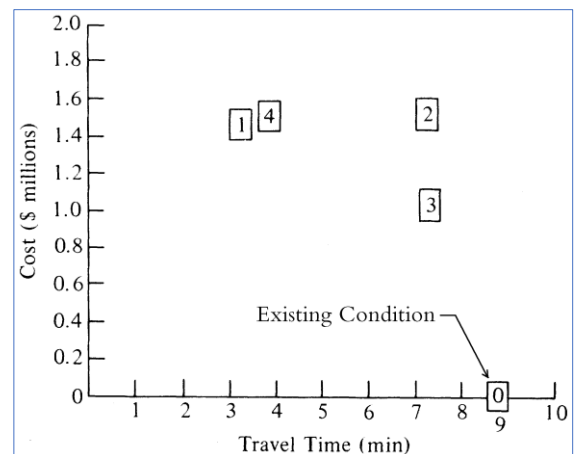
## Step 5: Evaluation of Alternatives – Harrington, Maine Road Relocation Project

- The **evaluation phase** involves comparing all alternatives based on specific **measures of effectiveness (MOEs)**.
- The goal is to **determine which alternative provides the best improvements** relative to its **cost and impact**.
- **Measures of Effectiveness (MOEs) considered in evaluation:**
  - Accident Reduction
  - Travel Speed Improvement
  - Construction Cost
  - Environmental and Social Impacts
  - Economic and Business Impact

99

## 1. Travel Time Improvements

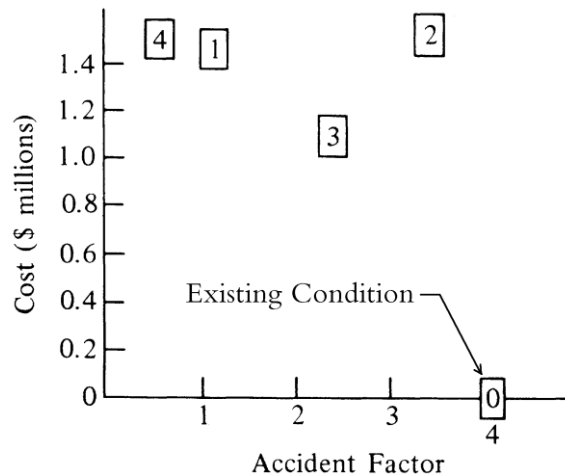
- **Objective:** Reduce congestion and improve traffic efficiency.
- **Results (Figure 11.4):**
  - Alternative 1 provides the greatest reduction in travel time.
  - Alternative 4 is the second-best option.
  - Alternatives 2 and 3 provide minor improvements.
- **Conclusion:**
  - Alternative 1 is the best for travel efficiency.
  - Alternatives 2 and 3 are less effective.



100

## 2. Accident Factor Reduction (Safety)

- **Objective:** Reduce the high accident rate, which is currently **four times the statewide average**.
- **Results (Figure 11.5):**
  - **Alternative 4 achieves the best safety improvement** (accident factor reduced to **0.6**).
  - **Alternative 1 is the second-best** (accident factor reduced to **1.2**).
  - **Alternatives 3 and 2 are less effective.**
- **Conclusion:**
  - Alternative 4 offers the greatest safety benefit.



101

## 3. Cost Analysis

- **Objective:** Ensure cost-effectiveness while achieving transportation goals.
- **Cost Comparison:**
  - Alternative 3 is the lowest cost (\$1.18 million).
  - Alternative 2 is the highest cost (\$1.58 million) but does not improve safety or travel time significantly.
  - Alternative 1 costs \$0.32M more than Alternative 3 but significantly improves safety and travel time.
  - Alternative 4 costs \$0.04M more than Alternative 1 but provides better accident reduction.
- **Conclusion:**
  - Alternative 2 is eliminated due to high cost with low benefits.
  - Alternatives 1 and 4 provide the best cost-effectiveness ratio.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
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Air quality (µg/m³ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

102

## 4. Residential Displacement

- **Objective:** Minimize the number of homes affected by construction.
- **Impact on Residences:**
  - Alternative 1 and Alternative 4 do not require any home relocations.
  - Alternative 3 would displace three residences.
  - Alternative 2 would displace seven residences.
- **Conclusion:**
  - Alternative 1 and Alternative 4 are preferable for minimizing community impact.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
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Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

103

## Air Quality Improvement

- **Objective:** Reduce pollution and improve environmental sustainability.
- **Evaluation of alternatives:**
  - **Alternative 1:** Best air quality improvement due to highest reduction in slow-moving traffic.
  - **Alternative 4:** Second-best improvement.
  - **Alternative 3:** Moderate improvement.
  - **Alternative 2:** Lowest improvement in air quality.
- **Conclusion:**
  - Bypassing the town center (Alternatives 1 & 4) improves air quality by shifting traffic to faster roads, reducing emissions per vehicle.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
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Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

104

## 2. Noise Levels

- **Objective:** Reduce noise pollution in residential and commercial areas.
- **Evaluation of alternatives:**
  - **Alternatives 1 & 4:** Lower noise levels due to better traffic flow outside town.
  - **Alternatives 2 & 3:** Higher noise levels as they continue to direct traffic through the town center.
- **Conclusion:**
  - Alternatives 1 and 4 offer the best solutions for minimizing traffic-related noise in urban areas.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
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Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

105

## 3. Tax Revenue Loss

- **Objective:** Minimize economic disruption and loss of tax revenue from displaced businesses and properties.
- **Evaluation of alternatives:**
  - **Alternative 1 & 4:** Slight tax losses.
  - **Alternative 3:** Moderate tax losses.
  - **Alternative 2:** Highest tax losses due to business and property displacements.
- **Conclusion:**
  - Alternative 2 is the least favorable option due to its negative economic impact.
  - Alternatives 1 and 4 minimize financial loss while improving infrastructure.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
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Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

106

## 4. Tree Removal Impact

- **Objective:** Preserve natural environments and maintain ecological balance.
- **Evaluation of alternatives:**
  - **Alternative 1:** Minimal tree loss.
  - **Alternative 2:** No trees removed.
  - **Alternative 3:** 25 acres of trees removed.
  - **Alternative 4:** 28 acres of trees removed (highest impact).
- **Conclusion:**
  - Alternative 2 is the most environmentally friendly regarding tree removal.
  - Alternatives 3 & 4 require significant deforestation, potentially impacting wildlife and local ecosystems.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
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Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

107

## 5. Water Runoff Impact

- **Objective:** Prevent excessive water runoff that could lead to flooding, soil erosion, or pollution of nearby water sources.
- **Evaluation of alternatives:**
  - **Alternative 0:** No additional runoff.
  - **Alternatives 1 & 2:** Some runoff.
  - **Alternatives 3 & 4:** **Highest runoff impact** due to larger construction areas.
- **Conclusion:**
  - Alternatives 3 & 4 require better drainage and stormwater management solutions.

Criteria	Alternatives				
	0	1	2	3	4
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
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Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

108

# Case Study : Relocation of Rural Road

## Step 6: Choice of Project

109

### 1. Cost Considerations in Project Selection

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- **Objective:** Select an alternative that **maximizes safety and efficiency while minimizing cost.**
- **Evaluation of alternatives:**
  - **Alternative 3 (\$1.18M)** → Lowest cost with moderate improvements.
  - **Alternative 1 (\$1.50M)** → Slightly more expensive but better overall benefits.
  - **Alternative 4 (\$1.45M)** → Similar to Alternative 1 but higher cost.
  - **Alternative 2 (\$1.58M)** → **Eliminated** due to high cost with lower benefits.
- **Conclusion:**
  - If funding is **limited, Alternative 3 is the best option.**
  - If **additional funds are available, Alternative 1 is preferred** due to better safety, environmental, and community benefits.

110

# Case Study : Relocation of Rural Road

## Step 7: Specifications and Construction

114

### Step 7: Specifications and Construction – Harrington, Maine Bypass Project

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- The final project selection **Alternative 1 (Southern Bypass)** has been approved for construction.
- This alternative includes:
  - **A new bridge over the Harrington River.**
  - **A new road connecting U.S. 1A to U.S. 1.**
- **Key Phases in the Construction Process:**
  - **Finalizing Design Specifications**
  - **Cost Estimation and Budgeting**
  - **Contractor Selection (Bidding Process)**
  - **Construction and Quality Control**
  - **Post-Construction Operations and Evaluation**

115

## Case Study 2

### Improving public transportation in Amman City

Source : Hussien, M., & Sharawneh, O. (2014). Comparison Between Monorail System and BRT System in Amman City. The Fourth Jordan International Conference and Exhibition for Roads and Transport, "High Priority Issues in the Future Transport Sector," 1-15.

116

## Situation Definition

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- **Urban Transportation Challenges:**
  - **Amman suffers from severe congestion** due to a rapidly growing population and increasing vehicle ownership.
  - **Public transport infrastructure is underdeveloped**, leading to heavy reliance on private cars.
- **Key Considerations:**
  - Need for a **high-capacity, independent, and sustainable** transit solution.
  - **Reduced congestion and travel time** with **minimal environmental impact**.

117



118

118

## Situation Definition - Study Area

- ❑ The section under consideration is starting from Jamal Abdunnasser square, reaching to the Sport city Circle (which extends 1.844 Km ),this segment starts from point A to B



119

## Situation Definition

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### 6.1.1 The characteristics results of the traffic flow of the year of 2025 , before construction any system:

	<b>Forward Direction</b> (From Abdalnasser sq. to Sport city circle)	<b>Backward Direction</b> (From Sport city circle to Abdalnasser sq.)
<b>Traffic Volume</b>	7555	7670
<b>Average Travel Time</b>	254.9 sec	262.3 sec
<b>Distance</b>	1343 m	1343 m
<b>Average Travel Speed</b>	18.97 Km/hr	18.42 Km/h
<b>LOS</b>	F	F

120

## Problem Definition

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### Problem Statement:

- **Severe traffic congestion** due to rising population & vehicle ownership.
- **Inefficient public transport system** leads to high dependence on private cars.
- **Existing bus services lack reliability and capacity.**

### Key Objectives

1. **Reduce Traffic Congestion** – Shift commuters from private vehicles to public transit.
2. **Improve Travel Efficiency** – Provide **higher speeds** and **shorter travel times**.
3. **Enhance Passenger Experience** – Offer **modern, comfortable, and reliable transit**.
4. **Ensure Sustainability** – Reduce emissions and support eco-friendly urban development.
5. **Optimize Public Investment** – Long-term **cost efficiency** through **high-capacity transit**.

121

## Problem Definition- Measure of Effectiveness



### Service Quality & Performance

Availability  
Absolute Travel Time  
Reliability



### Passenger Experience

Comfort  
Convenience  
Safety & Security



### Operational & Network Efficiency

Area Coverage  
Frequency  
Capacity



### Economic & Financial Considerations

Investment Cost  
Operating Cost



### Environmental & Long-term Sustainability

Passenger Attraction  
System Impact  
Environmental Impact

122

## Search for Solutions

### Alternative 1: Bus Rapid Transit (BRT)

- **Features:**
  - Dedicated lanes to improve bus travel times.
  - **Lower initial investment**, easier to implement.
- **Drawbacks:**
  - **Requires road space**, which may worsen congestion.
  - **Limited scalability**
  - **Lower public appeal.**
  - **Station designs require significant urban modifications.**



123

## Search for Solutions

### Alternative 2: Monorail System

- **Features:**
  - **Elevated rail system** avoiding road congestion.
  - **High-speed and high-capacity transport.**
- **Drawbacks:**
  - **Higher upfront cost.**
  - **Longer construction time but greater long-term benefits.**



124



125

## Analysis of Performance

Factor	Existing Traffic (No BRT/Monorail)	After BRT Implementation	After Monorail Implementation
<b>Passenger Capacity</b> (Passengers Per Hour Per Direction)	N/A (Existing Road Traffic)	15,000	24,000 - 48,000
<b>Traffic Volume (Forward Direction)</b>	7,555 vehicles/hour	4,442 vehicles/hour	6,663 vehicles/hour
<b>Average Travel Speed</b>	18.97 km/h	13.27 km/h (slower)	19.92 km/h (faster)
<b>Impact on Road Congestion</b>	High congestion due to private vehicles	Increases congestion due to road lane reduction	Reduces congestion by shifting private car users to transit
<b>Road Space Required</b>	Full road access for vehicles	Reduces available lanes for private vehicles	Elevated structure, does not affect road space
<b>Public Perception</b>	Heavy reliance on private cars	Lower acceptance due to similarity to buses	More favorable due to reliability and modern appeal
<b>Long-Term Feasibility</b>	Not sustainable	Limited capacity & scalability	High-capacity, expandable system

126

## Evaluation of Alternatives

Measure of Effectiveness	Monorail	BRT	Higher Rated System
<b>Availability</b>	Very Good	Good	Monorail
<b>Absolute Travel Time</b>	Very Good	Good	Monorail
<b>Reliability</b>	Very Good	Good	Monorail
<b>Comfort</b>	Good	Poor	Monorail
<b>Convenience</b>	Good	Poor	Monorail
<b>Safety &amp; Security</b>	Good	Fair	Monorail
<b>Area Coverage</b>	Very Good	Very Poor	Monorail
<b>Frequency</b>	Very Good	Good	Monorail
<b>Investment Cost</b>	Poor	Good	BRT
<b>Operating Cost</b>	Good	Fair	Monorail
<b>Capacity</b>	Good	Poor	Monorail
<b>Passenger Attraction</b>	Very Good	Good	Monorail
<b>System Impact</b>	Very Good	Good	Monorail
<b>Environmental Impact</b>	Very Good	Very Poor	Monorail
<b>Durability</b>	Good	Poor	Monorail
<b>Efficient Transport Future</b>	Good	Poor	Monorail

127

## Choice of Project

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- **Preferred Alternative: Monorail System**
- **Reasons for Selection:**
  - **Higher long-term capacity.**
  - **Better operational efficiency.**
  - **Public perception favors modern rail-based transit.**

128

## Specification & Construction

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- **Proposed Monorail Route:**
  - **10.6 km corridor** from **Sweileh Terminal to Sport City.**

129

# *Transportation Engineering and Planning*

## Module | 2 | Introduction

### 2.2 |Urban transportation planning

*Dr. Hamza Mohammad Alkuime*

1

Urban and rural areas

2

## Urban Area Definition

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### ❑ Definition:

- **An urban area is a place within boundaries set by responsible agencies**, based on population and infrastructure development.

### ❑ Urban Area Categories:

- **Small Urban Areas** ( $5,000 < \text{Population} < 50,000$ )
- **Urbanized Areas** ( $\geq 50,000$  Population)

### ❑ Characteristics of Urban Areas:

- **High population density**
- **Well-developed infrastructure** (roads, utilities, public transport)
- **Diverse land use** (commercial, industrial, residential zones)
- **Strong economic and social activity**

3

## Definition of Urban and Rural Areas

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### *Urban areas*

Greater Tokyo Area, Japan, the world's **most populated urban area**, with about 38 million inhabitants



Image source: [https://en.wikipedia.org/wiki/File:Giza\\_area\\_at\\_dusk\\_from\\_Tokyo\\_Tower.jpg](https://en.wikipedia.org/wiki/File:Giza_area_at_dusk_from_Tokyo_Tower.jpg)

4

4

## Rural Area Definitions

- **Areas located outside officially designated urban boundaries**
- **Lower population density, typically less than 5,000**
- **Characteristics:**
  - Less developed infrastructure
  - More open land, agriculture, and natural landscapes
  - Limited public services and transportation
  - Primarily residential and agricultural economy



5

## Suburban Areas

- **Suburban areas are transitional zones between urban and rural areas.**
- Located **outside central cities** but still part of a metropolitan region.
- **Characterized by a mix of residential, commercial, and open spaces.**
- ☐ **Characteristics of Suburban Areas:**
  - **Moderate population density**, lower than urban centers but higher than rural areas.
  - **Predominantly residential**, with single-family homes and planned neighborhoods.
  - **Dependence on private vehicles**, with **limited public transportation options.**
  - **More open spaces** and lower levels of congestion compared to urban cores



6

# Road Classifications

8

## Road Classifications

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- Highways are classified based on:**
- Their *Location*** (*Urban, Rural*)
- Their *Function*** *in terms of traffic flow and accessibility*

9

## Highway Classification – Location-Based

---

Highways and streets are classified based on their location:

**Urban Roads**

- Serve areas **within cities and metropolitan regions**
- Facilitate **high traffic volumes, intersections, and mixed road users**
- **Urban roads focus on accessibility and multimodal use.**

**Rural Roads**

- Found **outside urban areas**, connecting towns, villages, and remote locations
- Typically have **lower traffic density** but support **higher speeds**
- **Rural roads prioritize mobility and long-distance travel efficiency**

10

---

**Urban**



**Rural**



11

# Functional Classification

12

## Functional Classification in Roadway Networks

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- ❑ Travel occurs through a network of **interdependent roadways** 🚗🗺️
- ❑ Each roadway segment moves traffic through the system towards destinations
- ❑ Functional classification defines the role of a roadway segment in traffic flow
- ❑ Roadways serve two primary travel needs:
  - Access to/egress from specific locations 🏠🏢
  - Travel mobility across longer distances 🚗➡️
- ❑ **Most roads provide a mix of both functions**

14

## Roadway Mobility Function

- **Limited access points** reduce entry and exit 🚧
- **Low travel friction** from vehicle **access/egress**
- **Designed for uninterrupted, high-speed movement** 🚗
- **Supports long-distance and regional travel**
- **Examples: Highways, freeways, expressways**

Extreme Example for Roadway Mobility Function



Aerial View of the Eisenhower (and Johnson) Tunnels along I-70, west of Denver, CO

There is no location that is immediately **"accessible"** to the roadway, thus the road roadway **entirely provides "mobility"**



View from Inside the Eisenhower Tunnel

16

15

## Roadway Accessibility Function

- **Frequent access points** allow easy entry and exit
- **Higher travel friction** due to **frequent stops**
- **Designed for local and short-distance trips**
- **Connects residential, commercial, and business areas**
- **Examples: Local roads,**

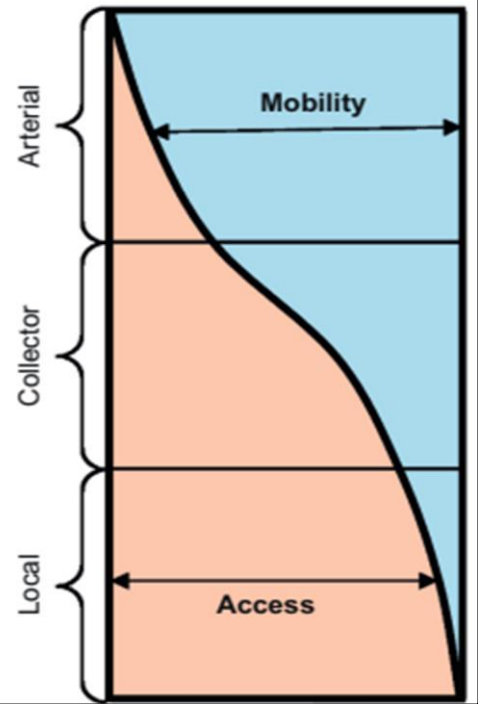
The roadway **entirely provides "accessibility"** and **offers almost nothing in terms of mobility**



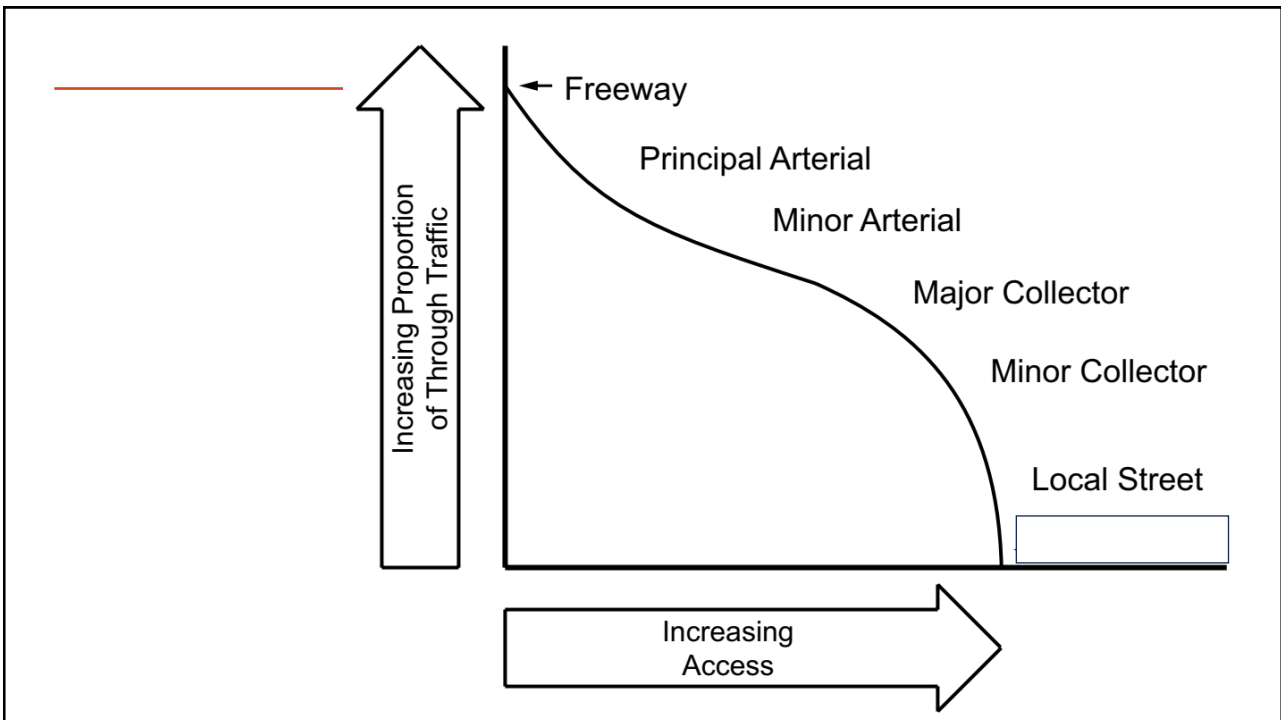
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## Road Functional Classifications

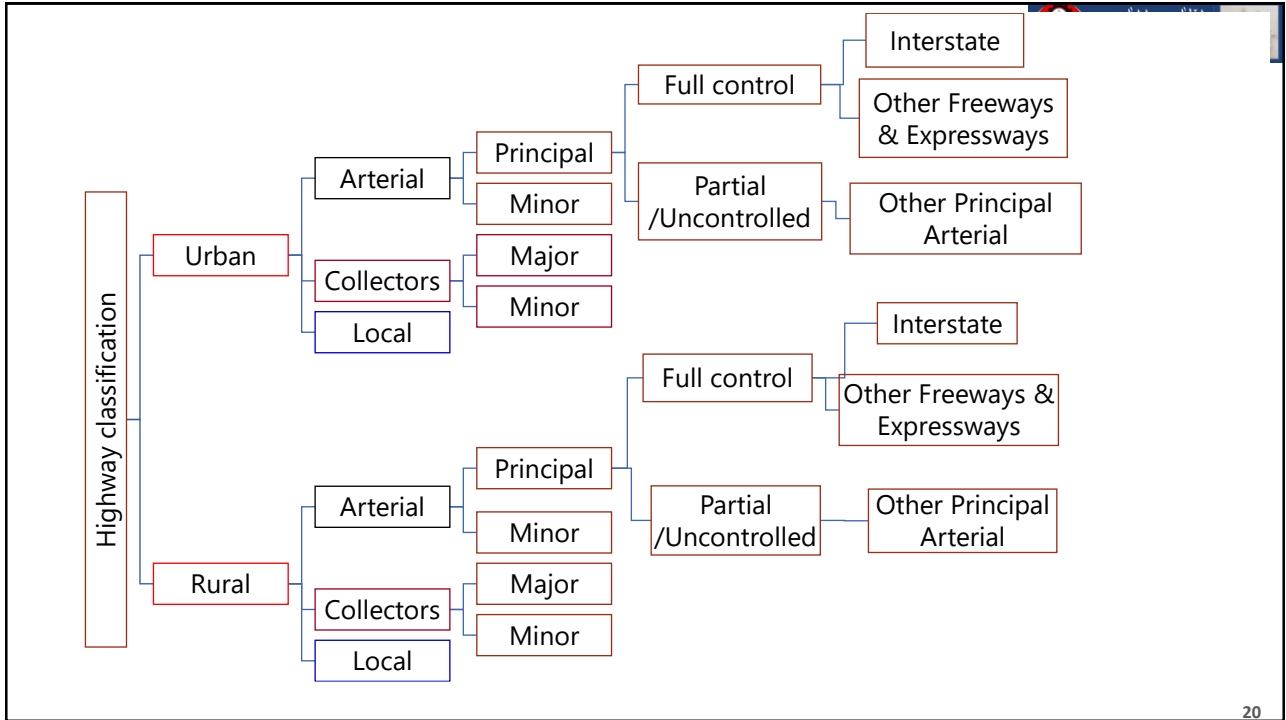
- Roads are classified based **on their role in mobility and access**
- Three main categories of functional classification:
  - Arterials** – High-speed, long-distance travel
  - Collectors** – Intermediate connection between Arterials and Locals
  - Local Roads** – Provide direct access to properties and neighborhoods



18




19




## Highway Location Classification

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Urban interstate



Rural two-lane highway

# Urban Transportation Planning

## Introduction

22

## Introduction to Urban Transportation Planning

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- **Urban transportation planning** involves evaluating and selecting **infrastructure solutions to support urban growth and mobility needs**.
- **Key drivers of urban transport planning:**
  - **New commercial & residential developments** (e.g., shopping malls, industrial parks).
  - **Expansion of key facilities** (e.g., airports, convention centers).
  - **Increased travel demand** from population and economic growth.
- ☐ Urban transportation planning is **divided into two-time horizons:**
  - **Short-Term Planning (1–3 Years)**
  - **Long-Term Planning (20-Year Horizon)**

23

## Short-Term Planning

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- ❑ Focuses on **optimizing existing infrastructure**.
- ❑ Improves **traffic flow** and **public transit operations**
- ❑ 1–3 Years
- ❑ Examples:
  - Traffic signal timing adjustments to improve intersection flow.
  - Carpooling programs to reduce congestion.
  - Bus route optimization and increased service frequency.

24

## Long-Term Planning - Examples

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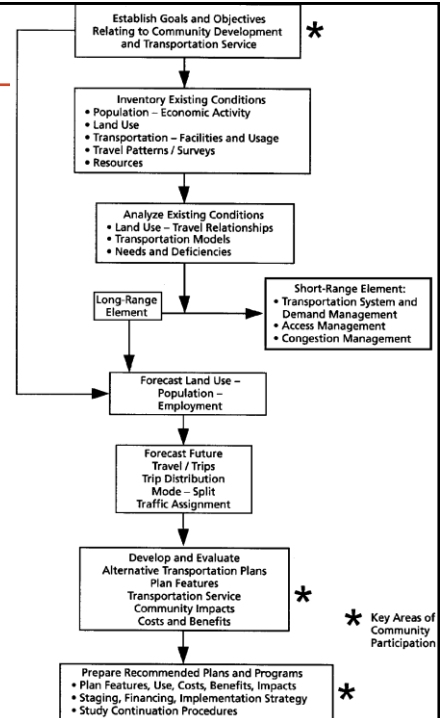
- ❑ Addresses **major infrastructure expansions and new projects**.
- ❑ Incorporates future growth projections and **long-term mobility needs**
- ❑ 20-Year Horizon
- ❑ Examples
  - New highway construction or freeway expansions.
  - Expansion of public transit systems (metro, BRT, high-speed rail).
  - Development of access roads to major commercial areas.

25

### Comprehensive Urban Area Transportation Planning Process

□ The planning process include:

1. Inventory of existing travel and facilities
2. Establishment of goals and objectives
3. Generation of alternatives
4. Estimation of project cost and travel demand
5. Evaluation of alternatives



28

# Urban Transportation planning in Jordan

Amman Queen Alia Light Rail Project - Pre-Feasibility Study

47

## Amman Queen Alia Light Rail Project - Pre-Feasibility Study

- ❑ The Ministry of Transport (the "Ministry") of the Hashemite Kingdom of Jordan has expressed an interest in obtaining support from the European Bank for Reconstruction and Development (the "EBRD" or the "Bank") for the preparation of a modernized and enhanced system of Light Rail Transit ("LRT")
- ❑ The Ministry has requested the Bank's assistance in establishing structured public transport services across the country through various interventions, including this Project. Through these interventions the Ministry would like to reduce traffic and congestions on roads, improve health and safety of the public as well as reduce pollution. The Project will be designed to address the lack of public transportation, especially from/to the airport by improving transport links with the airport and introducing institutional reform in the sector and introduction of public service contracts and a private sector operator, as feasible.

<https://www.ebrd.com/work-with-us/procurement/pn-47538.html>

48

## Amman Queen Alia Light Rail Project - Pre-Feasibility Study

- ❑ In order to identify EBRD's potential involvement in the Project, the Bank is seeking a consultant (the "Consultant") to provide an initial assessment of project rationale and outline feasibility, including an expert analysis of various technical considerations, route analysis and connectivity, investment requirements (rolling stock and infrastructure) and potential private sector involvement in the operation of the future LRT system.

<https://www.ebrd.com/work-with-us/procurement/pn-47538.html>

49

# Urban Transportation planning in Jordan

## Feasibility study on underground transport in Amman

50

### Feasibility study on underground transport in Amman

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- ❑ Jordanian authorities have launched a feasibility study with a Chinese engineering company for the development of an underground railway system in capital Amman, said a report.
- ❑ The study will determine whether establishing an underground railway system in Amman is possible and feasible
- ❑ "The Chinese company will look into the topography of Amman, its population and several other elements that determine whether such a project can be done or not



51

- 
- ❑ The proposal to establish a metro transit system in Amman seeks to **ease off traffic congestion in the capital** by providing commuters with transportation alternatives to using their vehicles.
  - ❑ “The proposed project should cover all of Amman’s district.
    - However, it remains only an idea until proven possible and feasible,” the official revealed.
    - “If proven feasible, GAM will not cover the cost of implementing the project, which will be executed by a private company after floating a tender,” the official added.
  - ❑ In addition, if the metro project was found feasible, it will be **implemented in parallel with the Bus Rapid Transit (BRT)**, said the official.

52

## Urban Transportation planning in Jordan

### Case Study on Air Pollution and CO<sub>2</sub> Emissions Reduction:

53

## Amman Bus Rapid Transit (BRT) System:

- *Case Study on Air Pollution and CO<sub>2</sub> Emissions Reduction:*
- This study discusses **how Amman's BRT system** aims to **tackle air pollution and improve mass public transportation** by introducing high-capacity buses operating on exclusive lanes.

**Bus Rapid Transit to Tackle Air Pollution, CO<sub>2</sub> Emissions, and Improve Mass Public Transportation**

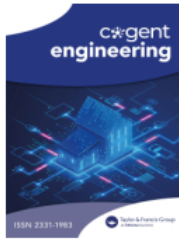
[https://www.c40.org/case-studies/bus-rapid-transit-to-tackle-air-pollution-co2-emissions-and-improve-mass-public-transportation/?utm\\_source=chatgpt.com](https://www.c40.org/case-studies/bus-rapid-transit-to-tackle-air-pollution-co2-emissions-and-improve-mass-public-transportation/?utm_source=chatgpt.com)

54

## Urban Transportation planning in Jordan

Traffic and environmental impacts of constructing and operating a BRT service: Case study in Amman, Jordan

55



Cogent Engineering

ISSN: (Print) (Online) Journal homepage: [www.tandfonline.com/journals/oaen20](http://www.tandfonline.com/journals/oaen20)

## **Traffic and environmental impacts of constructing and operating a BRT service: Case Study in Amman, Jordan**

Lina Shbeeb

[https://www.tandfonline.com/doi/full/10.1080/23311916.2023.2283316?utm\\_source=chatgpt.com](https://www.tandfonline.com/doi/full/10.1080/23311916.2023.2283316?utm_source=chatgpt.com)

56

## Urban Transportation planning in Jordan

Environmental and Social Impact Assessment Report for the Amman and Amman-Zarqa Bus Rapid Transit (BRT) Systems

57

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**Environmental and Social Impact Assessment  
Report for the Amman and Amman-Zarqa Bus  
Rapid Transit (BRT) Systems**

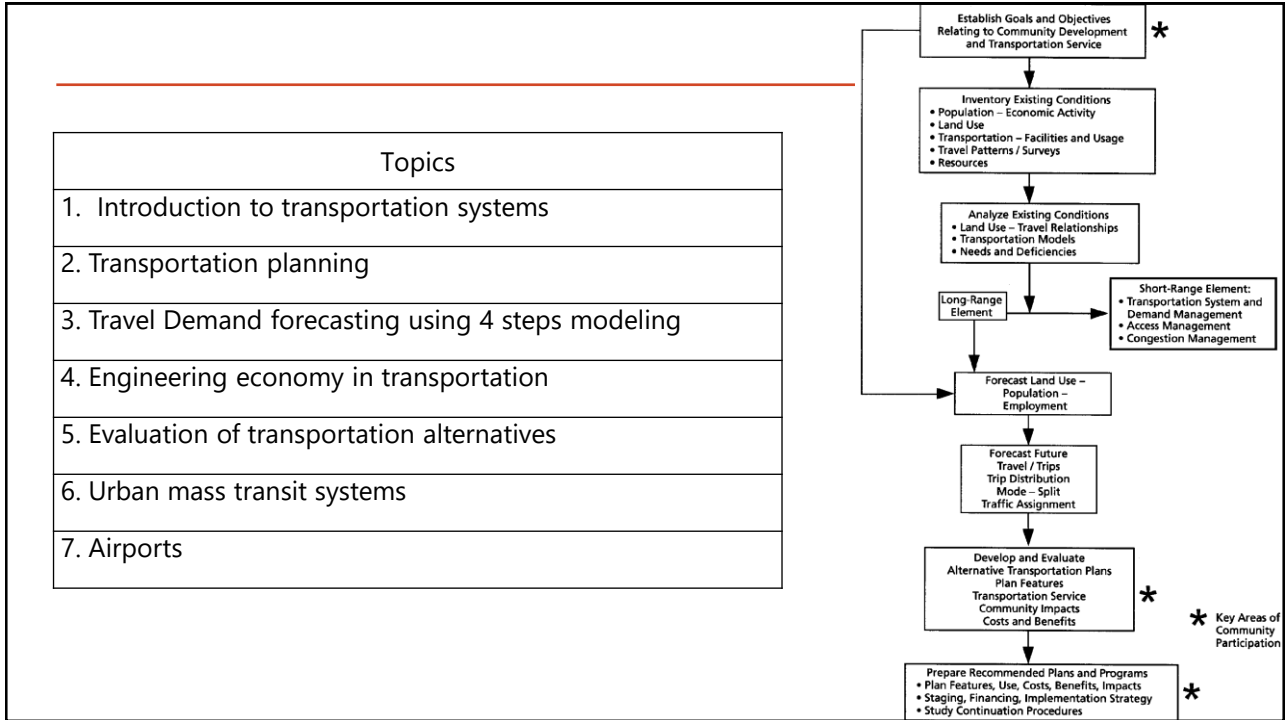
**Draft Final Report**  
November 2017

[http://www.ammanbrt.jo/contents/Articles/2020/4/20/%D8%AF%D8%B1%D8%A7%D8%B3%D8%A9%D8%AA%D9%82%D9%8A%D9%8A%D9%85%D8%A7%D9%84%D8%A3%D8%AB%D8%B1%D8%A7%D9%84%D8%A8%D9%8A%D8%A6%D9%8A\\_2017-11-07160320.pdf](http://www.ammanbrt.jo/contents/Articles/2020/4/20/%D8%AF%D8%B1%D8%A7%D8%B3%D8%A9%D8%AA%D9%82%D9%8A%D9%8A%D9%85%D8%A7%D9%84%D8%A3%D8%AB%D8%B1%D8%A7%D9%84%D8%A8%D9%8A%D8%A6%D9%8A_2017-11-07160320.pdf)

58

What Next ?

59



# Transportation Engineering and Planning

Module | 3 | Forecasting Travel in Urban Transportation Planning

## 3.1 | Travel Demand Forecasting: Definitions and terms

*Dr. Hamza Mohammad Alkuime*

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### Transportation Demand

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

2

## Capacity

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- Capacity refers to **a transportation facility's ability to accommodate a moving stream of people or vehicles within a given time period.**

3

## Mode

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### Definition:

- Mode refers to **a specific form of transportation that people or goods use to travel from one location to another.**

### Types of Transportation Modes:

- **Private Modes** – Cars, motorcycles, bicycles.
- **Public Transit** – Buses, trams, subways, commuter rail.
- **Non-Motorized** – Walking, cycling.
- **Freight Modes** – Trucks, cargo rail, shipping, air freight.
- **Air Transport** – Domestic and international flights.
- **Multimodal Transport** – A combination of two or more modes for a single trip (e.g., train-to-bus transfer).

4

## Performance Measures

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### ❑ Definition:

- Performance measures are **indicators used to evaluate how well a transportation system is functioning.**

### ❑ Key Performance Indicators (KPIs):

- **Average Speed** – Measures efficiency and congestion levels.
- **Reliability of Travel** – Predictability of trip durations over time.
- **Accident Rates** – Safety assessment of roadways and transport systems.
- **Traffic Volume** – Number of vehicles passing a point per hour.
- **Passenger Load Factor** – Measures public transit utilization.
- **Emissions Levels** – Environmental impact of transportation.

5

## Land Use

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### ❑ Definition:

- Land use refers to **how land is allocated** for residential, commercial, industrial, transportation, and recreational activities.

### ❑ Key Types of Land Use:

- **Residential** – Homes, apartments, and housing complexes.
- **Commercial** – Offices, shopping centers, and business districts.
- **Industrial** – Factories, warehouses, and logistics hubs.
- **Transportation** – Roads, railways, airports, and transit hubs.
- **Recreational/Open Space** – Parks, stadiums, and green areas.

### ❑ Importance in Transportation Planning:

- Influences **travel behavior and commuting patterns.**

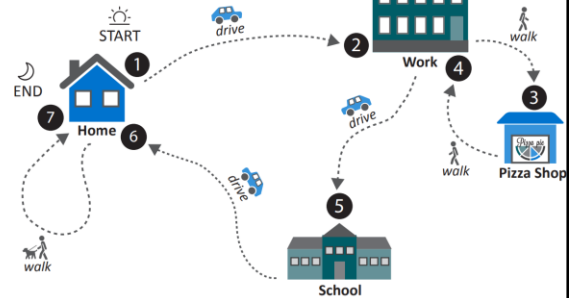
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## Trip

### □ Definition:

- A **trip** refers to a single movement of a person or vehicle **from an origin to a destination** using **a specific mode of transport**.
- It is the **basic unit of travel behavior analysis** in transportation planning.

### A Full Travel Day Example



7

## Socioeconomics

- Describes **social and economic** status and living conditions
- Focuses on **“what people have”** and **“how they live”**

### Key Variables:

- Income level , Education level. Occupation, Employment status
- Housing tenure (rent/own), Access to services (healthcare, transportation)

### □ Example:

Median household income: \$38,000  
 25% have a college degree  
 15% are unemployed

8

## Socioeconomics and Demographics

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### ❑ Socioeconomics

- Describes the **social and economic conditions** that shape people's lives, such as wealth, education, job status, and access to services.
- Reflects **how people live**, their **quality of life**, and their **resources**.
- Focuses on **"what people have"** (e.g., income, housing) and **"how they live"** (e.g., access to healthcare or transport).

### ❑ Demographics

- Refers to the **statistical characteristics** that define a population's structure and identity.
- Helps understand **"who" the people are** based on quantifiable traits.
- Used to segment populations by key traits for planning and policy-making.

9

## Key Socioeconomic Indicators: **what people have** and **"how they live"**

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- ❑ **Income Level** : Measures how much money a household earns annually.  
*Example: A family earns \$38,000 per year (median income).*
- ❑ **Education Level** : Highest level of education completed by individuals.  
*Example: 25% of residents hold a college degree.*
- ❑ **Occupation** : Type of job or profession people engage in.  
*Example: Common occupations include teacher, mechanic, and cashier.*
- ❑ **Employment Status** : Describes whether individuals are working, seeking work, or not employed.  
*Example: 15% of adults are unemployed in the area.*
- ❑ **Housing Tenure** : Indicates if housing is owned or rented by the occupant.  
*Example: 60% of households rent their homes, 40% own.*
- ❑ **Access to Services** : Evaluates how easily people can reach essential services.  
*Example: 80% of homes are within 1 km of a bus stop and clinic.*

10

## Key Demographic Indicators:

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- ❑ **Age** : Measures how old individuals are; helps identify needs for schools, jobs, or elderly care.  
*Example: 22% of the population is under 18.*
- ❑ **Gender** : Indicates the distribution of males, females in a population.  
*Example: 49% male, 51% female.*
- ❑ **Marital Status** : Classifies individuals as single, married, divorced, widowed, etc.  
*Example: 60% are married; 10% are widowed.*
- ❑ **Household Size**: Counts the number of people living together in one housing unit.  
*Example: Average household size is 3.2 people.*
- ❑ **Birth/Death Rates** :Tracks population change over time due to natural increase or decrease.  
*Example: Birth rate = 12.5 per 1,000 people/year.*
- ❑ **Population Density**: Refers to the number of people living per unit of land area (e.g., per km<sup>2</sup>).  
*Example: Urban area density = 4,000 people/km<sup>2</sup>.*

11

## Urban Transportation Planning

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- Focuses on **developing, improving, and maintaining city transport infrastructure.**
- Includes **roadways, public transit, pedestrian and bicycle facilities.**

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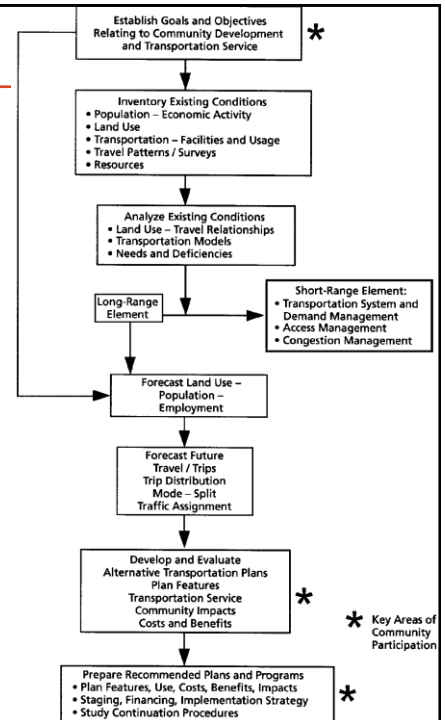
## Planning-Level Demand Estimation

### □ Purpose:

- Forecast **future travel demand based on** land use, economic activity, and population growth.
- Predict **traffic volumes on highways and transit networks.**

### □ Outcome:

- Helps transportation planners **determine future infrastructure needs.**
- Identifies **congested areas and necessary upgrades** for improved service levels.



15

## Travel Forecasting Process

### □ Key Elements:

- **Defining the Study Area**
- **Defining Traffic Analysis Zones (TAZs)**
- **Data Collection (Inventories)**
- **Analysis of Existing Conditions & Calibration**
- **Forecast of Future Travel Demand**
- **Analysis of the Results**

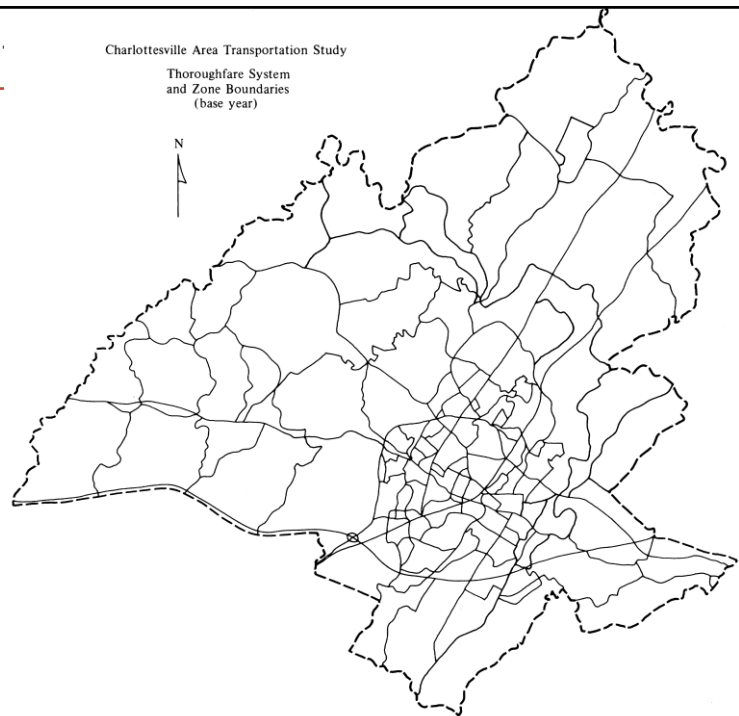
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# Study Area

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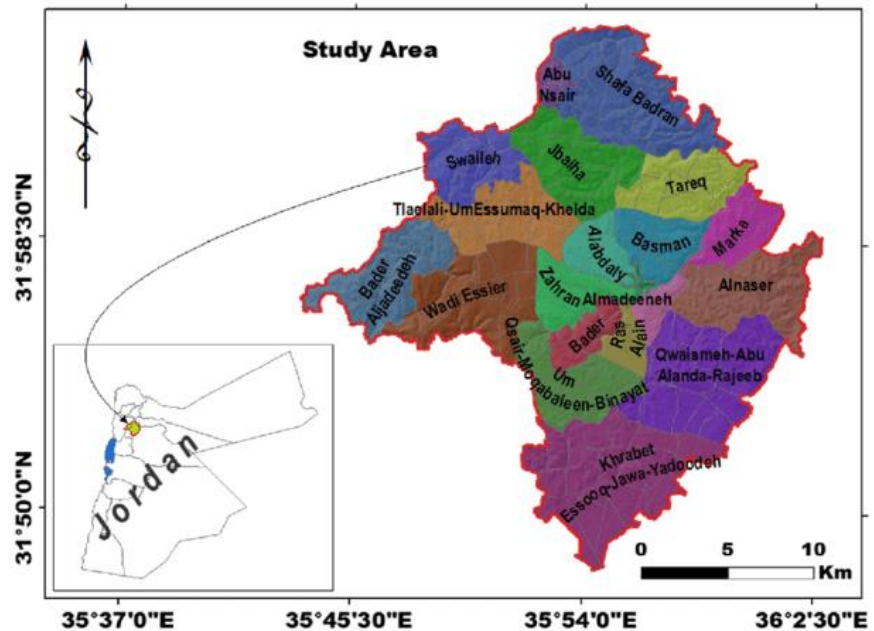
## Study Area in Transporta

- ❑ A **study area** is the **geographic region** where transportation data is collected and analyzed to plan and forecast travel demand.
- ❑ It defines the boundaries for transportation studies and includes various land uses, road networks, and traffic patterns.



18

## Amman study area



19

### Key Characteristics of a Study Area

- ❑ **Defined Before Data Collection** : The study area is established **before beginning surveys and traffic analysis** to **ensure relevant data** is captured.
- ❑ **Covers Various Levels of Planning**
  - **National Level** – Analyzes interstate and country-wide transportation systems.
  - **Regional Level** – Examines transportation links between multiple cities or metropolitan areas.
  - **Urban Level** – Focuses on city-wide traffic, public transit, and road infrastructure.
- ❑ **Includes Multiple Traffic Analysis Zones (TAZs)** : The study area is subdivided into **Traffic Analysis Zones (TAZs)** to organize travel data efficiently.

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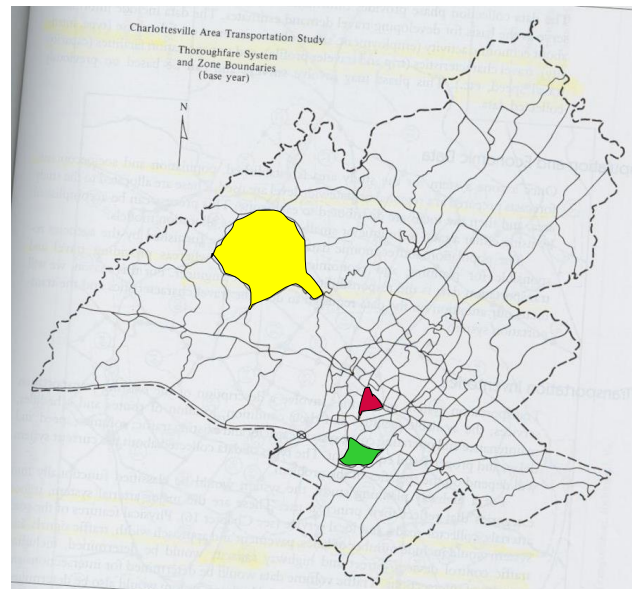
# Traffic Analysis Zones (TAZs)

21

## Traffic Analysis Zones (TAZs)

### □ Definition:

- A **Traffic Analysis Zone (TAZ)** is a **geographic unit** used in transportation planning and travel demand modeling to analyze traffic patterns, land use, and trip generation.



22

## Why Are TAZs Needed?

### ❑ Dividing the Study Area into Manageable Units

- Large study areas need to be **broken down into smaller zones** to simplify data collection and analysis.
- TAZs help **segment regions based on travel characteristics and land use patterns.**

### ❑ Accurate Travel Demand Forecasting

- Helps estimate **trip generation, trip distribution, mode choice, and route assignment.**

### ❑ Capturing Land Use and Socioeconomic Characteristics

- Ensures **homogeneous socioeconomic zones** for precise travel behavior analysis.

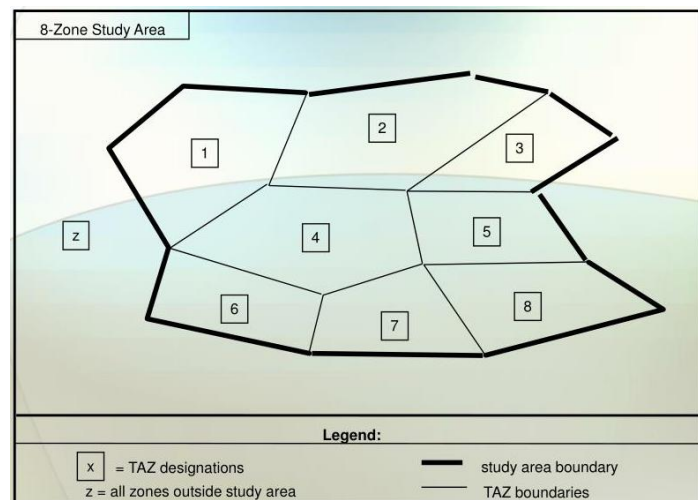
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## Types of Traffic Analysis Zones (TAZs)

❑ Traffic Analysis Zones (TAZs) are categorized **based on their location relative to the study area.**

### ❑ Two Main Types of Zones:

- **Internal Traffic Zones** – Located **within the study area.**
- **External Zones** – Represent areas **outside the study area.**



24

## Internal Traffic Zones

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### ❑ Definition:

- Internal traffic zones are **within the defined study area** and contribute to local traffic generation and attraction.

### ❑ Characteristics:

- Contain **residential, commercial, and industrial areas**.
- Generate **intra-zonal** and **inter-zonal** trips.
- Used to **analyze local travel behavior**.

25

## External Zones

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- External zones represent areas **outside the study area boundary** but still influence travel demand.

### ❑ Characteristics:

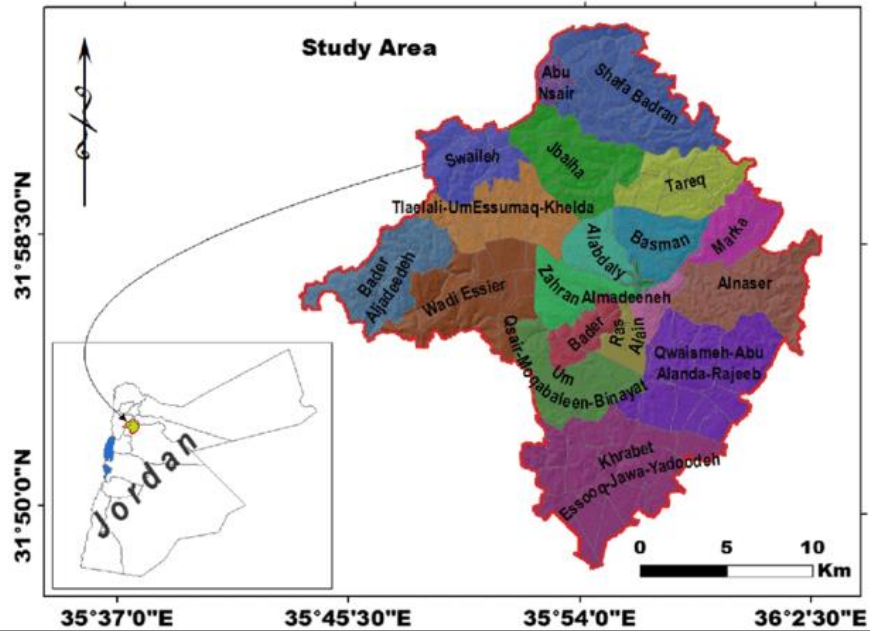
- Capture **trips entering and exiting the study area**.
- Represent **regional traffic flow and intercity connectivity**.
- Used for **highway planning and long-distance travel forecasting**.

### ❑ Examples:

- A **highway connection to a neighboring city**.
- An **airport outside the urban study area** attracting passenger trips.

26

# Amman Zones



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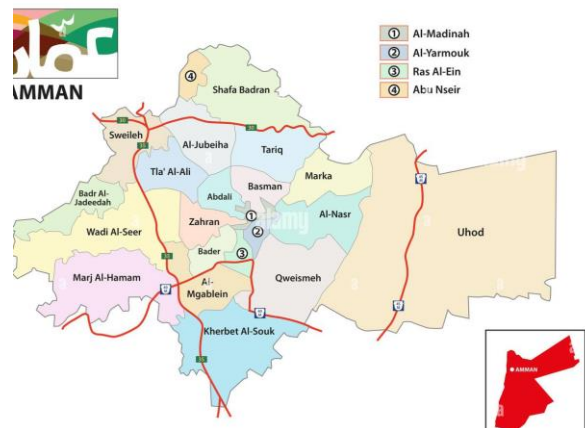
## Guidelines for Defining Traffic Zones – Amman City Examples

- ❑ **1. Socioeconomic Characteristics Should Be Homogeneous**
- **Guideline:** Each traffic analysis zone (TAZ) should include areas with similar income levels, employment patterns, and land use to ensure accurate travel behavior analysis.
- ❑ **Why This Matters:**

  - Homogeneous zones allow for **more accurate trip generation and mode choice modeling.**

- **Example in Amman:**

  - **Abdoun** can be a separate TAZ due to its high-income residential and commercial characteristics.
  - **Al-Wehdah** should be a separate TAZ as it consists of a lower-income community with distinct travel patterns.



28

## Guidelines for Defining Traffic Zones

### ❑ 2. Intrazonal Trips Should Be Minimized

- **Guideline:** A zone should be small enough that most **trips leave the zone** rather than **occurring within it**.

### ❑ Why This Matters:

- Minimizing intrazonal trips allows for **more effective modeling of interzonal travel demand**.
- Supports **accurate calibration** of trip distribution and assignment models.

### • Example in Amman:

- **Al-Rabieh** should be a separate zone because most residents **commute to work outside the neighborhood**.
- **Queen Alia International Airport** should not be part of a large regional zone, as most trips originating from the airport **leave the area** rather than staying within.



29

## Guidelines for Defining Traffic Zones

### ❑ 3. Physical, Political, and Historical Boundaries Should Be Used Where Possible

- **Guideline:** Zones should align with major **natural barriers, administrative boundaries, or historically significant areas** to ensure logical divisions.

### ❑ Why This Matters:

- Ensures **consistency with official maps and census data**, making data collection and integration easier.

### • Example in Amman:

- **Jabal Al-Luweibdeh** should be a separate TAZ due to its historical and cultural significance, distinct from surrounding commercial areas.



30



# Guidelines for Defining Traffic Zones

## 6. Zones Should Use Census Tract Boundaries Where Possible

- **Guideline:** Using census tracts allows planners to align transportation and demographic data for better forecasting.

### Why This Matters:

- Enables **direct integration** of census-based socioeconomic and demographic statistics.
- Reduces the need for **data interpolation or estimation** between non-matching zones.

### Example in Amman:

- **Al-Madina Al-Munawara Street** can be divided based on existing census districts rather than arbitrary street cuts.



# Guidelines for Defining Traffic Zones

## 7. The Total Number of Zones Should Not Be Too Large to Overwhelm Computer Resources

- **Guideline:** The number of TAZs should be optimized to balance accuracy and computational efficiency.

### Why This Matters:

- Excessive zones increase **data processing time** and can strain **computing resources**.

### Example in Amman:

- A city-wide study should **limit zones to around 1,000 for a population of 1 million**, meaning districts like **Tla' Al-Ali and Khalda** may be merged into one TAZ rather than split into excessive subdivisions.



## Agency Guidelines for TAZ Selection

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- ❑ It may be necessary to exercise some judgment in determining the total number of zones
- ❑ **Agencies** may provide some guidance for achieving these criteria
  - An average of 1,000 people/zone for smaller areas
  - A ratio of between 0.9 and 1.1 for productions to attractions trips
  - No more than 10,000 trips should be generated for a given zone
  - A ratio of labor force (the sum of employed and unemployed persons) to employment must be at least 0.80

35

# Transport Network

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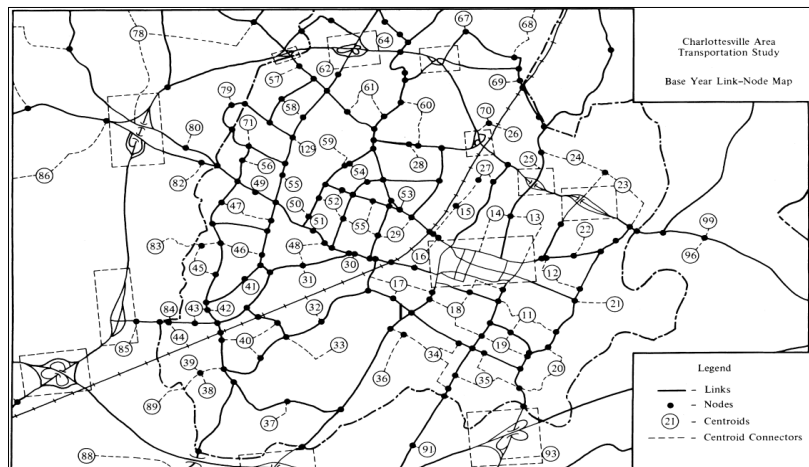
## Transport Network – Overview

- ❑ A transport network is a **system of interconnected routes, terminals, and transport modes that facilitate the movement of people and goods.**
- ❑ Types
  - Road Network
  - Rail Network
  - Air Transport Network
  - Water Transport Network
  - Public Transit Network.

37

## Road Network

- ❑ A road network consists of **interconnected roads** and supporting infrastructure designed for vehicular and pedestrian movement.



38

## Main Components of a Road Network

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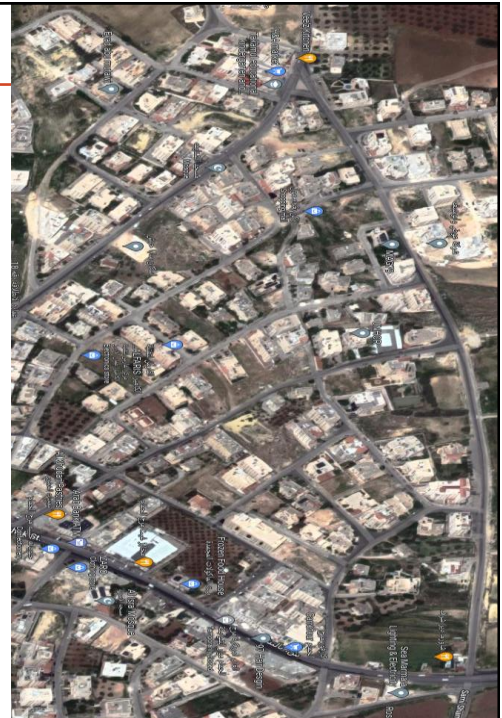
1. **Nodes** – Key points where roads intersect or connect.
2. **Links** – Road segments connecting different locations.
3. **Terminals** – Points where trips start, stop, or transfer between routes.
4. **Centroids** – Represent the central location of traffic zones.
5. **External Stations** – Entry and exit points for intercity and regional traffic.

39

## Nodes in a Road Network

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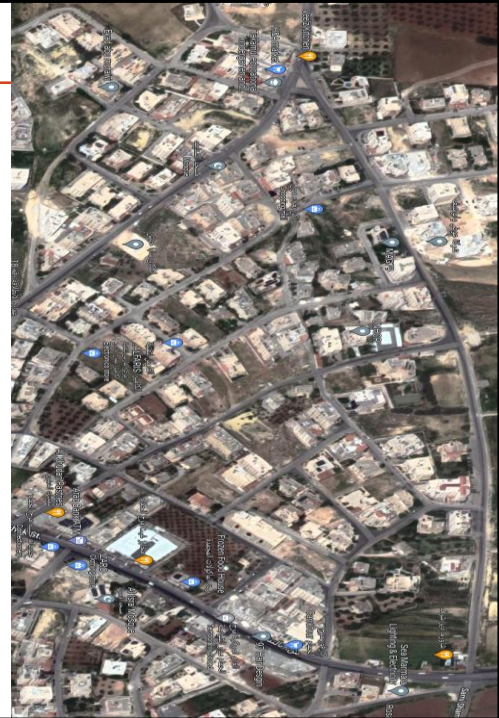
- Nodes are **points where movement begins, ends, or changes direction in the road network.**
  - **The end point of a link**
  - **location** where a link changes direction, capacity, width, or speed
- ☐ **Types of Nodes:**
1. **Intersections** – Points where multiple roads meet.
  2. **Roundabouts** – Circular junctions for continuous traffic flow.
  3. **Traffic Signals** – Control vehicle movement at junctions.
  4. **Interchanges** – Multi-level connections between highways.



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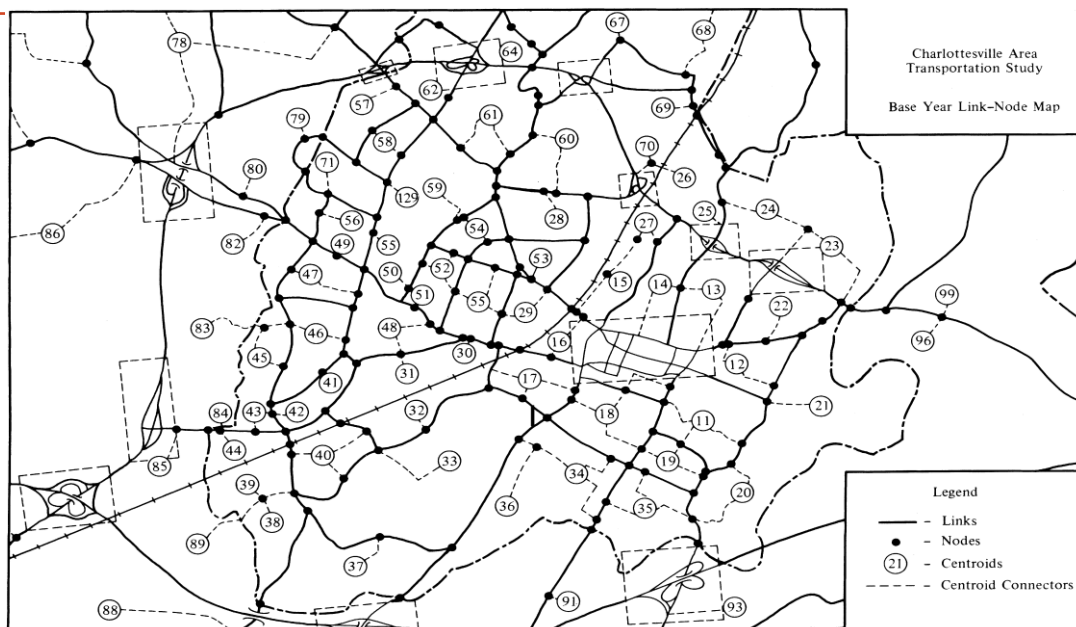
## Links in a Road Network

- Links are **the road segments that connect nodes** and **allow movement within the network**.
  - A portion of the highway system that can be **described by its capacity, lane width, and speed**
- ☐ **Types of Links:**
- 1. Expressways and Highways** – High-speed roads for long-distance travel.
  - 2. Arterial Roads** – Connect major urban centers.
  - 3. Collector Roads** – Distribute traffic between local and arterial roads.
  - 4. Local Streets** – Provide access to homes, businesses, and small roads.

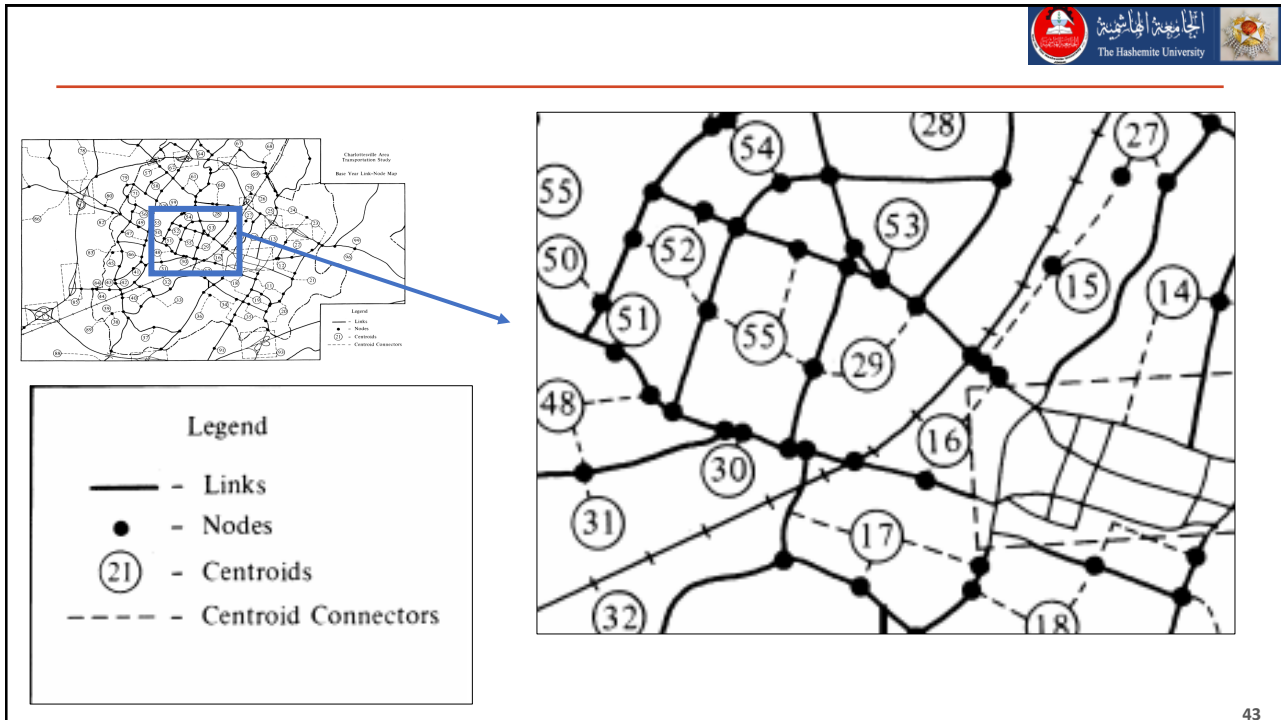


41

## A computerized network of the existing street and highway system



42



43

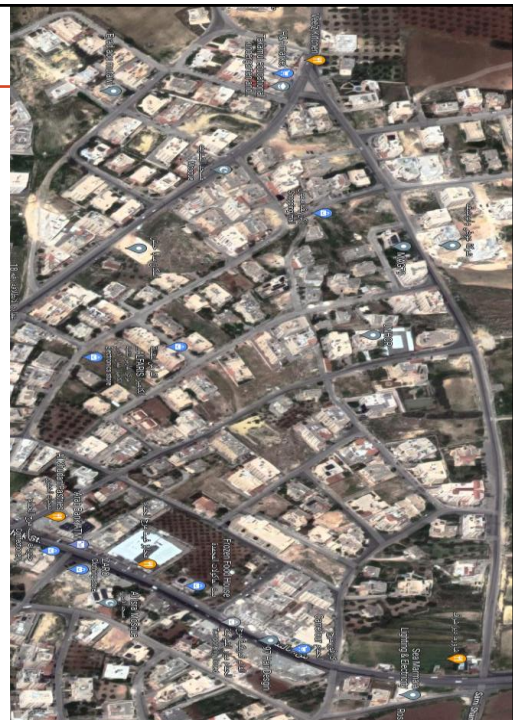
43

## Terminals in a Road Network

- **Terminals** are locations where **traffic begins, ends, or changes between routes.**

### Types of Terminals:

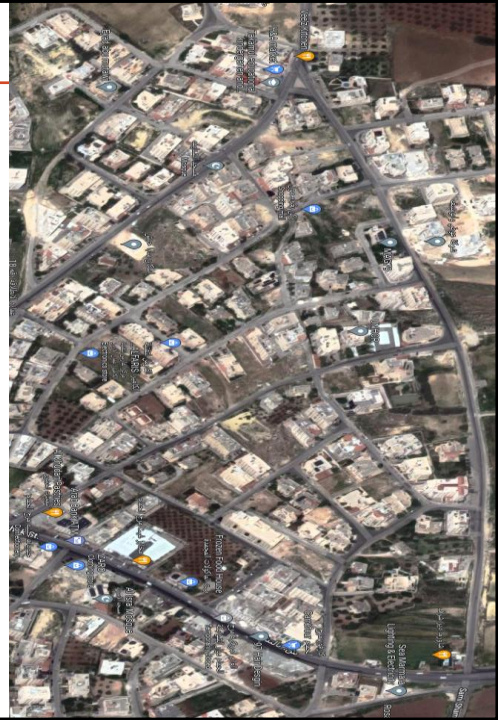
1. **Bus Stations and Depots** – Serve public transportation users.
2. **Parking Lots and Park-and-Ride Areas** – Provide vehicle storage.
3. **Freight Terminals** – Handle goods transportation.



44

## Centroids in a Road Network

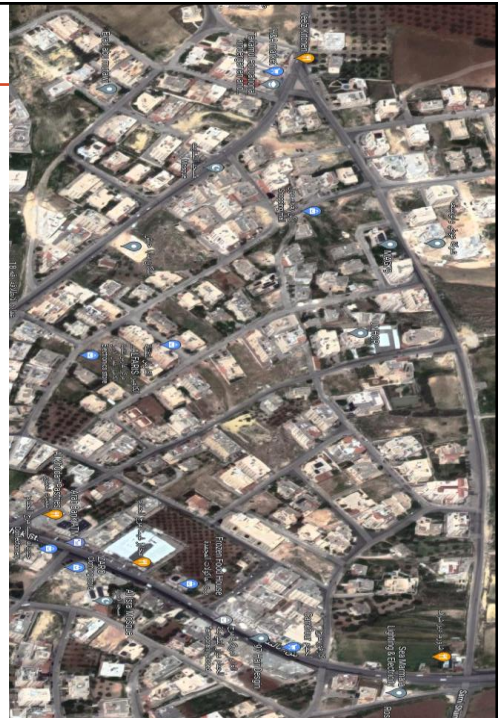
- Centroids represent **the central location of a traffic analysis zone (TAZ)**, summarizing all trips generated in that zone.
  - The location within a zone where trips are considered to **begin and to end**
- ☐ **Functions:**
- Simplifies traffic modeling** by aggregating travel demand.
  - Represents trip origins and destinations** within a zone.
  - Connected to the road network through centroid connectors.**



45

## Centroid Connectors

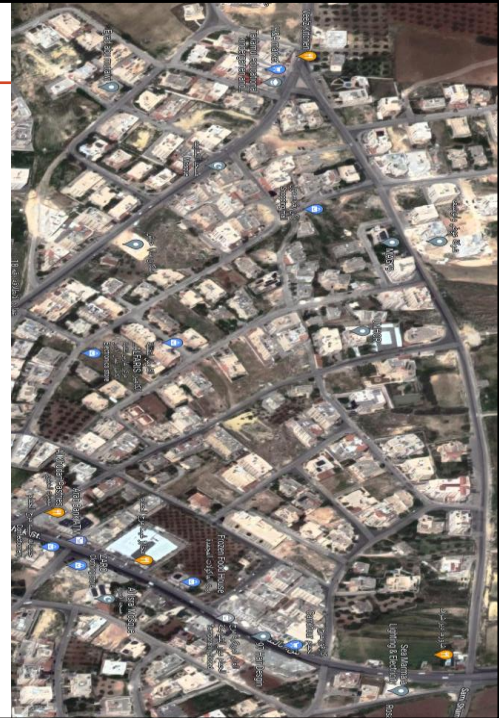
- Centroid connectors** are **imaginary links** that connect centroids to the actual road network.



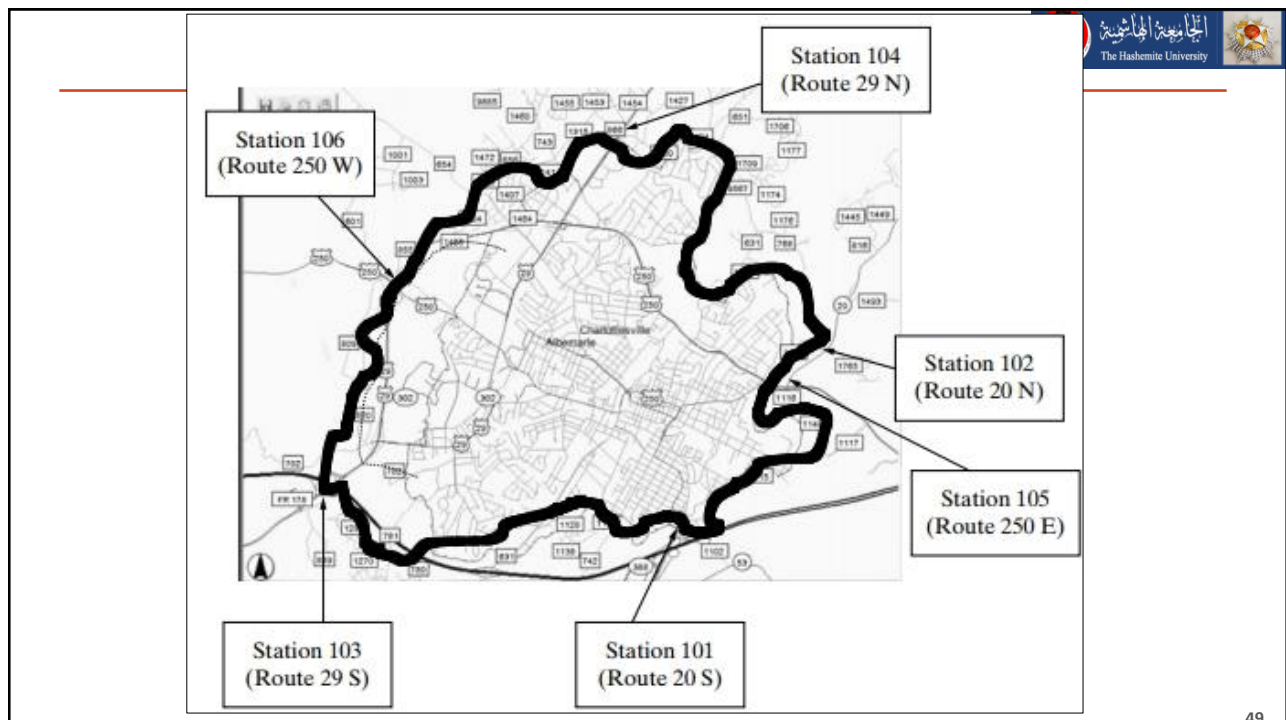
46

## External Stations in a Road Network

- External stations are **entry and exit points** for vehicles moving between the study area and external regions.
- **Types:**
- Highway Entry/Exit Points** – Connecting cities or regions.
  - Border Crossings** – Regulating international travel and trade.
  - Airports and Seaports** – Handling long-distance transportation.



48



49

# Transportation Engineering and Planning

Module | 5 | Forecasting Travel in Urban Transportation Planning

## 3.2 | Data Collection (Inventories)

*Dr. Hamza Mohammad Alkuime*

1

### Data Collection

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- **Definition:** The data collection phase provides **essential information** about a city's demographics, land use, economic activity, and transportation infrastructure.
- **Purpose:** To **develop accurate travel demand estimates**

2

## Types Collected data

---

### 1. Economic Activity:

1. **Employment Levels:** Understanding the workforce size and distribution **helps predict commuting patterns.**
2. **Business Activity:** Data on commercial operations, including sales volumes and service industries, **indicate areas with high attraction rates for trips.**
3. **Income Levels:** Household income **influences travel behavior, mode choice, and trip frequency.**

### 2. Land Use Data:

1. **Type and Intensity:** Identifying residential, commercial, industrial, and mixed-use **areas provides insight into trip generation and attraction.**

### 3. Travel Characteristics:

1. **Trip Purpose:** Categorizing trips by purpose (e.g., work, education, shopping) **aids in understanding travel motivations.**
2. **Traveler Profiles:** Demographic data, such as age, gender, and vehicle ownership, **help in modeling travel behavior.**
3. **Mode of Transport:** Information on whether travelers use private vehicles, public transit, walking, or cycling is **essential for mode choice analysis**

3

## Data Collection Methods

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### Two Main Types of Data are Collected:

- **Primary Data (Travel Surveys):** Data directly gathered through **surveys, interviews, or field observations specifically designed for the study.**
- **Secondary Data:** **Pre-existing information obtained** from sources such as land use databases, demographic records, road network inventories, and transportation system reports.

4

# Data Collection (Inventories)

## Travel Surveys

5

### Travel Surveys in Travel Demand Forecasting – Overview

---

- Travel surveys **collect data on passenger and goods movements** to **forecast future travel demand**.
- Provide essential input for **trip generation, trip distribution, mode choice**, and **traffic assignment models**.

6

## Types of Travel Surveys Related to Travel Demand Forecasting

---

- Household Travel Survey
- Origin and Destination (O-D) Survey
- Mode Choice Survey
- Traffic Volume Survey
- Speed and Delay Survey
- Parking Survey
- Public Transit Ridership Survey
- Freight and Goods Movement Survey
- Intermediate Public Transport (IPT) Survey
- Pedestrian Survey
- Workplace Travel Survey
- Intercept Survey
- License Plate Survey
- GPS and Mobile Tracking Survey
- Trip Purpose Survey

7

# Data Collection (Inventories)

## Household Travel Survey

8

## Travel Survey Methods

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- **Face-to-Face Interviews:**  
Households are visited, and surveyors **collect data in person**, providing detailed responses **but requiring significant time and resources**.
- **Telephone Surveys:**  
Randomly selected households **provide travel data via phone calls**, offering a **faster and cost-effective method** **but potentially introducing response bias**.
- **Online and App-Based Surveys:**  
Digital surveys and mobile applications **record real-time travel behavior**, offering an **efficient and convenient approach** **but requiring internet access**.

9

## Advanced Travel Survey Methods

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- **GPS and Mobile Tracking:**  
Utilizes GPS-enabled devices or smartphones to **collect accurate, location-based travel data**, **offering high precision** **but raising privacy concerns**.
- **Travel Diaries:**  
Participants **manually record daily or weekly trips**, providing **detailed insights** into travel behavior **but requiring significant respondent effort**.


10

## Data Collected in Household Travel Surveys

- **Household Characteristics:** Number of members, age, income, and vehicle ownership information.
- **Trip Purpose:** Reasons for travel such as work, education, shopping, medical visits, leisure, and business activities.
- **Mode of Transport:** Modes used including car, bus, metro, bicycle, walking, rideshare services, and train.
- **Trip Timing and Frequency:** Information on peak and off-peak travel periods and trip durations.
- **Trip Distance and Routes:** Origin and destination points of trips and the major corridors utilized.
- **Travel Costs and Constraints:** Expenses related to fuel, transit fares, parking, and accessibility challenges.

11

## Home Interview Survey Data Collection

Travel Day _____ and Date <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> Sample Number <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/>										 NORTH CENTRAL TEXAS COUNCIL OF GOVERNMENTS HOME INTERVIEW SURVEY										<b>Section IV: Administrative</b> A. Household Telephone Number _____ B. Interviewer _____ C. Telephone Contacts (If Any) _____ Date Time Purpose/Duration _____ D. Personal Contacts In Household: Date Time Titled To/Comments _____ E. Completed Interview Submitted: Date By _____ I Certify That All Information On This Form Is Correct And True. Signature of Interviewer _____ F. If Interview Submitted Incomplete Interviewer's Reason: _____ Date Initials _____ Supervisor's Comments: _____ Date Initials _____ G. First Edit: Fail Pass Date Initials _____ H. Final Edit: Fail Pass Date Initials _____ I. Coding Complete Date Initials _____																																																																																																																								
<b>Section I: Household Data</b> A. Sample Address _____ House Number, Street Name, Apt. No. _____ City/Town _____ County _____ Zip Code _____ B. Structure Type _____ C. Number of People Living at this Address _____ D. Number of People Age 5 and Over Living at this Address _____ E. Number of Out-of-Area Visitors Staying at this Address _____ F. Number of Passenger Cars, Vans, and Pickups Available for Use _____ G. Household Income (Do Not Ask Until Interview Is Complete) _____										<b>Section II: Data on Persons Age 5 and Over</b> <table border="1"> <thead> <tr> <th>Person Number</th> <th>✓ If Interviewed</th> <th>Relation To Head</th> <th>Age</th> <th>Sex</th> <th>Licensed to Drive?</th> <th>Occupation</th> <th>Industry</th> <th>Worked on Travel Day?</th> <th>Made Trips on Travel Day?</th> <th>Made Other Trips on Travel Day?</th> </tr> </thead> <tbody> <tr> <td>01</td> <td><input checked="" type="checkbox"/></td> <td>Head</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>02</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>03</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>04</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>05</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>06</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>07</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>08</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>09</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> <tr> <td>10</td> <td><input type="checkbox"/></td> <td></td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td><input type="checkbox"/> M <input type="checkbox"/> F</td> <td>1 YES 2 NO</td> <td></td> <td></td> <td>1 YES 2 NO 3 Interviewer</td> <td>1 YES 2 NO</td> <td>1 YES 2 NO</td> </tr> </tbody> </table>										Person Number	✓ If Interviewed	Relation To Head	Age	Sex	Licensed to Drive?	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12

# Household Travel Survey

Case Study: National Household Travel Survey (NHTS) – United States

13

## National Household Travel Survey (NHTS) – Overview

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- **NHTS** is the **official U.S. travel behavior survey**, conducted by the **Federal Highway Administration (FHWA)**.
- Collects **detailed data** on household travel patterns, trip characteristics, and mode choices.
- Analyzes **how, where, and why people travel** across different regions.
- Monitors **commuting trends** and **transportation mode shifts** over time.

<https://nhts.oml.gov/>

14

## NHTS surveys

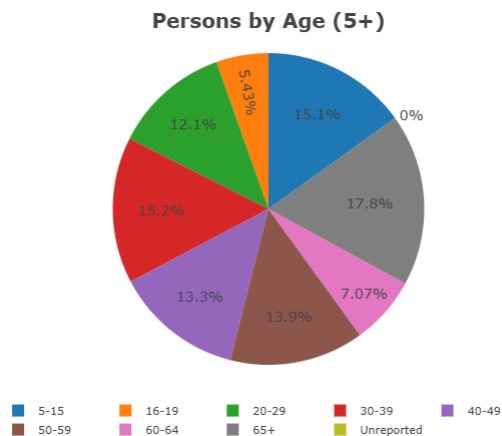
- **Geographic Coverage:** Nationwide survey across **all U.S. states.**
- **Data Collected:**
  - **Trip purpose** (work, education, shopping, leisure).
  - **Mode of travel** (car, public transit, walking, cycling).
  - **Trip distance and duration.**
  - **Time of day travel patterns.**
  - **Household characteristics** (income, vehicle ownership).
- **Survey Methods:**
  - **Online & phone interviews** (since 2017).
  - **GPS and mobile tracking (future NextGen NHTS 2024).**

<https://nhts.oml.gov/>

15

## Key Findings

- **Largest Age Group:** Individuals aged **65 and over** represent the highest share at **17.8%** of the surveyed population.
- **Middle-Age Groups:** Ages **30–39** (15.2%), **40–49** (13.3%), and **50–59** (13.9%) each account for a significant portion.
- **Youth Segment:** Ages **5–15** constitute **15.1%**, reflecting a strong presence of school-aged travelers.
- **Young Adults:** Ages **20–29** represent **12.1%**, a key group likely to use diverse travel modes.
- **Lower Reporting:** Only **5.43%** belong to the **16–19** age group, possibly due to data collection timing or survey participation rates.
- **Unreported Data:** A small portion of responses was **unreported**, but it appears very minimal.

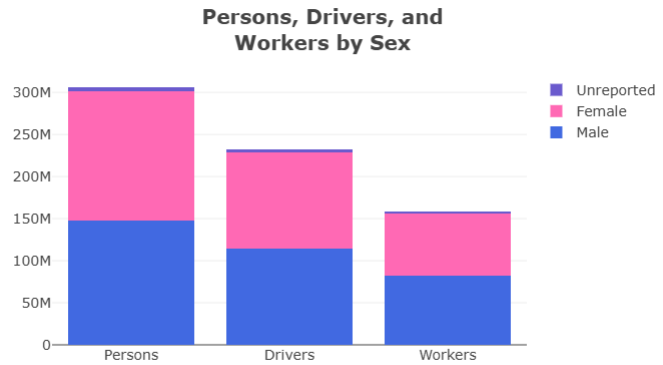


<https://nhts.oml.gov/>

16

## Key Findings: Persons, Drivers, and Workers by Sex

- **Population Composition:** The total population includes a nearly even distribution of **males and females**, with a small share **unreported**.
- **Driver Distribution:** Among licensed drivers, **males slightly outnumber females**.
- **Worker Distribution:** The number of **male workers** exceeds **female workers**, reflecting differences in workforce participation.
- **Higher Male Representation:** Males consistently represent a higher share among drivers and workers compared to their share in the overall population.
- **Female Representation:** Females are well-represented in all categories but show a slight drop in the workforce group compared to the persons group.

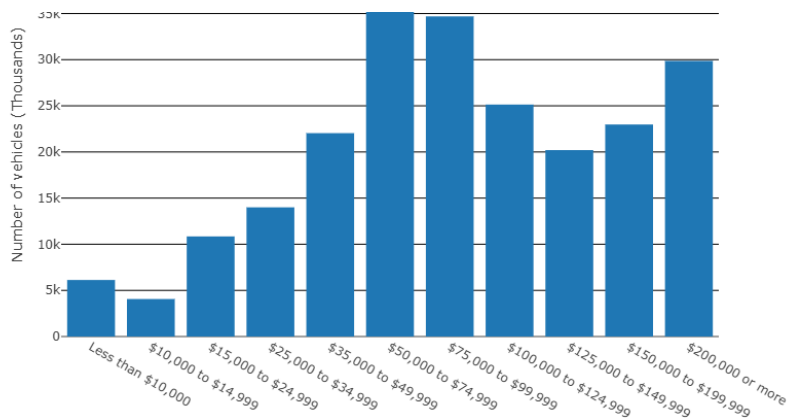


<https://nhts.oml.gov/>

17

## Key Findings: Vehicle Ownership by Household Income

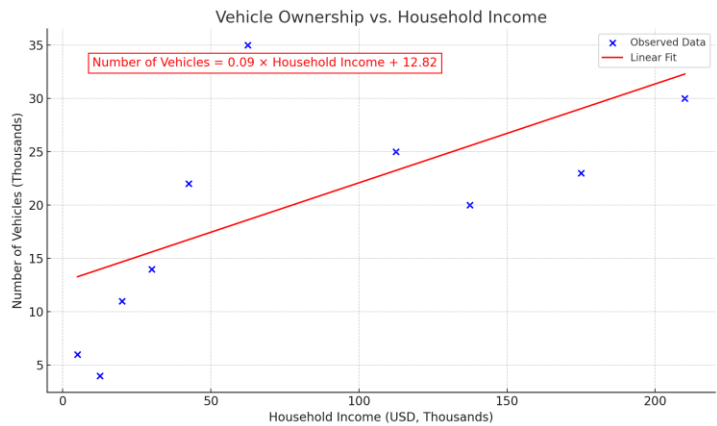
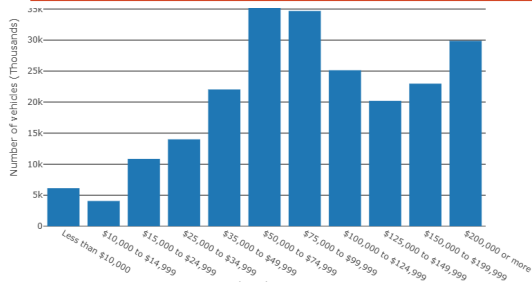
- **Middle-Income Households:** Households earning **\$35,000 to \$74,999** report the highest number of vehicles.
- **Vehicle Ownership Peaks:** The **\$50,000–\$74,999** income group shows the greatest vehicle ownership overall.
- **High-Income Contribution:** Households earning **\$200,000 or more** also report a very high number of vehicles, close to peak levels.
- **Lower Ownership at Low Incomes:** Households earning **less than \$10,000** or **\$10,000–\$14,999** have the fewest vehicles.



<https://nhts.oml.gov/>

18

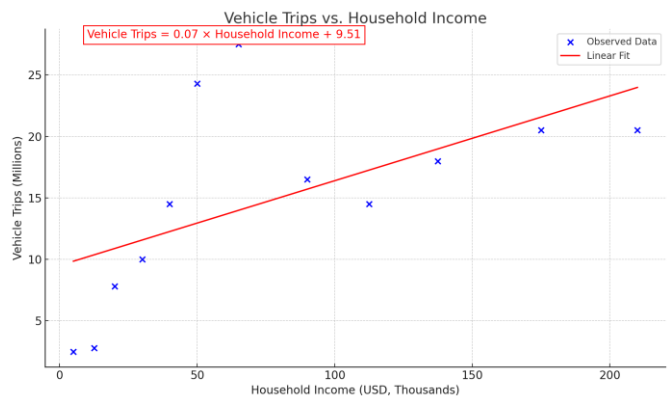
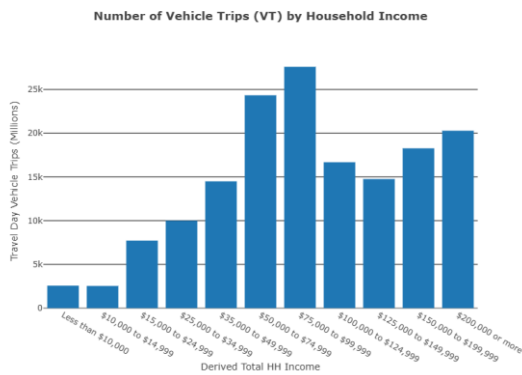
## Key Findings: Vehicle Ownership by Household Income



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19

## Key Findings: Vehicle Trips by Household Income

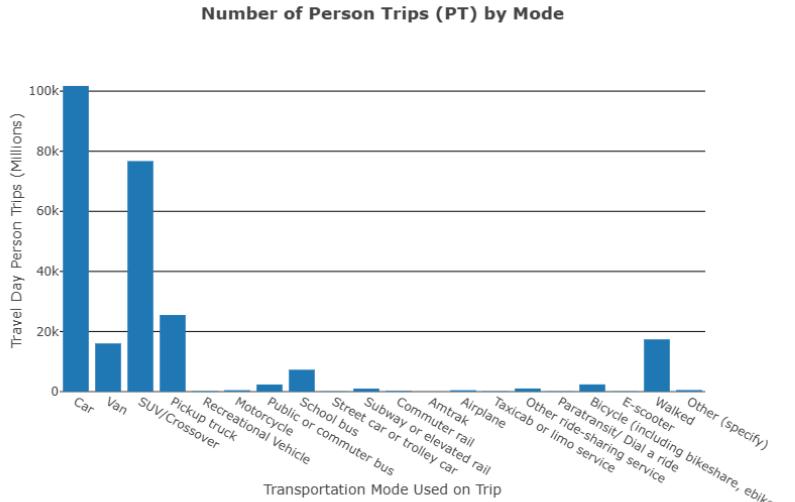


<https://nhts.oml.gov/>

21

## Key Findings: Number of Person Trips by Mode

- **Car Travel Dominates:** Cars are the **most widely used mode**, accounting for over **100 million person trips** daily.
- **SUVs and Crossover Vehicles:** The **second-highest mode** is **SUVs/Crossovers**, followed by **pickup trucks** and **vans**.
- **Low Use of Public Transit:** Modes such as **public buses**, **subways**, and **commuter rail** show **significantly fewer trips** compared to private vehicles.
- **Walking Is Significant:** **Walking trips** are notably high, with nearly **20 million person trips** daily.



<https://nhts.oml.gov/>

34

# Data Collection (Inventories)

Origin and Destination (O-D) Survey

38

## Origin and Destination (O-D) Survey – Overview

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- An **Origin and Destination (O-D) Survey** collects data on **where trips begin (origin) and end (destination)**.
- **Purpose:**
  - Understand **how people and goods move** within a study area.
  - Identify **congestion hotspots and alternative routing needs**.

39

## Methods of Conducting an Origin-Destination (O-D) Survey

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- **Roadside Interview Surveys:**  
Directly question drivers at selected checkpoints; provide **real-time trip data** but may **disrupt traffic flow**.
- **License Plate Surveys:**  
Record vehicle plates at multiple locations to track **movement patterns**; useful for studying **highway and arterial road usage**.
- **Household Travel Surveys:**  
Collect detailed **O-D trip data** from residents; offer insights into **daily travel behavior** and **modal choices**.

40

## Methods of Conducting an Origin-Destination (O-D) Survey

- **GPS and Mobile Data Tracking:**  
Use smartphones or in-vehicle systems to analyze **real-time movement**; highly accurate but raises **data privacy concerns**.
- **Public Transport O-D Surveys:**  
Conduct surveys at transit hubs to help **optimize transit routes** and **improve schedules**.
- **Big Data Analytics (CCTV, Toll Records, Smart Cards):**  
Analyze toll booth, traffic camera,; efficient for **large-scale studies** but requires **advanced data processing**.

41



**2002 Onboard Transit Survey**

The San Diego Association of Governments, and your transit operators, want your help to improve transit service by answering the questions below and returning this form before you get off the bus. All responses are confidential. Please fill out this form each time you get one. Thank you.

PLEASE ANSWER THESE QUESTIONS FIRST

<p>1. Where are you coming from?</p> <p>1. Home                      4. Shopping 2. Work                      5. Recreation/visit friends 3. School                    6. Other (specify: _____)</p> <p>2. What is the address of that place? (Specify street name AND cross street OR address)</p> <p>Street No.    Street Name _____ Nearest Cross Street    City _____</p>	<p>3. What is the zip code where you live? _____</p> <p>4. Where are you going?</p> <p>1. Home                      4. Shopping 2. Work                      5. Recreation/visit friends 3. School                    6. Other (specify: _____)</p> <p>5. What is the address of that place? (Specify street name AND cross street OR address)</p> <p>Street No.    Street Name _____ Nearest Cross Street    City _____</p>
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## Survey

6. Where did you get on THIS bus?  
(Specify street name AND cross street OR address) \_\_\_\_\_

7. How did you get to THIS bus?  
1. Transferred from bus route    5. Drove alone  
2. Transferred from trolley        6. Carpooled, then parked  
3. Transferred from Coaster      7. Was dropped off  
4. Walked \_\_\_\_\_ blocks      8. Other (specify: \_\_\_\_\_)

8. Where will you get off THIS bus?  
(Specify street name AND cross street OR address) \_\_\_\_\_

9. After you get off THIS bus, will you...  
1. Transfer to bus route    5. Drive alone  
2. Transfer to trolley        6. Carpool (ride with others)  
3. Transfer to Coaster      7. Be picked up  
4. Walk \_\_\_\_\_ blocks      8. Other (specify: \_\_\_\_\_)

10. Did you have a car that you could have used today instead of the bus?    1. Yes    2. No

11. How did you pay to use THIS bus?  
1. Transfer slip    3. Monthly pass  
2. Cash            4. Other (specify: \_\_\_\_\_)

12. How often do you ride the bus?  
\_\_\_\_\_ days a week    9. Less than one day per week

13. Are you:    1. Male    2. Female

14. Do you consider yourself:  
1. Hispanic                      3. Asian (non-Hispanic)  
2. White (non-Hispanic)    4. African American (non-Hispanic)  
5. Other (specify: \_\_\_\_\_)

15. What is your age? \_\_\_\_\_

16. What is the total yearly income of all the people in your home?  
1. Under \$10,000                      5. \$40,000 - \$49,999  
2. \$10,000 - \$19,999                    6. \$50,000 - \$59,999  
3. \$20,000 - \$29,999                    7. \$60,000 or more  
4. \$30,000 - \$39,999

17. How do you rate transit service in your area?  
1. Good                      2. Average                      3. Poor


18. How many vehicles are available for use by all the people in your home? \_\_\_\_\_ vehicles

19. Have you previously filled out this form for THIS bus route?  
1. Yes    2. No

20. Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

42

## Origin and Destination (O-D) Survey



**TRIMET**  
RIDERSHIP SURVEY

*To help us plan better service, please tell us about your **ONE-WAY** trip. Fill out this form even if you have already received one before, or rarely use TriMet. When finished, place the form in the envelope near the door, or you may return it by postage-paid mail.*

**This One-Way Trip**

**1. Where did you come from on this trip?** *(check one best answer)*

Home     Personal business     Visiting friends/relatives  
 Work     Shopping     Medical appointment  
 School     Other: \_\_\_\_\_  
 Recreation: \_\_\_\_\_

**2. Where was that located?** *(see question 1)*  
*(Complete address & city OR street/cross street & city OR landmark.)*  
*(circle one)*  
 NE SE NW SW  
 Street: N S E W \_\_\_\_\_  
 Nearest Cross Street: \_\_\_\_\_  
 City: \_\_\_\_\_ Zip Code: \_\_\_\_\_

**3. How did you get to the stop where you got on this bus?** *(check one best answer)*

Walk \_\_\_\_\_ # blocks     Transferred from MAX  
 Drove     Dropped off by someone  
 Transferred from bus#: \_\_\_\_     Other: \_\_\_\_\_

**4. Where was that bus stop located?**

**11. Did your employer or school pay for any portion of your fare?**

No     Yes

**12. What is the major reason you are using the bus for this one-way trip?** *(check one best answer)*

I do have a car but prefer to use TriMet.  
 I don't have a car because I prefer to use TriMet.  
 I don't have a car available for me to use.  
 I don't drive or don't know how to drive.

**13. If transit service were not available, how would you make this kind of trip?** *(check one best answer)*

Use a car     Bicycle  
 Walk     I would not make this trip  
 Ride with a friend     Other: \_\_\_\_\_  
 Use a taxi

**About You**

**14. How many trips have you taken on a TriMet bus/MAX/streetcar in the last month?** *(count each direction as one trip)*

0 or 1     13 to 29

43

## Key Data Collected in an O-D Survey

- **Trip Origin and Destination Locations** – Start and end points of travel.
- **Trip Purpose** – Work, education, shopping, leisure, freight, etc.
- **Mode of Travel** – Car, bus, train, cycling, walking.
- **Trip Duration and Distance** – Total travel time and length of trip.
- **Time of Travel** – Peak and off-peak hour distributions.
- **Route Choice** – Highways, arterial roads, or alternative streets used.

44

## Origin Destination Matrix

		DESTINATIONS													
		Dellwig	Frintrop	Beding...	Gersch...	Borbe...	Schön...	Bochold	Berge...	Vogelh...	Altene...	Karnap	Katern...	Stopp...	Altene...
ORIGINS	Dellwig	5726	1363	1119	1201	2019	571	1290	1520	511	298	414	126	158	589
	Frintrop	1440	5046	1658	320	1840	961	855	446	161	134	177	78	120	285
	Bedingrade	1116	1828	4202	345	1932	1586	1095	549	235	206	50	81	227	344
	Gerschede	1334	320	378	1561	1450	252	773	740	260	98	40	40	58	341
	Borbeck-Mitte	1993	1847	1992	1553	9041	3563	4662	1964	885	668	509	236	365	1516
	Schönebeck	588	1028	1704	271	3971	7046	2558	795	407	147	48	67	258	397
	Bochold	1579	977	1434	977	5182	2902	10563	2258	1386	953	296	422	673	2800
	Bergeborbeck	1849	536	653	761	2157	719	2176	4499	1224	866	686	308	367	1452
	Vogelheim	438	156	196	193	746	276	1183	1131	3371	1892	826	559	440	2057
	Altenessen-Nord	334	137	236	103	701	134	771	875	1761	9628	2739	2057	1313	7004
	Karnap	314	192	58	50	324	68	253	537	797	2811	5928	777	294	2196
	Katernberg	145	55	73	39	282	82	395	305	719	2072	718	11935	3303	3299
	Stoppenberg	192	153	326	57	367	221	586	357	363	1489	395	3390	11426	4385
	Altenessen-Süd	752	269	289	281	1293	363	2908	1402	2238	7106	2366	3370	4388	21729
	Nordviertel	715	215	328	252	991	498	2311	1334	919	1786	1035	1489	2375	6408
	Altendorf	522	461	831	376	1943	1383	3894	877	592	680	344	360	649	1818
	Frohnhausen	431	365	494	292	1254	1138	1625	542	503	439	208	274	450	1244
Holsterhausen	389	313	462	133	986	1014	1335	642	486	700	325	478	792	1987	
Fulerum	21	20	60	52	93	165	107	31	45	60	18	56	50	336	

<https://www.tomtom.com/products/origin-destination-matrix-analysis/>

# Transportation Engineering and Planning

Module | 3 | Forecasting Travel in Urban Transportation Planning

## 3.3 | Introduction to Four-Step Model

*Dr. Hamza Mohammad Alkuime*

1

### Transportation Demand

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

2

## Transportation Demand: Nature and Analysis

- **Transportation demand is a derived demand**
- People travel **not just to move**, but **to fulfill other purposes** (e.g., reaching school, work, or services)
- Demand arises **from the need to participate in activities, not from the movement itself**
- Therefore, two key aspects of **travel demand analysis** are:
  - **Land Use**
  - **Trip Purpose**

3

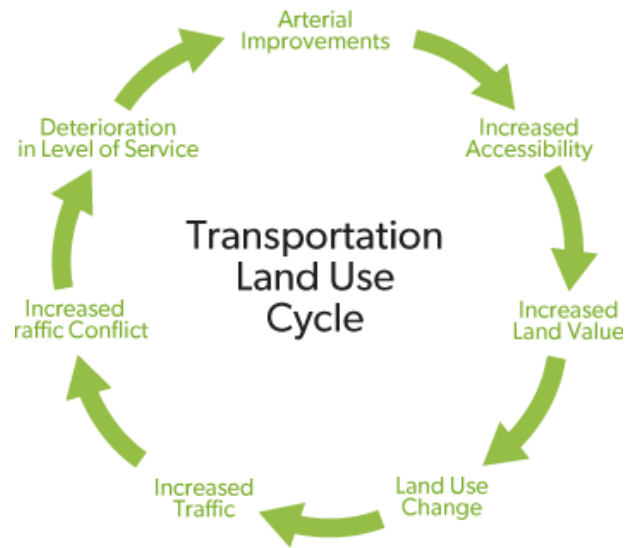
## Factors That Affect Transport Demand

Demographics	Economics	Prices	Transport Options	Service Quality	Land Use
Number of people (residents, employees and visitors).	Number of jobs	Fuel prices and taxes	Walking	Relative speed and delay	Density
	Incomes	Vehicle taxes & fees	Cycling	Reliability	Mix
Incomes	Business activity	Road tolls	Public transit	Comfort	Walkability
Age/lifecycle	Freight transport	Parking fees	Ridesharing	Safety and security	Connectivity
Lifestyles	Tourist activity	Vehicle insurance	Automobile	Waiting conditions	Transit service proximity
Preferences		Public transport fares	Taxi services	Parking conditions	Roadway design
			Telework	User information	
			Delivery services	Social status	

4

## Transportation Demand: Land-Use Relationship

- The relationship between land use and transportation is **cyclical**, not one-way
- Changes in land use** influence transportation **needs and demand**
- These transportation changes then **affect land-use patterns** again
- This interdependence creates a continuous **feedback loop**
- Cycle stages include:**
  - Arterial improvements → Increased accessibility
  - Higher land value → Land-use change
  - Increased traffic → Traffic conflicts
  - Deterioration of level of service → Need for improvements

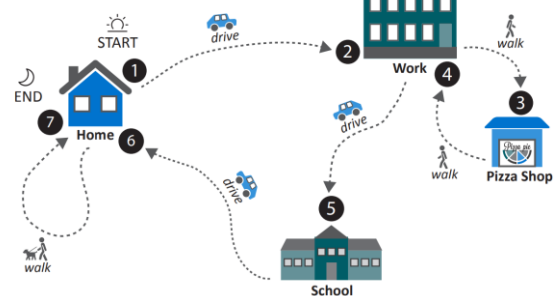


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## Trip Definition

- A **trip** is an outward **movement from an origin to a destination**
- Trip purposes** vary, such as going to work, school, shopping, or leisure
- Each individual may make **multiple trips per day**, forming a **full travel chain**
- It is the **basic unit** used in modeling and measuring **travel demand**

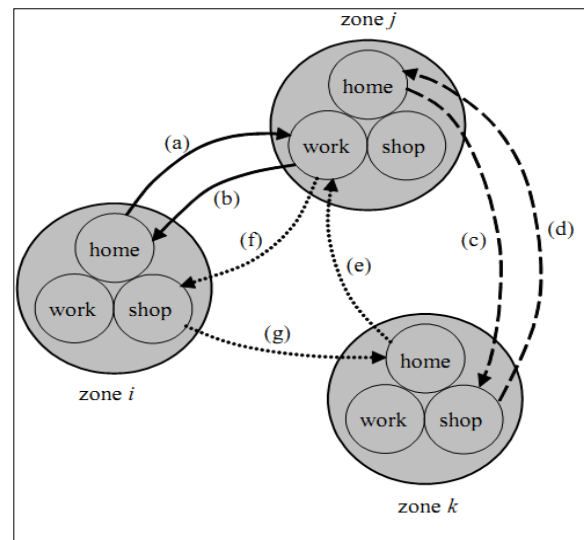
A Full Travel Day Example



6

## Trip Purpose Categories

- **1. Home-Based Work (HBW)**
  - Trips between **home** and the **workplace** of the traveler
  - Example: commuting from home to office and back
- **2. Home-Based Other (HBO)**
  - Trips between **home** and **non-work destinations** (e.g., school, shops, recreation)
  - Includes purposes like shopping, dining, or visiting family
- **3. Non-Home Based (NHB)**
  - Trips that **do not begin or end at home**
  - Example: traveling from office to restaurant, or from a store to a friend's house



7

## Influence of Trip Purpose on Travel Behavior

- **Travel behavior is shaped by the purpose of the trip**, influencing decisions and travel patterns
- **Work Trips:**
  - Involve a **limited set of routine decisions**
  - **Fixed destination and schedule** (e.g., daily commute to office)
  - Mode and route are often **pre-selected and rarely change**
- **Recreation Trips:**
  - Characterized by **greater flexibility and spontaneity**
  - Decisions include **whether to go, where to go, when, and how**
  - More influenced by personal preference and external factors (e.g., weather, mood)

8

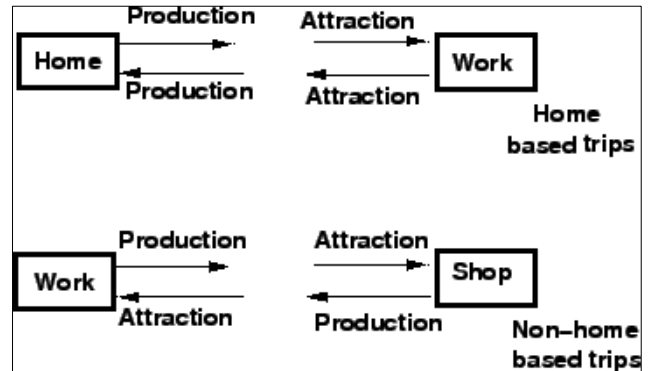
## Trip Types

- **Trip Production**

- Defined as the **origin** or starting point of a trip
- **Home is the production point** for all home-based trips
- For **non-home-based trips**, the **first trip origin** (e.g., from work) is labeled as the production point

- **Trip Attraction**

- Defined as the **destination** or endpoint of the trip
- Common attractions include **work, school, shops, or leisure locations**
- Any trip that **does not start at home** is classified based on its **destination as an attraction**



- **From Diagram:**

- Home → Work = **Production** → **Attraction**
- Work → Shop = **Production** → **Attraction** (non-home-based)
- Shop → Home = **Production** → **Attraction**

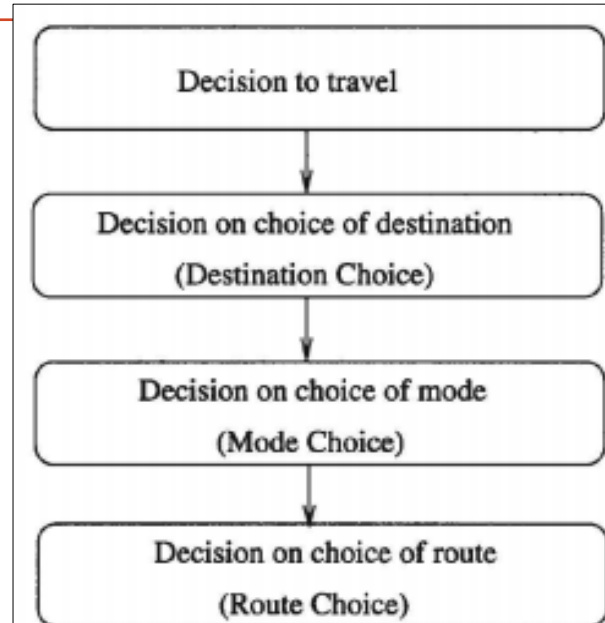
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Trip-maker travel decisions

10

## Trip-Maker Travel Decisions

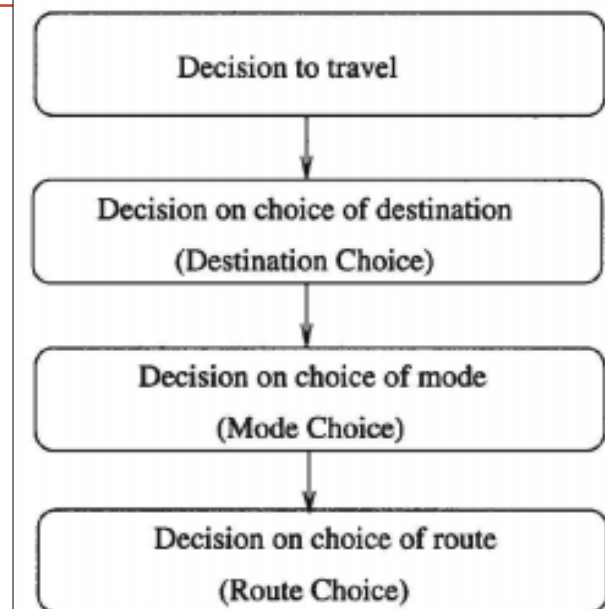
- Trip-making involves a **sequence of decisions** made by the traveler
- These decisions influence **when, where, how, and along which path** travel occurs
- The process can be classified into four key steps:
  - **Decision to travel** : Whether a trip is necessary (based on need, cost, time, etc.)
  - **Destination choice** : Selecting where to go (e.g., work, school, shopping)
  - **Mode choice** : Choosing the method of transport (e.g., car, bus, walk)
  - **Route choice** : Deciding the path or roadway to reach the destination



11

## Scenario: Trip-Maker Travel Decisions in Action

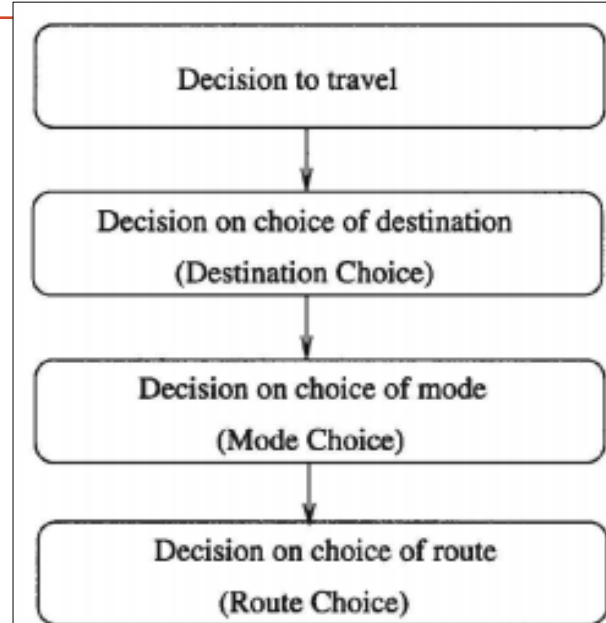
- **Context:** A university student decides to attend a weekend study group at a friend's house in the city
- **Step 1 – Decision to Travel**
  - The student realizes they need help preparing for Tuesday's exam
  - They decide that joining the study group will improve their performance → **trip is needed**
- **Step 2 – Destination Choice**
  - They consider options: campus library, home study, or friend's house
  - They choose the friend's house in **downtown Amman**, where the group is meeting



12

## Scenario: Trip-Maker Travel Decisions in Action

- **Step 3 – Mode Choice**
  - Options: walk, drive, take a bus, or use ride-sharing
  - Chooses to take the **public bus** due to no available parking and low cost
- **Step 4 – Route Choice**
  - Two routes are available
    - Route A (direct but crowded)
    - Route B (slightly longer but more reliable)
  - Chooses **Route B** using the city's BRT (Bus Rapid Transit) system for faster, uninterrupted service



13

What is Demand Modeling in Transportation?

14

## What is Demand Modeling in Transportation?

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- **Demand modeling** is the process of **estimating and predicting** how **people travel across a transportation system**
- The **Four Step Process** is a widely used framework in travel demand modeling

15

## What is the Four Step Process?

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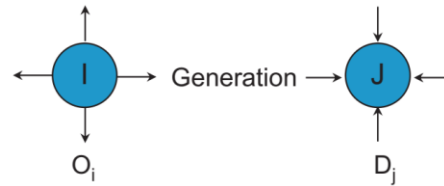
- It estimates future travel patterns based on **land use, population, and network data**
- It includes the following steps :
  1. Trip Generation
  2. Trip Distribution
  3. Mode Choice
  4. Traffic Assignment
- Each step simulates a key decision made by the traveler

16

## The Four-Step Travel Forecasting Process

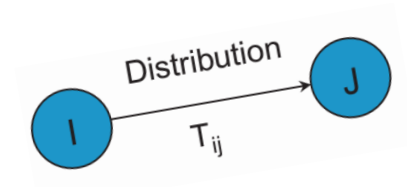
### □ Trip Generation

- *How many trips?*
- Estimates the **number of trips** produced and attracted in each zone



### □ Trip Distribution

- *From where to where?*
- Connects trip origins and destinations to form **origin-destination (O-D) pairs**

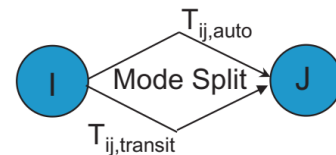


17

## The Four-Step Travel Forecasting Process

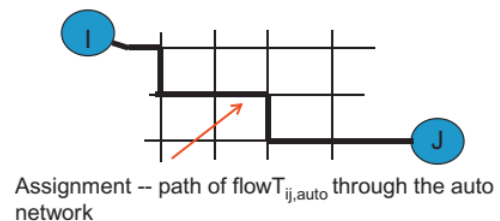
### □ Mode Choice

- *On what mode?*
- Predicts how trips are split among travel **modes** (car, bus, walk, etc.)



### □ Traffic Assignment

- *On what route?*
- Assigns trips to specific **routes** in the transportation network

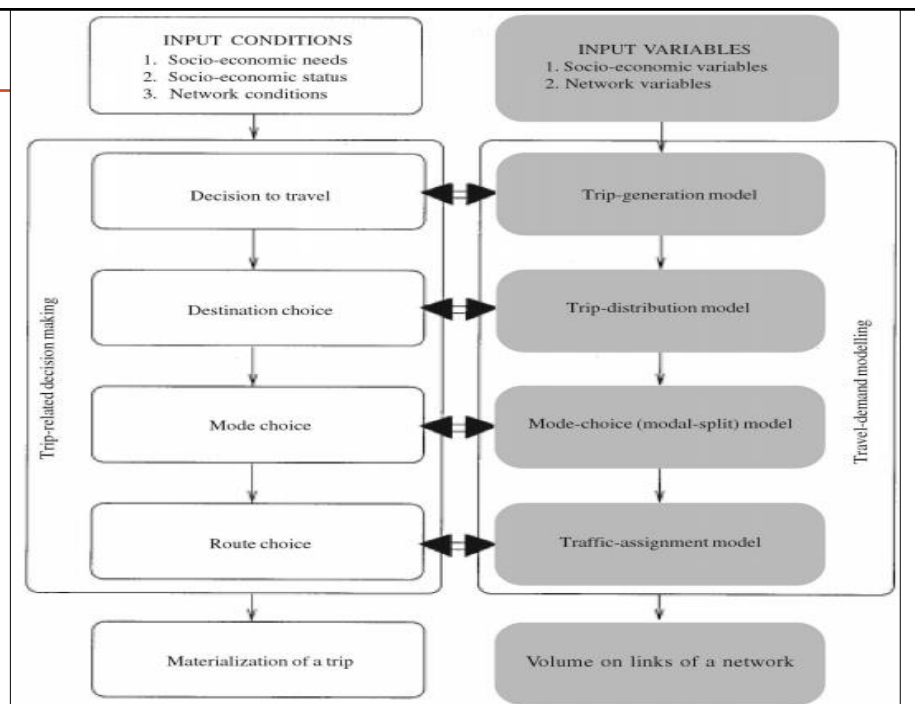


18

# Linking Travel Decisions to Demand Modeling

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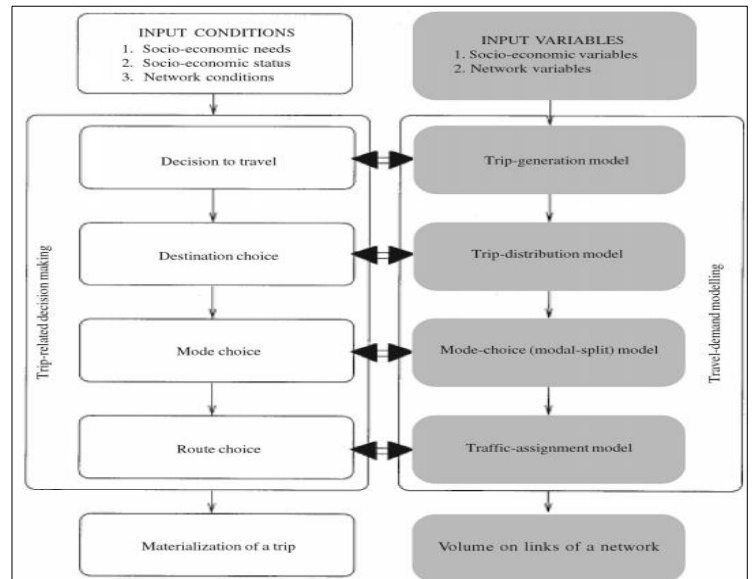
- **Sequential demand analysis** connects real-world **traveler decisions** with **analytical models**



20

## Step 1 – Decision to Travel vs. Trip Generation

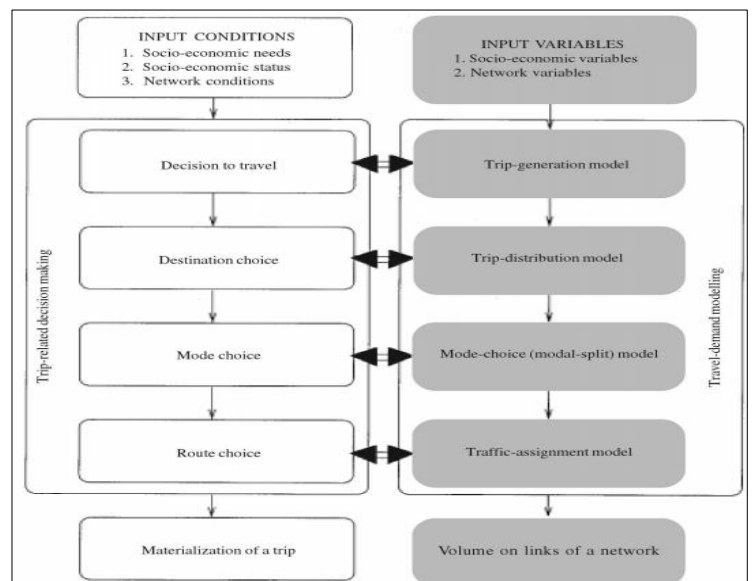
- **Decision to Travel**
  - Traveler evaluates **need and motivation** (e.g., work, shopping, leisure)
  - Influenced by **personal needs and economic factors**
- **Trip Generation Model**
  - Estimates **how many trips** are generated in each zone
  - Output: **number of trips** produced and attracted by each zone



21

## Step 2 – Destination Choice vs. Trip Distribution

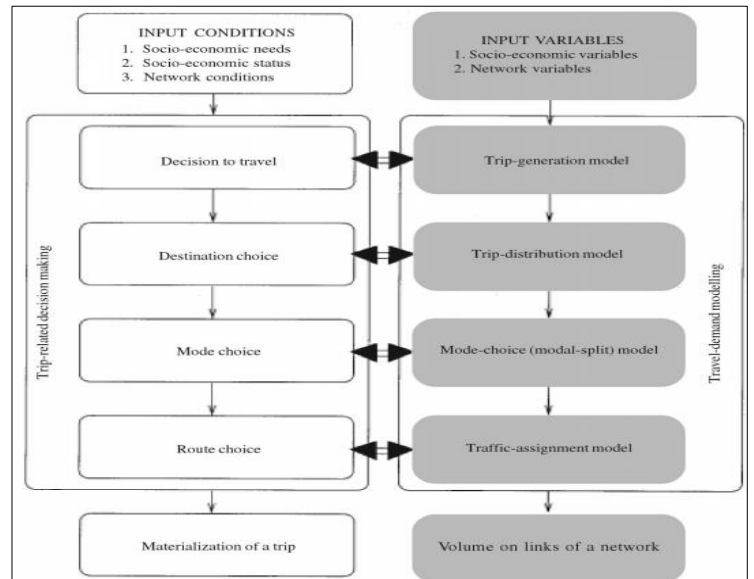
- **Destination Choice**
  - Traveler decides **where to go** for the activity
  - Factors include **distance, accessibility, purpose, and attractiveness** of locations
- **Trip Distribution Model**
  - Predicts the **origin-destination (O-D) patterns**
  - Distributes the trips generated to appropriate destinations



22

## Step 3 – Mode Choice vs. Mode Choice Model

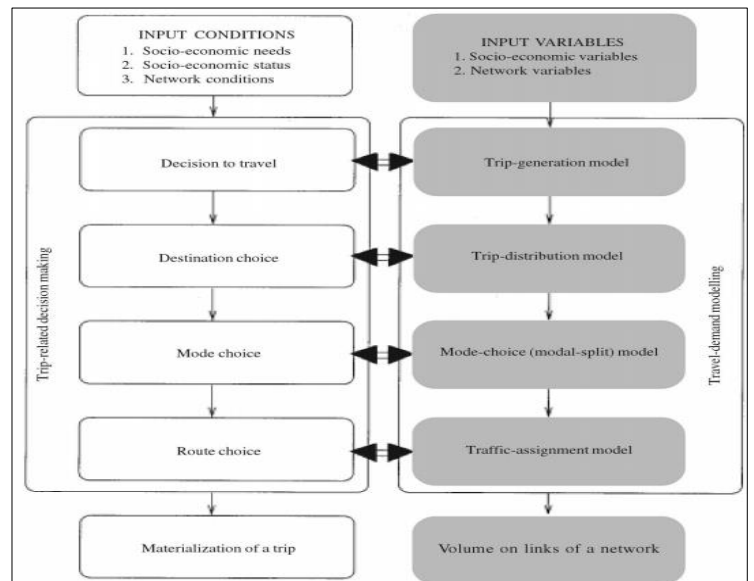
- **Mode Choice**
  - Traveler selects **how to travel** (car, bus, walk, bike, etc.)
  - Influenced by **cost, time, convenience, comfort, and availability**
- **Mode Choice (Modal Split) Model**
  - Allocates trips to different **modes of transport**
  - Output: share of trips by each mode (e.g., 60% car, 30% transit, 10% walking)



23

## Step 4 – Route Choice vs. Traffic Assignment

- **Route Choice**
  - Traveler chooses **which path or road** to take to reach destination
  - Influenced by **travel time, congestion, distance, tolls, and reliability**
- **Traffic Assignment Model**
  - Assigns trips to specific **routes in the transport network**
  - Output: **volume of traffic** on each network link



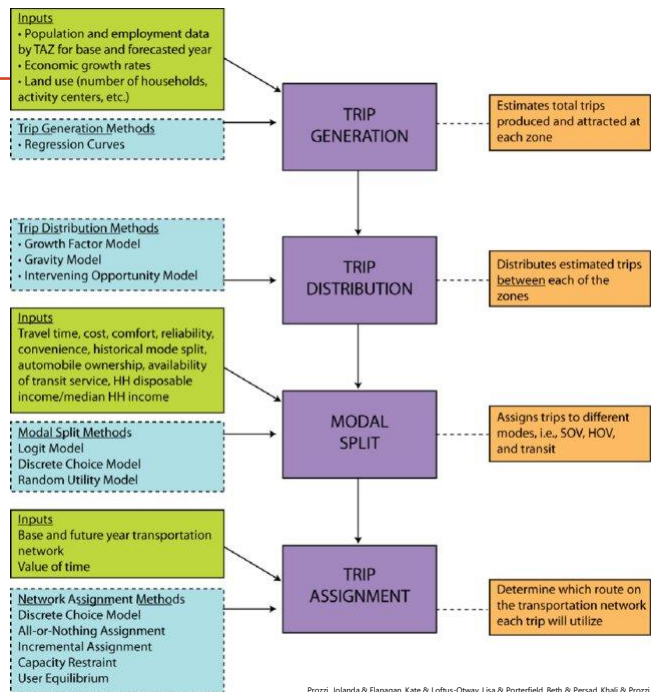
24

# Analysis Procedures

25

## Step 1 – Data Collection

- **Purpose:** Gather all necessary data to support accurate forecasting
- **Key Data Sources:**
  - **Demographic:** population, income, household size
  - **Land Use:** housing units, employment centers, activity zones
  - **Travel Behavior:** trip rates, mode preferences, trip purposes
  - **Transportation Network:** roadways, transit routes, capacities, travel times
- **Tools:** Household travel surveys, traffic counts, census data, GIS

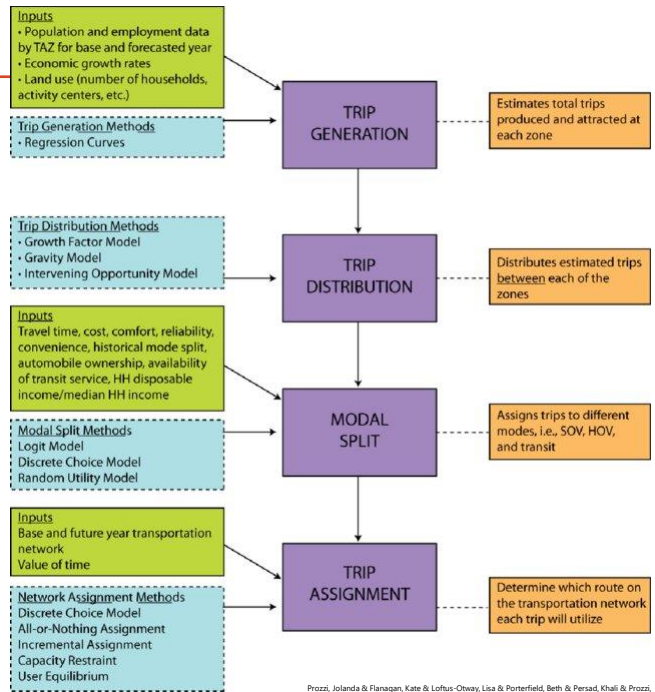


Prozzi, Jolanda & Flanagan, Kate & Lofhus-Onway, Lisa & Porterfield, Beth & Persad, Khalil & Prozzi, Jorge & Michael, C., Actual vs. Forecasted Toll Usage: A Case Study Review, S. Report Date.

26

## Step 2 – Trip Generation

- **Inputs:**
  - Population and employment data (by TAZ)
  - Economic growth rates
  - Land use (households, activity centers)
- **Methods:**
  - Regression curves
  - Trip generation models
- **Outputs:**
  - Total number of trips **produced and attracted** in each zone

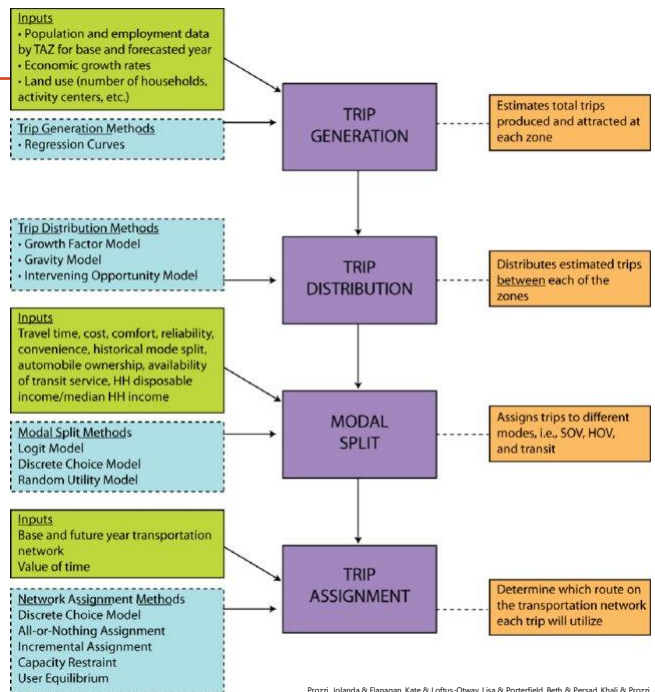


Prozzi, Jolanda & Flanagan, Kate & Loftus-Onway, Lisa & Porterfield, Beth & Persad, Khalil & Prozzi, Jorge & Michael, C. Actual vs. Forecasted Toll Usage: A Case Study Review. 5. Report Date.

27

## Step 3 – Trip Distribution

- **Inputs:**
  - Origin trip ends from trip generation
  - Impedance factors (time, distance, cost)
- **Methods:**
  - Growth Factor Model
  - Gravity Model
  - Intervening Opportunity Model
- **Outputs:**
  - **Origin-Destination (O-D) matrix:** number of trips between each pair of zones

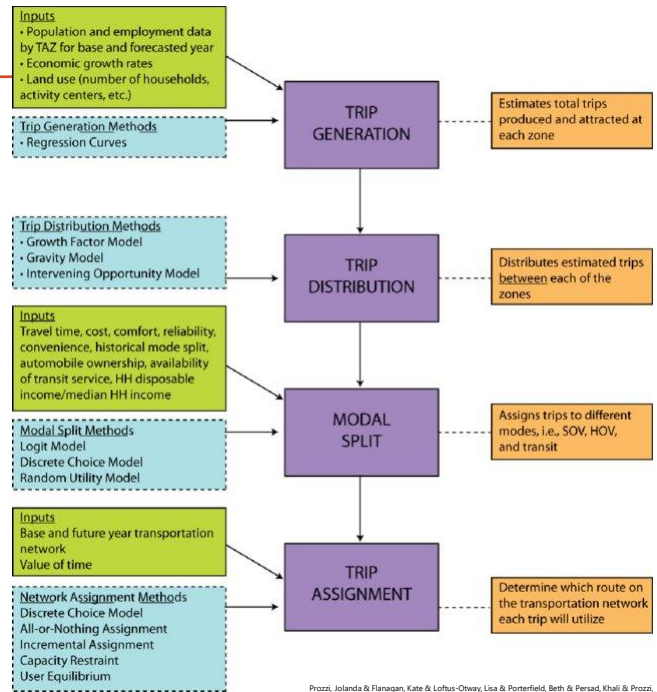


Prozzi, Jolanda & Flanagan, Kate & Loftus-Onway, Lisa & Porterfield, Beth & Persad, Khalil & Prozzi, Jorge & Michael, C. Actual vs. Forecasted Toll Usage: A Case Study Review. 5. Report Date.

28

## Step 3 – Modal Split

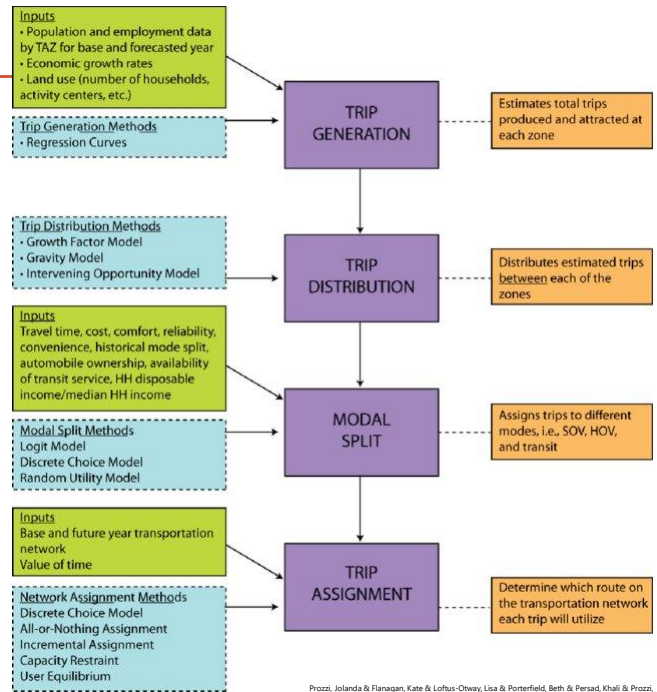
- Inputs:**
  - Travel time, cost, comfort, reliability
  - Mode availability and convenience
  - Auto ownership, income levels
  - Historical mode shares
- Methods:**
  - Logit Model
  - Discrete Choice Model
  - Random Utility Model
- Outputs:**
  - Trips **assigned to different modes** : e.g., SOV (Single-Occupant Vehicle), HOV (High-Occupancy Vehicle), transit



29

## Step 4 – Trip Assignment

- Inputs:**
  - Road and transit network (base & forecast years)
  - Value of time
  - Travel time, congestion levels
- Methods:**
  - Discrete Choice Model
  - All-or-Nothing Assignment
  - Incremental Assignment
  - Capacity Restraint
  - User Equilibrium
- Outputs:**
  - Route allocation** of trips: traffic volumes on road links or transit lines



30

# Transportation Engineering and Planning

Module | 3 | Forecasting Travel in Urban Transportation Planning

## 3.4 | Trip Generation Modeling Using Trip Rates and Regression

*Dr. Hamza Mohammad Alkuime*

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### Trip Generation – Definition

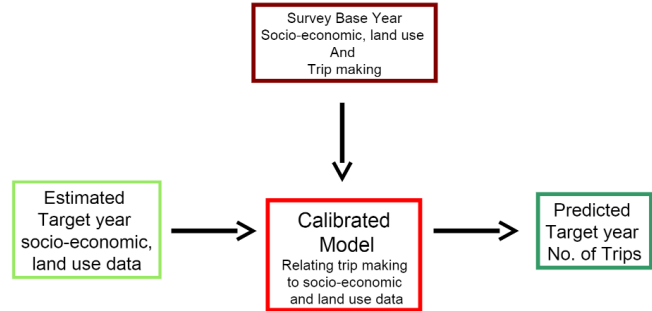
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- **Trip Generation** is the process of estimating the **total number of trips** generated in a zone
- Covers both:
  - **Home-Based (HB)** trips
  - **Non-Home-Based (NHB)** trips

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## Trip Generation – Process

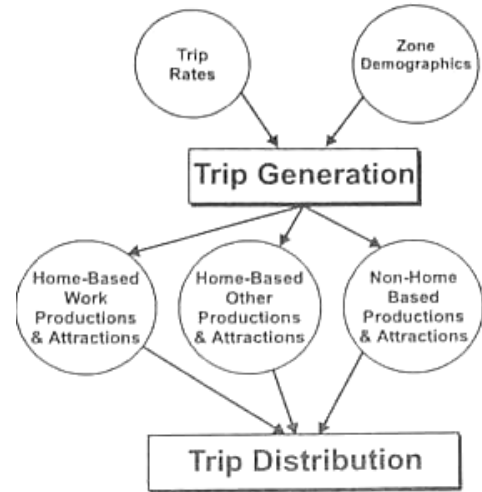
- **Step 1: Base Year Survey**
  - Collect **socio-economic, land use, and trip-making** data for the current/base year.
- **Step 2: Model Calibration**
  - Develop a model that relates **trip generation** to observed **land use and socio-economic variables**.
  - Use statistical methods like **regression analysis** for calibration.
- **Step 3: Future Input Estimation**
  - Estimate **future-year** socio-economic and land use data (e.g., projected population, employment, households).
- **Step 4: Trip Forecasting**
  - Apply the **calibrated model** to future data to predict the **number of trips** for the target year.



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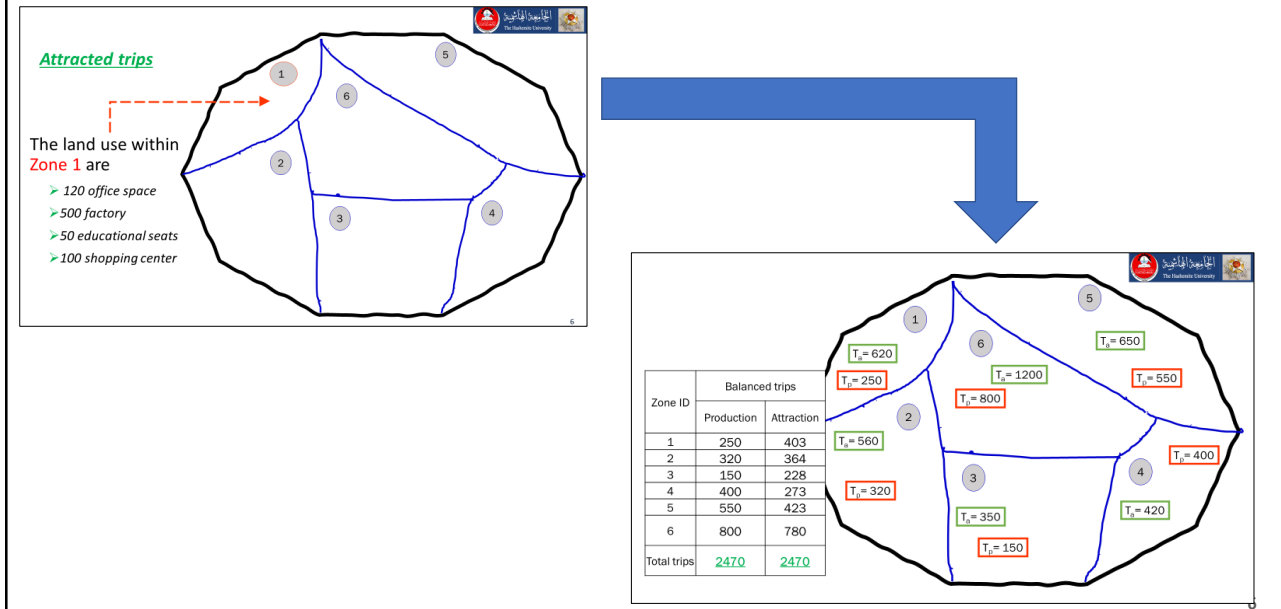
## Trip Generation – Inputs

- **1. Socioeconomic Data**
  - Population and household characteristics
  - Income levels
  - Car ownership
- **2. Land Use Data**
  - Number of housing units
  - Retail/commercial floor space
  - Employment by sector



5

## Trip generation



6

## Trip Generation Modeling

- Regression methods
- Trip Rates
- Cross-Classification Method

7

# Trip Generation

## Trip Rates

9

### Trip rate

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- **Trip rate** is the average number of trips generated per unit of a given land use (e.g., per household, per 1000 ft<sup>2</sup> of commercial space).
- Expressed as:
  - *Trips per dwelling unit* (residential)
  - *Trips per employee* (office)
  - *Trips per 1000 ft<sup>2</sup> GFA* (retail, services)

10

## Example Trip Rates by Land Use Type

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- **Fast Food Restaurant (Drive-Thru):**
  - Average Trip Rate: **496.12 trips/day per 1,000 ft<sup>2</sup>**
- **Office Building (General):**
  - Average Trip Rate: **11.03 trips/day per 1,000 ft<sup>2</sup>**
- **Single-Family Detached Housing:**
  - Average Trip Rate: **9.44 trips/day per dwelling unit**
- **Elementary School:**
  - Average Trip Rate: **1.29 trips/day per student**
- **Medical Office:**
  - Average Trip Rate: **34.80 trips/day per 1,000 ft<sup>2</sup>**

11

## Trip Generation Example – Elementary School

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- **Find the average trips for a elementary school is planned for 600 students**

12

## Trip Generation Example – Elementary School

---

- A elementary school is planned for **600 students**
- **Calculation:**
  - **Average Trip Rate: 1.29 trips/day per student**
  - Total Trips/Day=600×1.29=774 trips/day
- **Interpretation:**  
The school is expected to generate **774 daily person-trips**, including students, parents, staff, and service vehicles.

13

## Trip Rate Development Process

---

- **1. Land Use Definition :** Identify the type of development (e.g., school, retail, hospital).
- **2. Data Collection:** Collect trip count data at multiple similar sites.
- **3. Normalization:** Normalize trips by a common variable (e.g., trips per student, per 1,000 ft<sup>2</sup> GLA).
- **4. Trip Rate Calculation:** Compute average trip rates:

$$\text{Trip Rate} = \frac{\text{Total Daily Trips}}{\text{Independent Variable (e.g., students)}}$$

14

## Example Trip Rate development – Elementary School

---

- **Independent Variable:** Number of Students
- **Observed Data (from surveys at 5 schools):**
  - School A: 300 students → 390 trips/day
  - School B: 450 students → 580 trips/day
  - School C: 200 students → 260 trips/day
  - School D: 350 students → 460 trips/day
  - School E: 250 students → 320 trips/day
- **Step 1 – Calculate Individual Trip Rates:**
  - Trip Rate (School A) =  $390/300 = 1.30$  trips/day/student
  - Similar calculation for others...
- **Step 2 – Compute Average Trip Rate:**
  - Average Trip Rate =  $1.30 + 1.29 + 1.30 + 1.31 + 1.285 = 1.296 \approx 1.29$

15

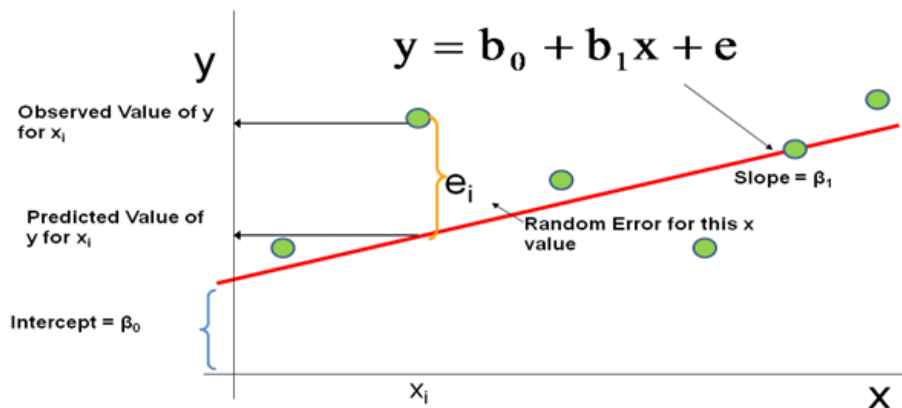
# Trip Generation

## Regression methods

16

## Regression Analysis

Definition: A statistical method that models the relationship between trip generation and influencing factors.



17

17

## Regression Analysis

*Learn more about Regression Analysis through these helpful video tutorials:*

English Resources:

- [An Introduction to Linear Regression Analysis – YouTube](#)
- [Linear Regression, Clearly Explained!!! – YouTube](#)
- [Excel - Simple Linear Regression – YouTube](#)
- [Excel 2016 Regression Analysis – YouTube](#)

Arabic Resources:

- [مبادئ الإحصاء - الانحدار الخطي البسيط ١ - YouTube](#)
- [تحليل وتفسير الانحدار باستخدام الاكسيل - YouTube](#)
- [Linear Regression – YouTube](#) الانحدار الخطي البسيط -

18

18

## Regression Analysis in Trip Generation

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*Quantifying the relationship between trips and influencing factors*

- **Objective:** To estimate the number of trips produced or attracted by a zone using statistical relationships.
- **Dependent Variable:**
  - **Number of trips generated** (e.g., daily person trips per household)
- **Independent Variables** may include:
  - **Household income, Car ownership, Family size, Residential density, Land use type and intensity**
- **Typical Model Structure:**
  - $Trips = a + b_1(Income) + b_2(Car\ Ownership) + b_3(Family\ Size) +$

19

## Example: Regression Model for Trip Generation

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**Model Objective:** Estimate the number of home-based work trips produced per household

**Model Form:**

$Trips = 2.1 + 0.75(\text{Household Size}) + 0.42(\text{Number of Vehicles}) + 0.03(\text{Household Income})$

**Where:**

- **Trips** = Number of trips produced per household
- **Household Size** = Number of persons in the household
- **Number of Vehicles** = Number of cars owned by the household
- **Household Income** = Monthly income (in hundreds of dollars)

**Example Calculation:** For a household with 4 people, 2 cars, and \$4,000 income:

$Trips = 2.1 + 0.75(4) + 0.42(2) + 0.03(40) = 2.1 + 3.0 + 0.84 + 1.2 = 7.14 \text{ trips/day} = 7.14 \text{ trips/day}$

20

## Trip Generation – Regression Development Process

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- **Step 1: Define Dependent Variable** : Total number of trips generated per zone or site
- **Step 2: Identify Independent Variables** : Socioeconomic data (e.g., number of employees, floor area, households)
- **Step 3: Collect Data** : Gather observed trip counts and corresponding land-use variables
- **Step 4: Develop Regression Model**
  - Use statistical tools (e.g., Excel, SPSS) to fit a regression line
    - Equation:
  - $\text{Trips} = a + bX_1 + cX_2 + \dots$
- **Step 5: Evaluate Model Accuracy** :
- **Step 6: Apply Model for Forecasting** : Predict trip generation for future or unstudied zones

21

Trip Generation regression development process

Case Studies in Jordan

22

## Develop a customized equation (e.g., planning model)

### Case studies in Jordan

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- ↪ Naser, Mohammad & Abo-Qudais, Saad & Faris, Hossam. (2015). **Developing Trip Generation Rates for Hospitals in Amman**. Jordan Journal of Civil Engineering. 9. 8-19.  
 ➤ [Microsoft Word - developing trip- mohammad naser et al 02 \(researchgate.net\)](#)
- ↪ Al-Madadha, Ayat & Imam, Rana. (2020). **Developing Trip Generation Rates for Restaurants in Amman**. 12. 69-79. International Journal of Information, Business and Management, Vol. 12, No. 2,  
 ➤ [Developing-Trip-Generation-Rates-for-Restaurants-in-Amman.pdf \(researchgate.net\)](#)
- ↪ Abu-Ameerh, S. 2007. **Trip attraction model for hospitals in Amman**. Master of Science in Civil Engineering in Transportation. Jordan University, Jordan.
- ↪ Al-Jabari, O. 2009. **Trip Attraction Model For Fast Food Restaurants In Amman**, Master of Science in Civil Engineering in Transportation, Jordan University, Jordan
- ↪ Al-Nawaiseh, H 2010. **Trip Attraction Model For Private Schools In Amman**, Master of Science in Civil Engineering in Transportation, Jordan University, Jordan
- ↪ Alkuime, H, 2015. **Trip Attraction Model For Universities In Jordan**. Master of Science in Civil Engineering in Transportation, Jordan University of Science and Technology

23

23

## Trip Attraction Model For Universities In Jordan

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Regression models were developed to predict vehicles trips within the day or peak hours, based on different characteristics of universities such as:

1. Number of students.
2. Number of administrative staff.
3. Number of academic staff.
4. Gross floor area of universities.
5. Number of studying rooms and labs.
6. Number of courses
7. Number of lectures

24

24

## Develop a customized equation (e.g., planning model)

### *Trip Attraction Model For Universities In Jordan*

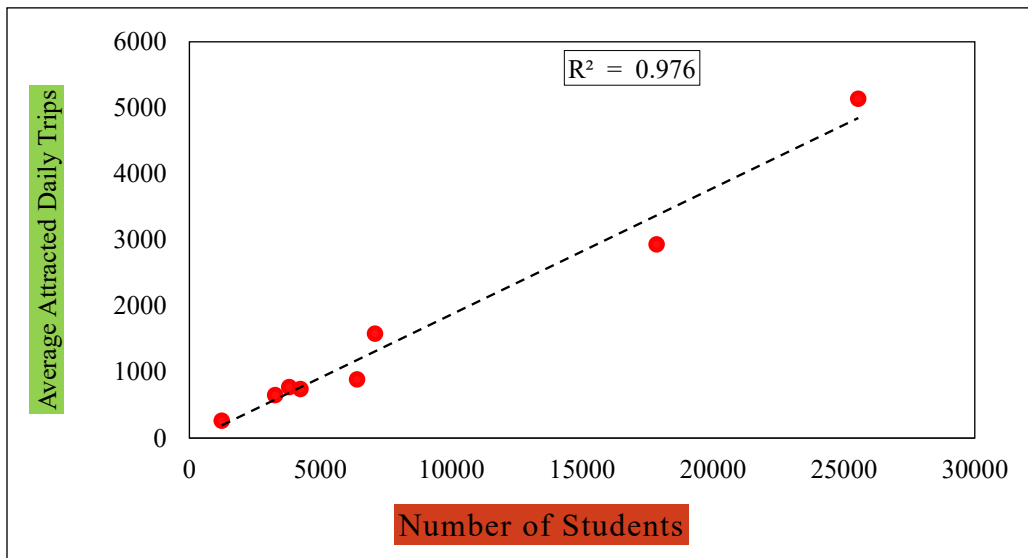
University Name	Type	Province
Jordan University of Science & Tech. (JUST)	Public	Irbid
Al al-Bayt University (AABU)	Public	Al-Mafraq
Jadara University	Private	Irbid
Irbid National University	Private	Irbid
Philadelphia Private University	Private	Amman
Zarqa University (ZU)	Private	Zarqa
Jarash University	Private	Jarash
Ajloun National Private Univ.	private	Ajloun

25

25

## Develop a customized equation (e.g., planning model)

### *Trip Attraction Model For Universities In Jordan*



26

26

## Develop a customized equation (e.g., planning model)

*Trip Attraction Model For Universities In Jordan*

Developed models	R <sup>2</sup>
$\text{LN}(V_{\text{TD}}) = 0.472 + 0.297 * \text{LN}(\text{GFA}) + 0.3256 * \text{LN}(\text{NS}) + 0.360 * \text{LN}(\text{NL})$	0.968
$\text{LN}(V_{\text{AD}}) = -0.205 + 0.296 * \text{LN}(\text{GFA}) + 0.325 * \text{LN}(\text{NS}) + 0.36 * \text{LN}(\text{NL})$	0.967
$\text{LN}(V_{\text{TH}}) = -2.643 + 0.985 * \text{LN}(\text{NS})$	0.985
$\text{LN}(V_{\text{AH}}) = -2.380 + 0.926 * \text{LN}(\text{NS})$	0.976

27

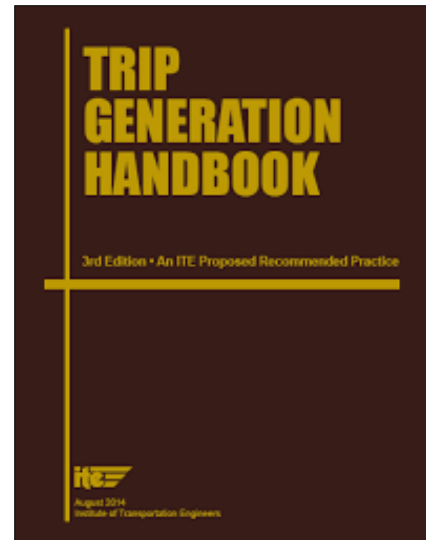
27

# Trip Generation Manuals

30

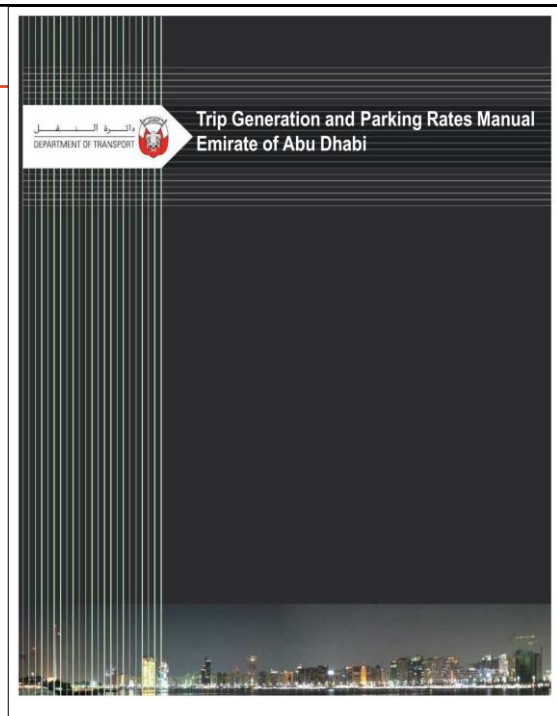
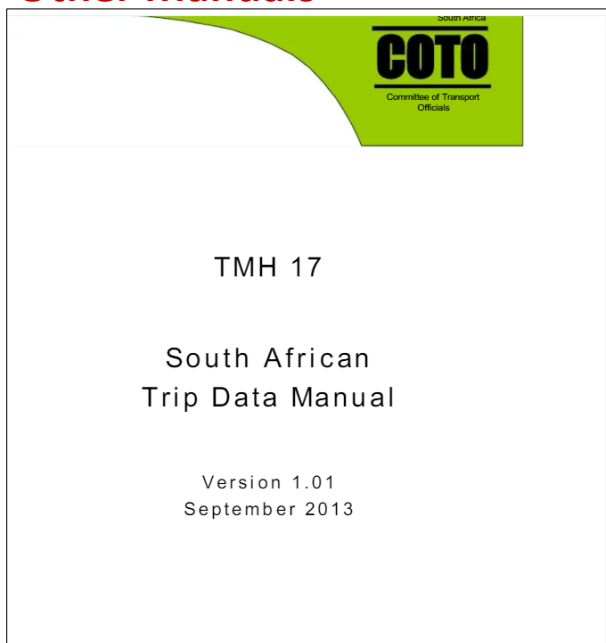
## Trip Generation Manuals

- **Trip Generation Manuals** are **standardized references** used to **estimate the number of trips** generated by different **land use types**.
- The most widely used manual is the **ITE Trip Generation Manual** published by the **Institute of Transportation Engineers**.
- It provides **average trip rates and regression models** based on land use type (e.g., residential, retail, school).



31

## Other Manuals



32

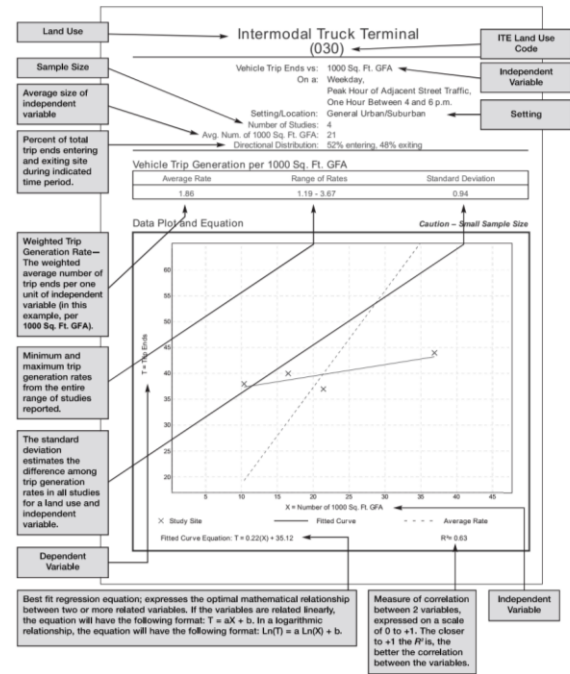
# ITE Trip Generation Manual: Land Use Categories

- **ITE Manual** categorizes land uses to estimate trips generated by different activity types.
- Major land use groups include:
  - **Port and Terminal:** airports, intermodal terminals, park-and-ride lots
  - **Residential:** single-family homes, apartments, senior housing
  - **Recreational:** parks, golf courses, bowling alleys
  - **Medical:** hospitals, assisted living facilities
  - **Industrial:** manufacturing plants, warehouses
  - **Office:** general office buildings, business parks
  - **Retail:** shopping centers, fast food, superstores
  - **Services:** banks, daycares, vehicle service centers

Land Use Codes		
<b>Port and Terminal (Land Uses 000-099)</b>		
<b>CODE</b>	<b>LAND USE</b>	
021	Commercial Airport	240 Mobile Home Park
022	General Aviation Airport	251 Senior Adult Housing—Detached
030	Intermodal Truck Terminal	252 Senior Adult Housing—Attached
090	Park-and-Ride Lot with Bus or Light Rail Service	253 Congregate Care Facility
		254 Assisted Living
		255 Continuing Care Retirement Community
<b>Industrial (Land Uses 100-199)</b>		
<b>CODE</b>	<b>LAND USE</b>	
110	General Light Industrial	260 Recreational Homes
130	Industrial Park	265 Timeshare
140	Manufacturing	270 Residential Planned Unit Development
150	Warehousing	
151	Mini-Warehouse	<b>Lodging (Land Uses 300-399)</b>
154	High-Cube Transload and Short-Term Storage Warehouse	<b>CODE</b>
155	High-Cube Fulfillment Center Warehouse	<b>LAND USE</b>
156	High-Cube Parcel Hub Warehouse	310 Hotel
157	High-Cube Cold Storage Warehouse	311 All Suites Hotel
160	Data Center	312 Business Hotel
170	Utility	320 Motel
180	Specialty Trade Contractor	330 Resort Hotel
<b>Residential (Land Uses 200-299)</b>		
<b>CODE</b>	<b>LAND USE</b>	
210	Single-Family Detached Housing	<b>Recreational (Land Uses 400-499)</b>
220	Multifamily Housing (Low-Rise)	<b>CODE</b>
221	Multifamily Housing (Mid-Rise)	<b>LAND USE</b>
222	Multifamily Housing (High-Rise)	411 Public Park
225	Off-Campus Student Apartment	416 Campground/Recreational Vehicle Park
231	Mid-Rise Residential with 1st-Floor Commercial	420 Marina
		430 Golf Course
		431 Miniature Golf Course
		432 Golf Driving Range
		433 Batting Cages
		434 Rock Climbing Gym
		435 Multipurpose Recreational Facility
		436 Trampoline Park
		437 Bowling Alley
		440 Adult Cabaret

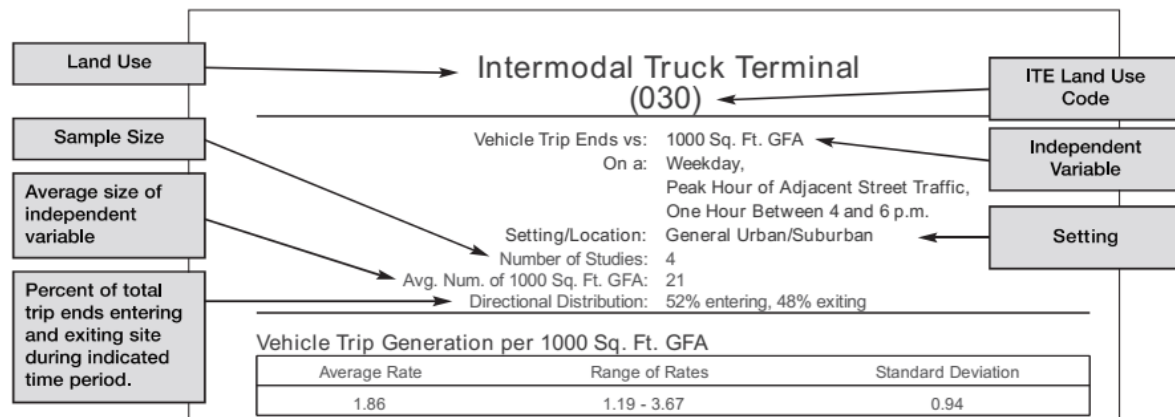
# ITE Trip Generation Manual

# Understanding Trip Rate Data

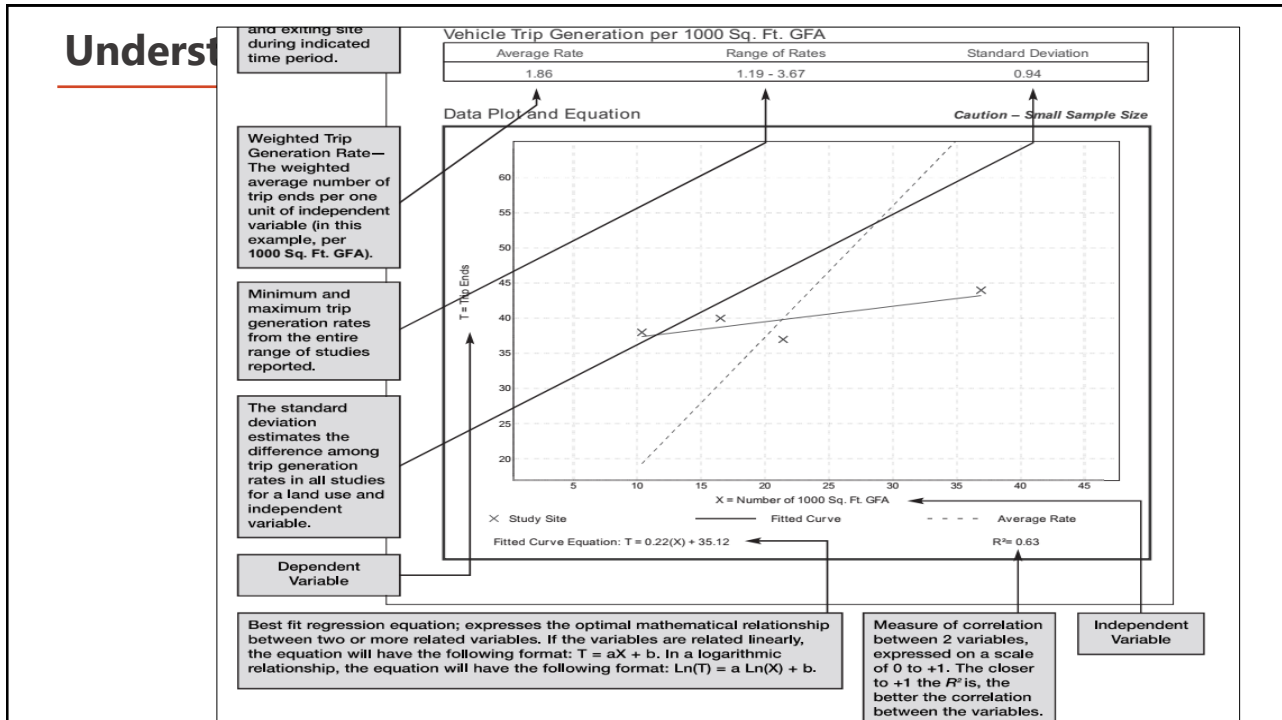


35

# Understanding Trip Rate Data



36



37

## ITE Trip Generation Manual – Steps for Estimating Trip Rates

- **Step 1:** Select the **Land Use Class**
- **Step 2:** Check **Sub-Classification** within the selected land use
- **Step 3:** Identify the appropriate **Independent Variable** (e.g., floor area, number of employees, number of students)
- **Step 4:** Choose the **Analysis Period** (e.g., daily, AM peak hour, PM peak hour)
- **Step 5:** Calculate the Trip Generation Rate using one of the following:
  - **Graphic Plot**
  - **Regression Equation**
  - **Weighted Average Trip Rate**

38

## Guidelines for Using the ITE Trip Generation Manual

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- **Ensure your zone lies within the *calibration limits* of the independent variables**
- **Use the regression equation first**
  - *Only if  $R^2 > 0.75$*  (strong statistical fit)
- **Use the average trip rate**
  - *Only if Standard Deviation (S.D.)  $< 1.1 \times$  Average Rate*

39

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## ITE Trip generation manual

### *Example No .1*

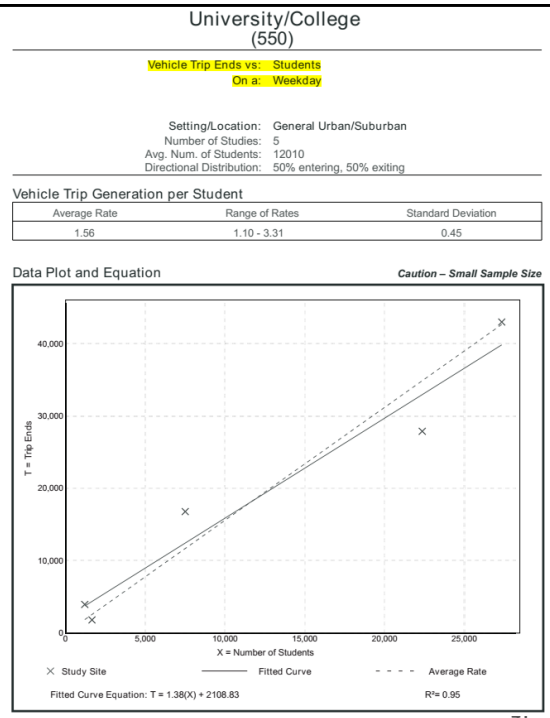
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## ITE Trip generation manual

### Example No. 1

Estimate the number of trips (T) entering and exiting a university with 20,000 student ?

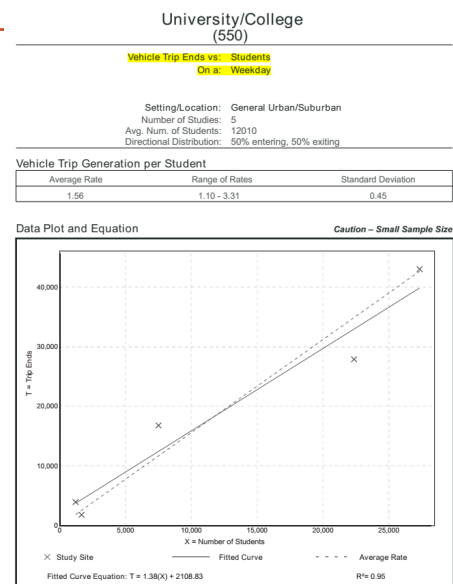


41

## ITE Trip generation manual

### Solution of example No. 1

1. Check the regression model
  - ❖  $R^2 = 0.95 > 0.75$ , thus use the model
2. Use the regression model
  - ❖  $T = 1.38(x) + 2108.83$ 
    - T = Vehicle Trip Ends
    - X = No. of students
  - ❖  $T = 1.38(20,000) + 2108.83$
  - ❖  $T = 29,708.83$
3. Directional Distribution: 50% entering, 50% exiting
  - % of entering trips
    - ❖  $0.5 * 29708 = 14,854$
  - % of exiting trips
    - ❖  $0.5 * 29708 = 14,854$



42

42

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## ITE Trip generation manual

### *Example No .2*

43

43

## ITE Trip generation manual

### *Example No .2*

---

A 500- acre site is being developed to support 400 single-family detached houses and a swimming pool with a clubhouse.

Estimate the **number of trips (T) exiting** the subdivision during **a typical am peak hour**.

44

44

## ITE Trip generation manual

### Example No. 2

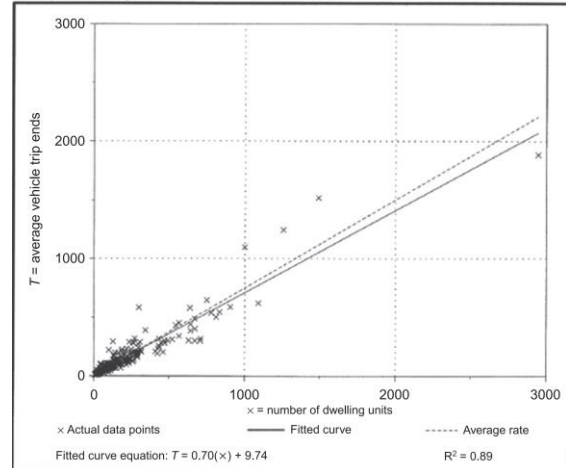
Average vehicle trip ends vs: Dwelling units  
On a: Weekday, peak hour of adjacent street traffic, one hour between 7 and 9 am

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

#### Trip generation per dwelling unit

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

#### Data plot and equation



45

## ITE Trip generation manual

### Solution of example No. 2

#### Solution

- Note that our site with 400 units is within the range of units for the study sites, with the bulk of the study sites having less than 1000 units.
- $R^2 = 0.89$ . Because this is  $>0.75$ , we can use the fitted curve equation to solve for the answer versus looking at the average rate.
- $T = 0.70 (X) + 9.74$ , where  $X$  is the number of dwelling units.

$$T = 0.70 (400) + 9.74$$

$$T = 290 \text{ total trips}$$

Now,  $T_{\text{exit}} = 0.75 (290) = 218$  trips exiting during the am peak hour. The 0.75 comes from the chart in that 75% are exiting and 25% are entering during the am peak hour.

46

46

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## ITE Trip generation manual

### *Example No .3*

47

47

## ITE Trip generation manual

### *Example No .3*

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You have been hired to conduct a TIA for a new fast-food restaurant with a drive-through window. Which of the following statements represents the best choice for estimating the number of trips into and out of the restaurant during the am peak?

- a.** Can't estimate the trips because there is no equation.
- b.** Can't estimate the trips because the standard deviation is too high.
- c.** Can use the average rate because the standard deviation is in acceptable limits.
- d.** Can use the average rate but should add a factor of safety to it.

48

48

## ITE Trip generation manual

*Solution of example No .3*

Rate: it refers to the number of trips per day per activity center.

### Fast-food restaurant with drive-through window (934)

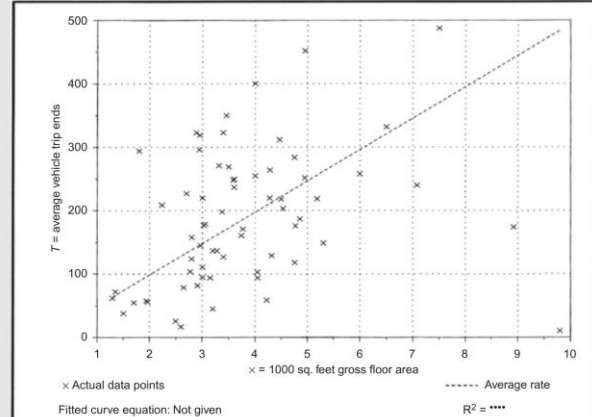
Average vehicle trip ends vs: 1000 sq. feet gross floor area  
On a: Weekday, peak hour of adjacent street traffic, one hour between 7 and 9 am

Number of studies: 65  
Average 1000 sq. feet GFA: 4  
Directional distribution: 51% entering, 49% exiting

#### Trip generation per 1000 sq. feet gross floor area

Average rate	Range of rates	Standard deviation
49.35	1.02–163.33	28.30

#### Data plot and equation



49

## ITE Trip generation manual

*Solution of example No .3*

As no equation is given for this land use code, it clearly is not an option for estimating trips. The scatter of the data further supports why the development of an equation was not appropriate for this example.

The land use code does contain an average rate of 49.35 trips per 1000 ft of gross floor area, and the standard deviation of the estimate is 28.30 trips. As this is less than 1.1 times the average, it is acceptable to use the average rate. The correct answer is (c).

50

50

## ITE Trip generation manual

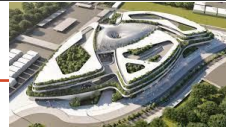
### Example No .4

51

51

## ITE Trip generation manual

### Example No .4



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

**Table 12.7** Trip Generation Rates by Trip Purpose and Employee Category

	<i>Attractions per Household</i>	<i>Attractions per Nonretail Employee</i>	<i>Attractions per Downtown Retail Employee</i>	<i>Attractions per Other Retail Employee</i>
HBW	—	1.7	1.7	1.7
HBO	1.0	2.0	5.0	10.0
NHB	1.0	1.0	3.0	5.0

52

52

## ITE Trip generation manual

*Solution of example No .4*

Rate: it refers to the number of trips per day per employee type (retail and nonretail)

**Table 12.7** Trip Generation Rates by Trip Purpose and Employee Category

	<i>Attractions per Household</i>	<i>Attractions per Nonretail Employee</i>	<i>Attractions per Downtown Retail Employee</i>	<i>Attractions per Other Retail Employee</i>
HBW	—	1.7	1.7	1.7
HBO	1.0	2.0	5.0	10.0
NHB	1.0	1.0	3.0	5.0

Estimated trips is function with employee type (retail and nonretail)

53

53

## ITE Trip generation manual

*Solution of example No .4*

Employed at the center are 650 non-retail and 220 retail and workers.

**Table 12.7** Trip Generation Rates by Trip Purpose and Employee Category

	<i>Attractions per Nonretail Employee</i>	<i>Attractions per Downtown Retail Employee</i>
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated HBW trips

$$(650 \times 1.7) + (220 \times 1.7) = 1479 \text{ trip/day}$$

54

54

## ITE Trip generation manual

*Solution of example No .4*

Employed at the center are 650 non-retail and 220 retail and workers.

	<i>Attractions per Nonretail Employee</i>	<i>Attractions per Downtown Retail Employee</i>
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated HBO trips

$$(650 \times 2) + (220 \times 5) = 2400 \text{ trip/day}$$

55

55

## ITE Trip generation manual

*Solution of example No .4*

Employed at the center are 650 non-retail and 220 retail and workers.

	<i>Attractions per Nonretail Employee</i>	<i>Attractions per Downtown Retail Employee</i>
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated NHB trips

$$(650 \times 1) + (220 \times 3) = 1310 \text{ trip/day}$$

56

56

## ITE Trip generation manual

*Solution of example No .4*

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### Estimated Total trips

$$\text{HBW: } (220 \times 1.7) + (650 \times 1.7) = 1479$$

$$\text{HBO: } (220 \times 5.0) + (650 \times 2.0) = 2400$$

$$\text{NHB: } (220 \times 3.0) + (650 \times 1.0) = 1310$$

$$\text{Total} = 5189 \text{ trips/day}$$

# *Transportation Engineering and Planning*

Module | 3 | Forecasting Travel in Urban Transportation Planning

## 3.5 | Trip Generation Modeling Using Cross – Classification

*Dr. Hamza Mohammad Alkuime*

1

### Introduction to Cross-Classification

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- **Cross-Classification** is a technique developed by **FHWA** to **determine the number of trips that begin or end at the home**
  - Focuses on ► **Home based trips**
- It classifies households into categories based on key variables to estimate trip-making behavior
- The **most commonly used variables** include:
  - *Average income*
  - *Auto ownership*
  - *Household size and stage* in the household life cycle

2

# Using Survey Data for Cross-Classification Trip Generation

- The image shows a **2002 Onboard Transit Survey** used to collect detailed household travel behavior
- Key survey inputs collected:
  - Household Income
  - Number of Vehicles per Household
  - Trips Made per Household
  - Number of People in Household
  - Trip purpose and origin/destination

**2002 Onboard Transit Survey**  
 The San Diego Association of Governments, and your transit operators, want your help to improve transit service by answering the questions below and returning this form before you get off the bus. All responses are confidential. Please fill out this form each time you get one. Thank you.

**PLEASE ANSWER THESE QUESTIONS FIRST**

1. Where are you coming from?  
 1. Home 4. Shopping  
 2. Work 5. Recreation/visit friends  
 3. School 6. Other (specify: \_\_\_\_\_)

2. What is the address of that place?  
 (Specify street name AND cross street OR address)  
 Street No. Street Name  
 Nearest Cross Street City

3. What is the zip code where you live? \_\_\_\_\_

4. Where are you going?  
 1. Home 4. Shopping  
 2. Work 5. Recreation/visit friends  
 3. School 6. Other (specify: \_\_\_\_\_)

5. What is the address of that place?  
 (Specify street name AND cross street OR address)  
 Street No. Street Name  
 Nearest Cross Street City

A. Sample Address \_\_\_\_\_ House Number, Street Name, Apt. No. \_\_\_\_\_ City/Town \_\_\_\_\_ County \_\_\_\_\_ Zip Code \_\_\_\_\_

B. Structure Type \_\_\_\_\_

C. Number of People Living at this Address \_\_\_\_\_

D. Number of People Age 5 and Over Living at this Address \_\_\_\_\_

E. Number of Out-of-Area Visitors Staying at this Address \_\_\_\_\_

F. Number of Passenger Cars, Vans, and Pickups Available for Use \_\_\_\_\_

G. Household Income: (Do Not Ask Until Interview Is Complete) \_\_\_\_\_

3

# Using Survey Data for Cross-Classification Trip Generation

**2002 Onboard Transit Survey**  
 The San Diego Association of Governments, and your transit operators, want your help to improve transit service by answering the questions below and returning this form before you get off the bus. All responses are confidential. Please fill out this form each time you get one. Thank you.

**PLEASE ANSWER THESE QUESTIONS FIRST**

1. Where are you coming from?  
 1. Home 4. Shopping  
 2. Work 5. Recreation/visit friends  
 3. School 6. Other (specify: \_\_\_\_\_)

2. What is the address of that place?  
 (Specify street name AND cross street OR address)  
 Street No. Street Name  
 Nearest Cross Street City

3. What is the zip code where you live? \_\_\_\_\_

4. Where are you going?  
 1. Home 4. Shopping  
 2. Work 5. Recreation/visit friends  
 3. School 6. Other (specify: \_\_\_\_\_)

5. What is the address of that place?  
 (Specify street name AND cross street OR address)  
 Street No. Street Name  
 Nearest Cross Street City

A. Sample Address \_\_\_\_\_ House Number, Street Name, Apt. No. \_\_\_\_\_ City/Town \_\_\_\_\_ County \_\_\_\_\_ Zip Code \_\_\_\_\_

B. Structure Type \_\_\_\_\_

C. Number of People Living at this Address \_\_\_\_\_

D. Number of People Age 5 and Over Living at this Address \_\_\_\_\_

E. Number of Out-of-Area Visitors Staying at this Address \_\_\_\_\_

F. Number of Passenger Cars, Vans, and Pickups Available for Use \_\_\_\_\_

G. Household Income: (Do Not Ask Until Interview Is Complete) \_\_\_\_\_



Household	Trips	Income	Cars	Household	Trips	Income	Cars
1	2	15500	0	11	7	88500	1
2	4	18000	0	12	9	82000	1
3	10	88000	2	13	9	32500	2
4	5	51000	0	14	11	51500	2
5	5	17500	1	15	10	49000	2
6	15	87000	3	16	11	72500	2
7	7	59000	1	17	12	86000	2
8	4	31000	0	18	8	45000	1
9	6	37500	1	19	8	73000	1
10	13	90000	3	20	9	65000	1

<https://www.youtube.com/watch?v=owlvi8Kjtpo>

4

4

Household	Trips	Income	Cars	Household	Trips	Income	Cars
1	2	15500	0	11	7	88500	1
2	4	18000	0	12	9	82000	1
3	10	88000	2	13	9	32500	2
4	5	51000	0	14	11	51500	2
5	5	17500	1	15	10	49000	2
6	15	87000	3	16	11	72500	2
7	7	59000	1	17	12	86000	2
8	4	31000	0	18	8	45000	1
9	6	37500	1	19	8	73000	1
10	13	90000	3	20	9	65000	1

↪ A matrix is established, based upon family income and car ownership:

↪ The numbers inside the matrix represent household sample numbers

		Car ownership		
		0	1	2 or more
Income (in 000's)	≤20	1,2	5	-
	20-40	8	9	13
	40-60	4	7,18	14,15
	60-80	-	19,20	16
	>80	-	11,12	3,6,10,17

5

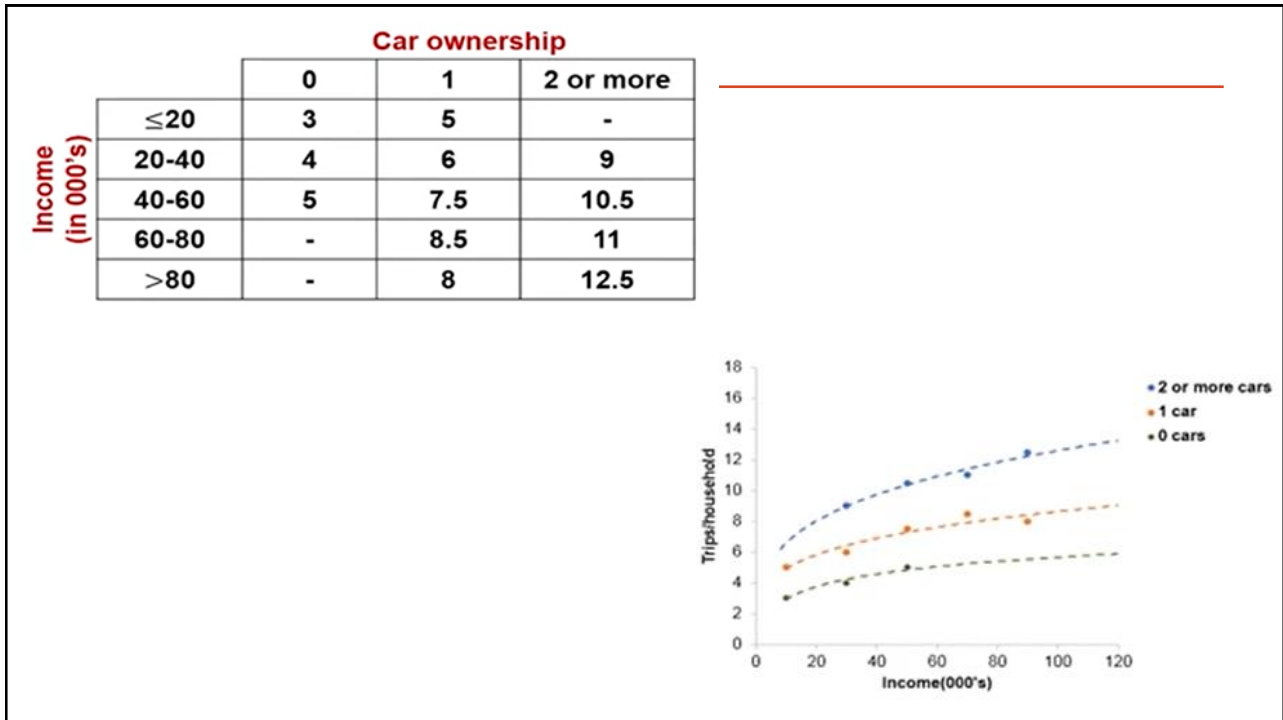
Household	Trips	Income	Cars	Household	Trips	Income	Cars
1	2	15500	0	11	7	88500	1
2	4	18000	0	12	9	82000	1
3	10	88000	2	13	9	32500	2
4	5	51000	0	14	11	51500	2
5	5	17500	1	15	10	49000	2
6	15	87000	3	16	11	72500	2
7	7	59000	1	17	12	86000	2
8	4	31000	0	18	8	45000	1
9	6	37500	1	19	8	73000	1
10	13	90000	3	20	9	65000	1

**Average** number of trips per household under each category is then calculated and summarized as:

Example : First cell  
Household = 1 and 2 , then  
average trips =  $2 + 4 / 2 = 3$  trips

		Car ownership		
		0	1	2 or more
Income (in 000's)	≤20	3	5	-
	20-40	4	6	9
	40-60	5	7.5	10.5
	60-80	-	8.5	11
	>80	-	8	12.5

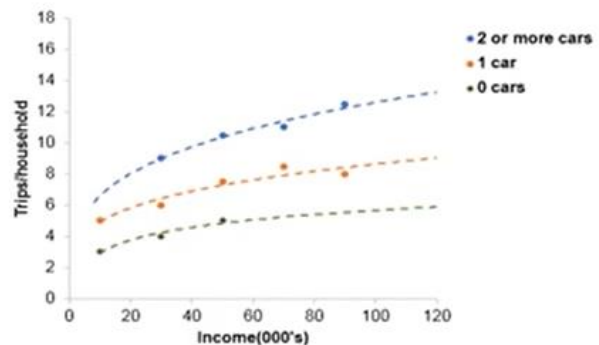
6



7

## Trip Forecasting

- ↪ The plotted points are fit with smooth curves, and the lines are extended — extrapolated — based on the shape of the curves and logic.
- ↪ The curve values are then used to develop a completed matrix, which can be used to make forecasts of trips.
- ↪ From the graph, we can predict that families that have an income of Rs. 60,000 and one car will make about 7 trips per day.



8

# Understanding Cross-Classification charts

9

## Using Survey Data for Cross-Classification Trip Generation

- ▶ This table summarizes responses from 20 households
- ▶ Each row corresponds to a unique household
- ▶ Columns include:
  - **Trips Produced per Household**
  - **Household Income (in \$1000s)**
  - **Autos per Household**
- These data are **grouped into categories** (e.g., income brackets and vehicle ownership levels) to compute:

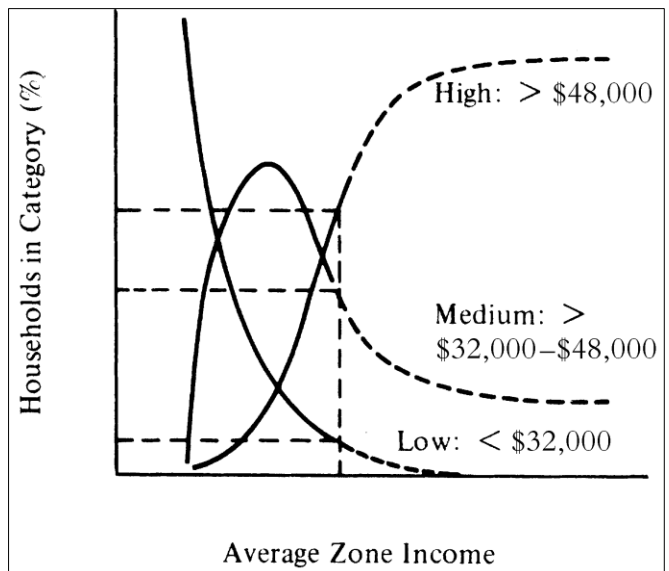
**Table 12.1** Survey Data Showing Trips per Household, Income, and Auto Ownership

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

10

## Income-Based Household Categorization for Cross-Classification

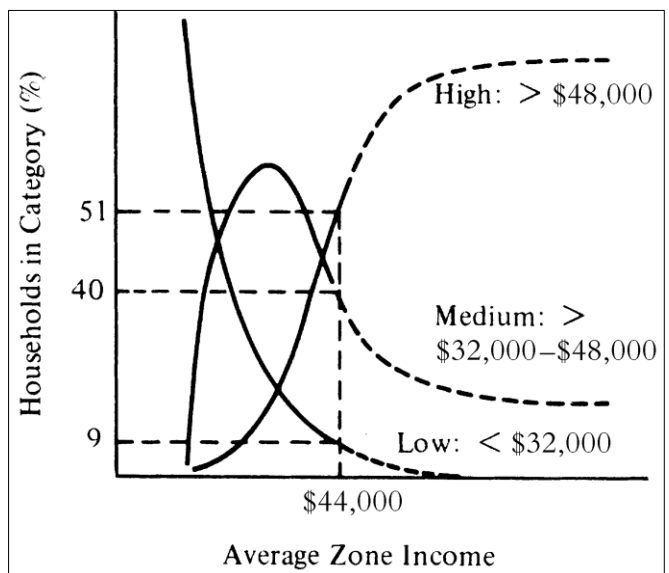
- The graph shows the **distribution of households** across three income categories based on **average zone income**
- X-axis:** Average income in a traffic analysis zone (TAZ)
- Y-axis:** Percentage of households (%) in each category
- Three **income categories** are defined:
  - Low Income:** Less than \$32,000
  - Medium Income:** Between \$32,000 – \$48,000
  - High Income:** Greater than \$48,000
- The curves represent the proportion of households that fall into each income group



13

## What the Income Distribution Curve Tells Us

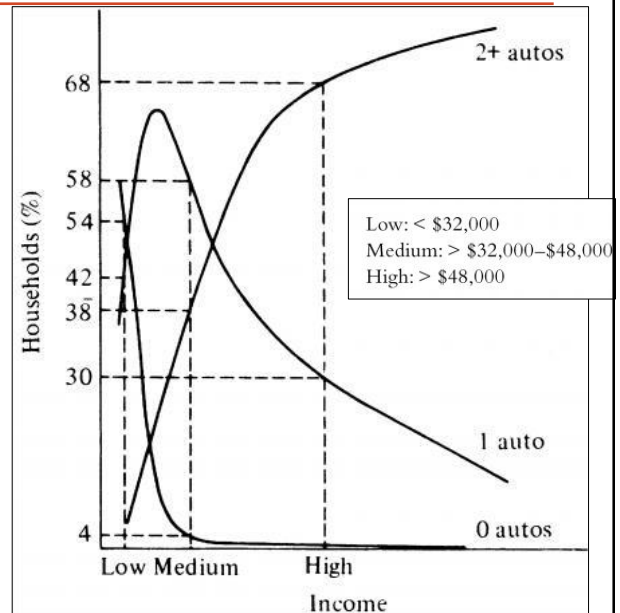
- At an average **zone income of \$44,000**:
  - 51%** of households are in the **medium-income** bracket
  - 40%** are in the **high-income** bracket
  - Only **9%** fall into the **low-income** group
- As zone income increases:
  - The **share of high-income households rises**
  - The **share of low-income households drops sharply**
- These percentages help estimate:
  - How many households per zone** belong to each category
  - How many **trips are generated** by each group using cross-classification tables



14

## Understanding Income and Vehicle Ownership Distribution

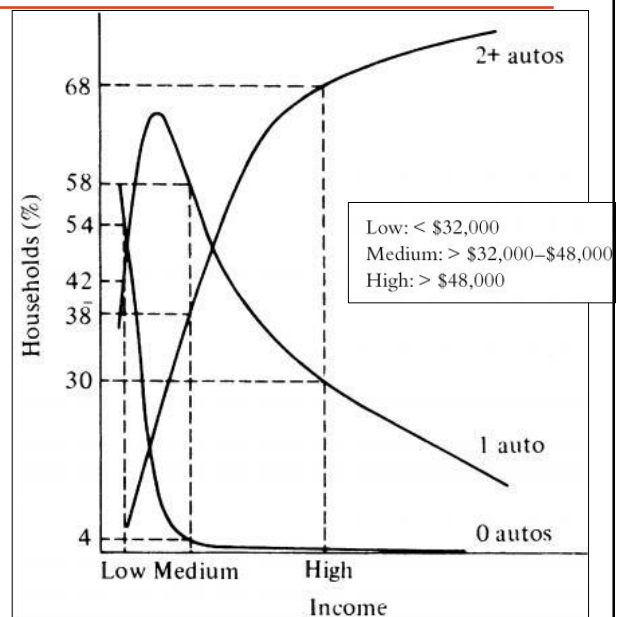
- The graph shows the **relationship between household income and number of autos per household**
- X-axis:** Household income categories
  - Low: < \$32,000
  - Medium: \$32,000 – \$48,000
  - High: > \$48,000
- Y-axis:** Percentage of households (%)
- Curves represent the share of households owning:
  - 0 autos
  - 1 auto
  - 2 or more autos



15

## Interpreting the Impact of Income on Vehicle Ownership

- As household income increases:**
  - The share of **0-auto households drops sharply**
  - The share of **1-auto households peaks in the medium income range**, then declines
  - The share of **2+ auto households rises significantly** with higher income

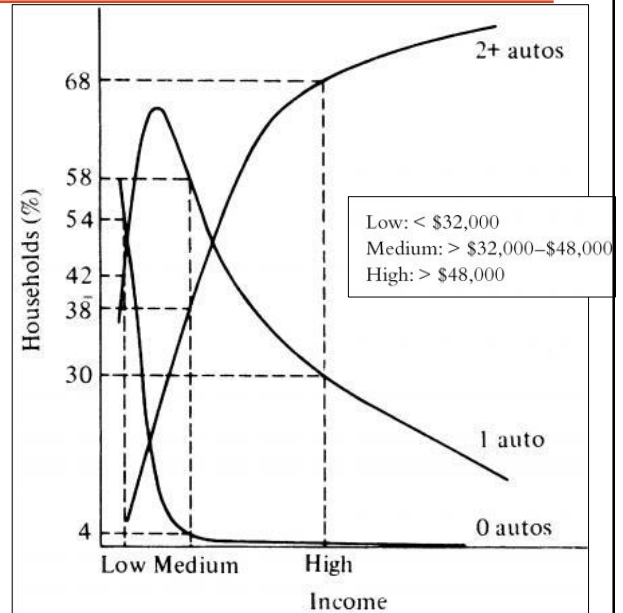


16

## Interpreting the Impact of Income on Vehicle Ownership

### Example: Zone with \$44,000 Average Income

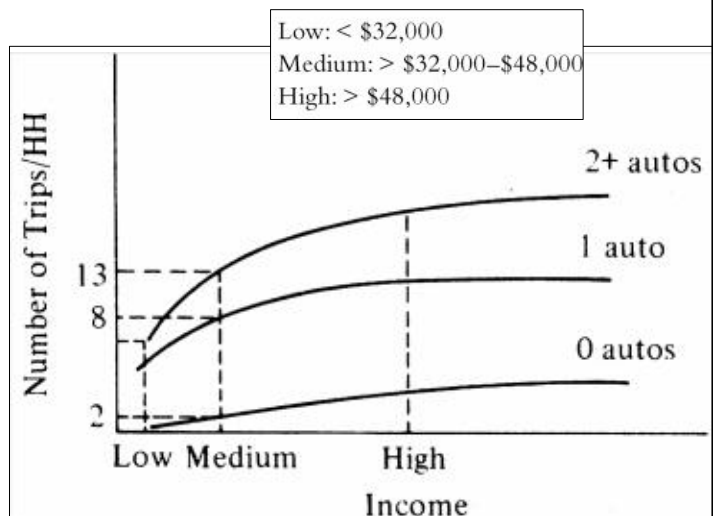
- This falls in the **medium income** category (\$32,000–\$48,000)
- Approximate distribution based on the graph:
  - 0 autos:** ~4% of households
  - 1 auto:** ~58% of households
  - 2+ autos:** ~38% of households



17

## Number of Trips per Household by Income and Auto Ownership

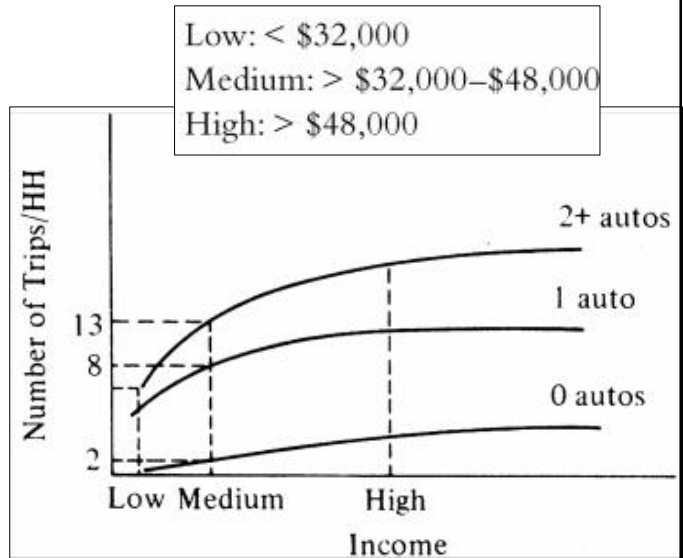
- This graph shows how **trip generation** varies by:
  - Household **income category** (Low, Medium, High)
  - Number of **autos per household** (0, 1, 2+)
- X-axis:** Income level
  - Low: < \$32,000
  - Medium: \$32,000–\$48,000
  - High: > \$48,000
- Y-axis:** Number of daily trips per household
- Three curves indicate trips per:
  - 0-auto households**
  - 1-auto households**
  - 2+ auto households**



18

## Interpreting Trip Production by Income and Vehicle Ownership

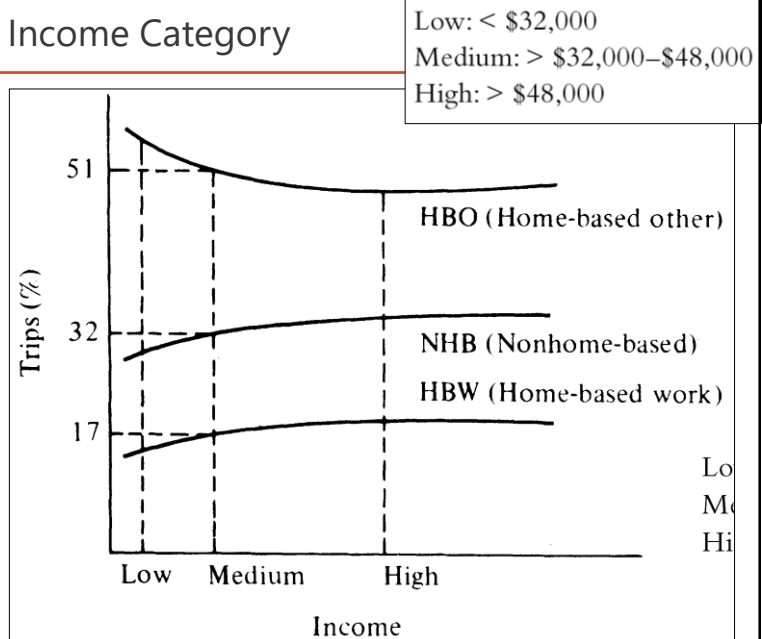
- As both income and vehicle ownership increase, **trip production also increases**
- For example, Zone with \$44,000 Average Income..... at **medium** income:
  - 0-auto HHs ≈ 2 trips/day
  - 1-auto HHs ≈ 8 trips/day
  - 2+ auto HHs ≈ 13 trips/day



19

## Trip Purpose Distribution by Income Category

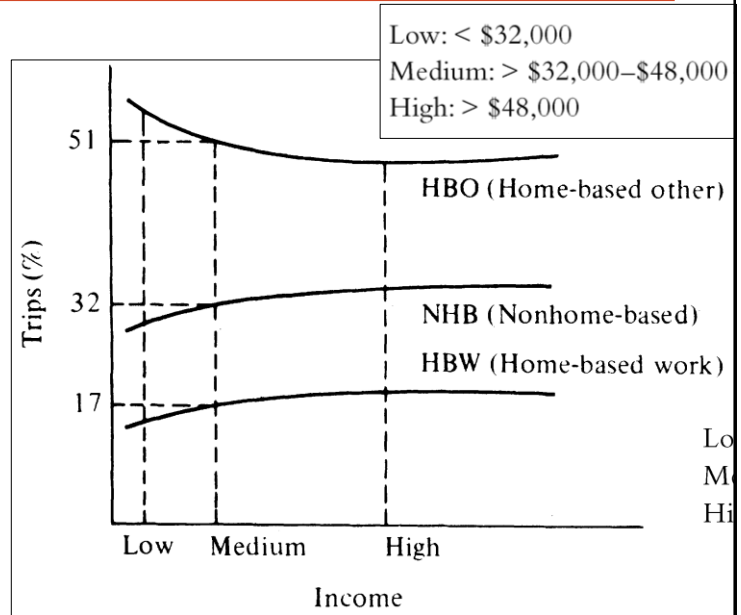
- This chart shows how **trip purposes** vary across **income groups**
- X-axis:** Income category
  - Low: < \$32,000
  - Medium: \$32,000–\$48,000
  - High: > \$48,000
- Y-axis:** Percentage of total trips (%)
- Three trip categories shown:
  - HBW:** Home-Based Work
  - NHB:** Non-Home-Based
  - HBO:** Home-Based Other
- Each curve shows the percentage of total trips from each category for different income groups



20

## Interpreting the Effect of Income on Trip Types

- For low-income households:
  - HBO trips dominate** (~51% of total trips)
  - HBW (commuting) trips make up only ~17%
- As income increases:
  - HBW trips increase slightly** (more work-related travel)
  - NHB trips increase modestly**
  - HBO trips decrease in share**, but still remain dominant

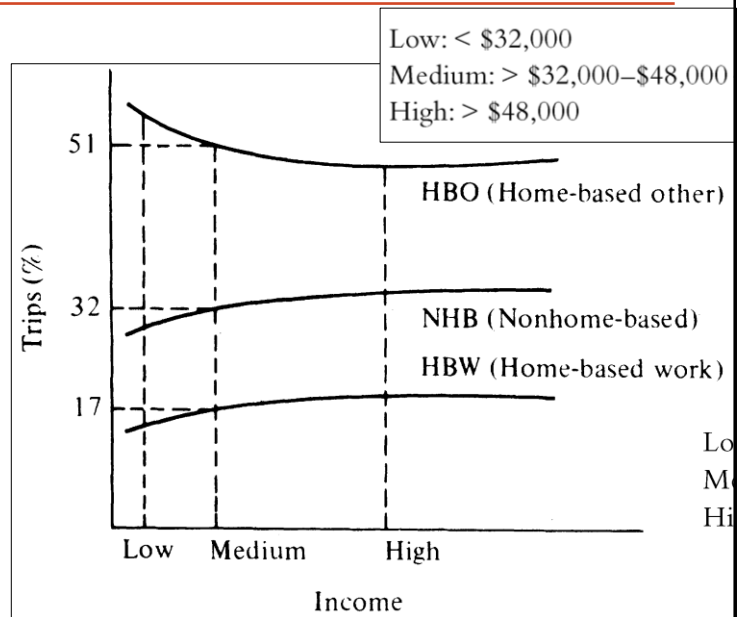


21

## Interpreting the Effect of Income on Trip Types

**Example: Zone with Average Household Income of \$44,000 (Medium Income)**

- Estimated **trip purpose shares** (based on chart and medium income range):
  - HBO (Home-Based Other):** ~51% of trips
  - NHB (Non-Home-Based):** ~32% of trips
  - HBW (Home-Based Work):** ~17% of trips



22

# Example No .1

## Developing Trip Generation Curves from Household Data

24

### Example No .1 : Developing Trip Generation Curves from Household Data

A travel survey produced the data shown in Table 12.1.

Twenty households were interviewed

Based on the data provided, develop a set of curves showing

1. The number of trips per household versus auto ownership?
2. The number of trips per household versus income

**Table 12.1** Survey Data Showing Trips per Household, Income, and Auto Ownership

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

25

25

## Cross – Classification

### *Solution of Example No. 1:*

**Step 1 :** Produce a matrix that shows the number and percentage of households as a function of auto ownership and income grouping

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

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

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

26

26

## Cross – Classification

### *Solution of Example No. 1:*

**Step 2 :** Produce a matrix shows Average Trips per Household versus Income and Car Ownership

**Table 12.3** Average Trips per Household versus Income and Car Ownership

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

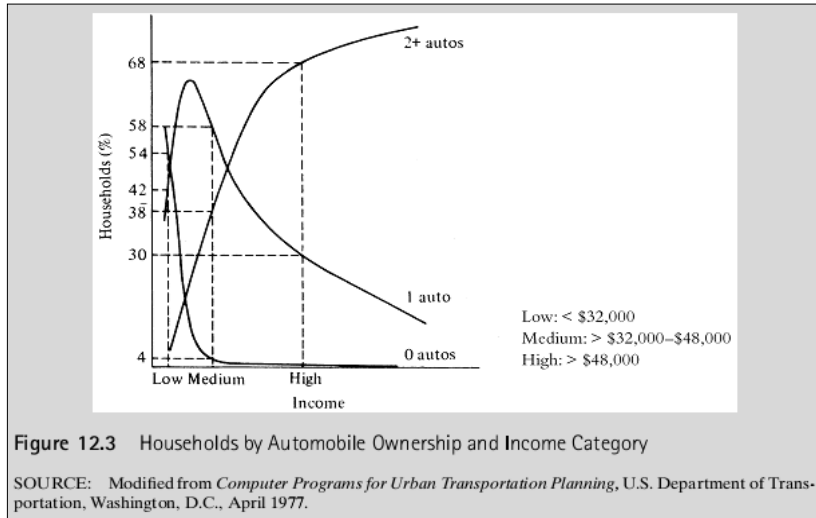
27

27

## Cross – Classification

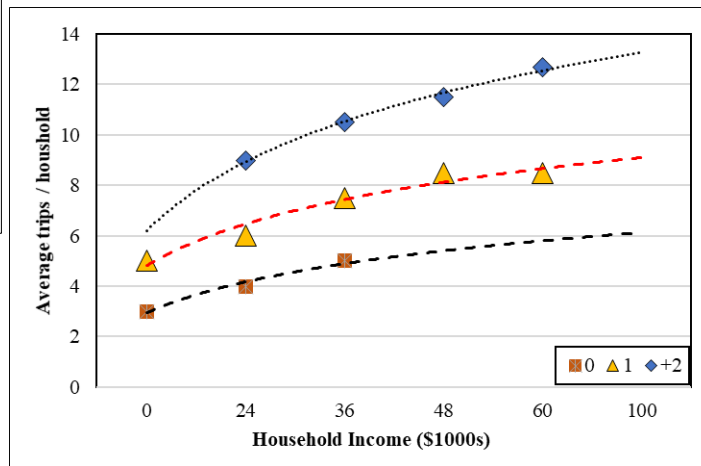
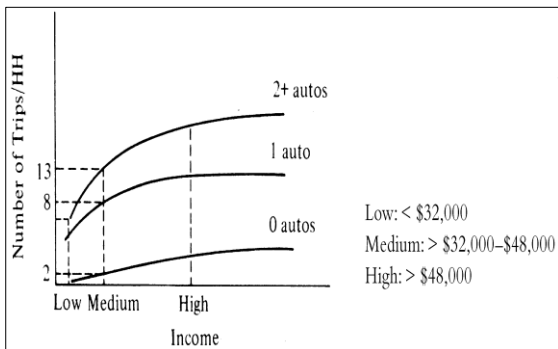
Solution of Example No. 1:

**Step 23** Plot Average Trips per Household versus Income and Car Ownership



## Cross – Classification

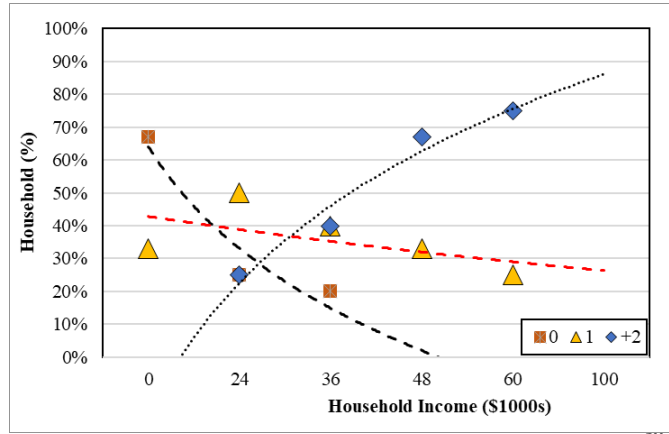
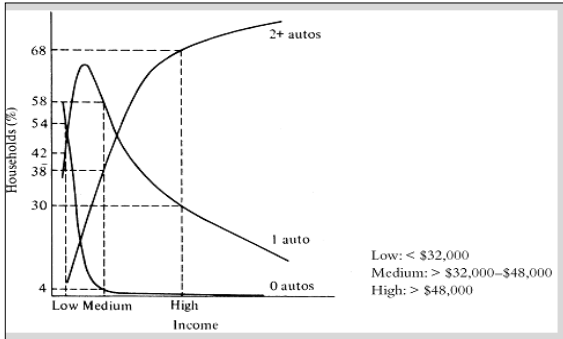
Solution of Example No. 1:



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

## Cross – Classification

Solution of Example No. 1:



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

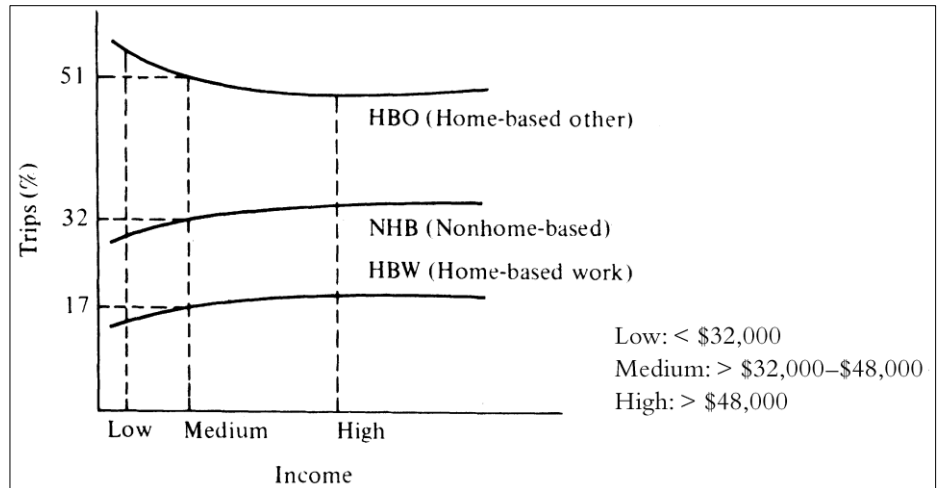
30

30

## Cross – Classification

Solution of Example No. 1:

**Addition work (Step 3):** Determine the percentage of trips by each trip purpose for each income category



\* Data is not given in the example

31

31

# Case Study

32

## Estimation of Trip Generation Rates for Residential Areas in Jordan

*Hashem R. Al-Masaeid<sup>1)</sup> and Sanaa S. Fayyad<sup>2)</sup>*

### ABSTRACT

The objective of this study was to **develop trip generation for residential areas**, where Irbid city was selected as a case study. **Household survey was carried out to collect data on trips and their purposes on typical workdays and holidays.** **Socio-economic characteristics of households were also obtained through field interviews.** **A total sample of about 2500 households was interviewed. 100 households were interviewed for validation purposes.** **Both regression analysis and cross-classification approach were used to model trip generation rates.** Analysis carried out in the study indicated that **the number of generated trips is influenced by family size, car ownership and income level.** On workdays, the analysis indicated that the number of home-based work trips constitutes about one-third of the total home-based trips. Also, it was found that the number of trips on holidays represent nearly one-third of the number of trips generated on workdays. Although performance of both approaches was very well, cross-classification approach proved to yield more accurate values. Compared with developed countries, trip generation rates for residential areas in Jordan were found to be substantially low.

33

33

Table 3. Cross-classification rates of HBO and NHB in Irbid city on a holiday

Income level	Family size/HH (sample size)	Car ownership					
		Zero		One		Two+	
		HBO	NHB	HBO	NHB	HBO	NHB
Low income	≤3/(120)	1.9	0.01	2.1	0.01	NA	NA
	4/(201)	2.0	0.03	2.5	0.03	NA	NA
	5/(191)	2.2	0.05	2.8	0.06	NA	NA
	6/(195)	2.3	0.05	2.9	0.05	NA	NA
	7/(162)	2.5	0.05	3.3	0.07	NA	NA
≥8/(119)	3.5	0.06	3.8	0.07	NA	NA	
Medium income	≥3/(124)	3.9	0.03	5.1	0.05	5.5	0
	4/(147)	5.0	0.05	6.1	0.07	6.5	0.03
	5/(163)	5.4	0.05	6.5	0.09	6.8	0.04
	6/(148)	5.55	0.06	6.9	0.11	7.3	0.03
	7/(155)	5.8	0.06	7.1	0.12	7.99	0.04
≥8/(80)	6.1	0.07	7.3	0.13	8.1	0.06	
High income	≤3/(24)	4.0	0	5.2	0.02	8.7	0.76
	4/(83)	5.2	0.04	5.5	0	5.9	0.7
	5/(79)	6.1	0	6.8	0.05	7.3	0.65
	6/(89)	6.6	0.07	7.1	0	7.56	0.63
	7/(77)	7.1	0	7.5	0	8.2	0.5
≥8/(55)	7.5	0	7.9	0	9.3	0.1	

34

34

Table 2. Cross-classification averages of HBW, HBO and NHB trips in Irbid city on a workday

Income level	Family size/HH (sample size)	Car ownership								
		Zero			One			Two+		
		HBW	HBO	NHB	HBW	HBO	NHB	HBW	HBO	NHB
Low income	≤3/(120)	1.62	5.18	.65	1.8	5.3	0.93	NA	NA	NA
	4/(201)	1.7	6.2	1.0	2.2	6.4	1.0	NA	NA	NA
	5/(191)	1.94	8.0	1.1	2.6	8.9	1.3	NA	NA	NA
	6/(195)	2.3	9.6	1.6	3.8	9.4	1.4	NA	NA	NA
	7/(162)	3.2	12.4	1.8	4.2	13.2	1.44	NA	NA	NA
≥8/(119)	4.0	12.5	2.1	4.6	13.4	1.5	NA	NA	NA	
Medium income	≤3/(124)	1.98	6.52	1.4	2.0	7.1	1.35	2.8	4.2	1.0
	4/(147)	2.4	9.0	2.3	2.7	9.2	1.6	1.6	11.7	1.0
	5/(163)	3.0	11.0	2.5	3.2	11.0	1.7	3.2	12.0	0.95
	6/(148)	4.0	11.2	2.7	4.2	11.28	2.0	4.8	12.2	0.90
	7/(155)	4.2	12.4	2.9	4.6	12.4	2.0	5.6	12.6	0.80
≥8/(80)	4.6	12.5	3.1	5.6	13.2	2.3	6.2	14.4	0.70	
High income	≤3/(24)	3.0	8.4	1.9	4.0	9.8	1.9	4.6	9.8	0.76
	4/(83)	4.0	8.78	2.3	4.2	10.2	2.4	5.4	10.2	0.70
	5/(79)	4.6	11.2	2.5	5.4	11.8	2.5	6.2	12.6	0.65
	6/(89)	3.6	12.2	2.7	5.8	14.8	2.8	6.6	15.0	0.63
	7/(77)	6.2	13.4	3.1	6.2	16.0	2.9	7.0	12.5	0.50
≥8/(55)	7.4	14.3	3.5	6.8	18.2	2.9	8.2	20.0	0.40	

NA: Not available.

35

35

Table 5. Comparison between total home-based production trips

Income level	Family size	Car ownership								
		Zero			One			Two+		
		Irbid	ITE	Dohuk	Irbid	ITE	Dohuk	Irbid	ITE	Dohuk
Low income	≤ 3	6.8	10.3	7.07	7.1	9.9	7.2	NA	NA	NA
	4	7.9	11.5	8.36	8.5	10.3	8.4	NA	NA	NA
	5	10.1	13.2	11.77	11.5	14.2	11.92	NA	NA	NA
	6	12.0	15.6	12.3	13.2	15.8	13.13	NA	NA	NA
	7	15.8	19.8	16.1	17.5	19.7	18.0	NA	NA	NA
	≥ 8	16.5	NA	16.49	17.8	NA	18.1	NA	NA	NA
Medium income	≤ 3	8.5	14.1	10.1	9.1	15	10.5	11.2	16.3	NA
	4	11.8	14.5	12.3	12.9	16.9	13.0	14.9	17.1	NA
	5	14.1	17.1	14.67	13.9	17	14.1	16.1	17.4	NA
	6	15.3	18.9	15.2	14.8	18.1	15.0	16.9	18.1	NA
	7	16.3	19.1	16.1	16.7	19.2	17.2	17.9	19.3	NA
	≥ 8	17.1	NA	18.2	18.8	NA	19.1	20.5	NA	35.6
High income	≤ 3	11.4	15	12	13.8	15.9	14.1	14.4	17.0	NA
	4	12.78	15.3	14	14.6	17.0	15.0	15.8	18.3	NA
	5	15.8	28.0	16.1	17.4	18.2	17.7	18.5	19.0	NA
	6	15.8	NA	18.0	19.1	20.0	20.0	21.6	NA	21.7
	7	19.4	NA	20.1	23.1	NA	23.5	22.6	NA	23.1
	≥ 8	21.7	NA	22.0	25.0	NA	35.2	28.1	NA	28.3

NA: Not available.

36

36

## Example No .2

Computing Trips Generated in a Suburban Zone

37

## Cross – Classification

- ↪ Consider a zone that is located in a suburban area of a city.
  - The population and income data for the zone are as follows.
    - ❖ Number of dwelling units: **60**
    - ❖ Average income per dwelling unit: **\$44,000**
- ↪ Determine the **number of trips per day** generated in this zone for each trip purpose, assuming that the characteristics depicted in **Figures 12.2 through 12.5** apply in this situation.



38

38

## Cross – Classification

*Solution of Example No .2*

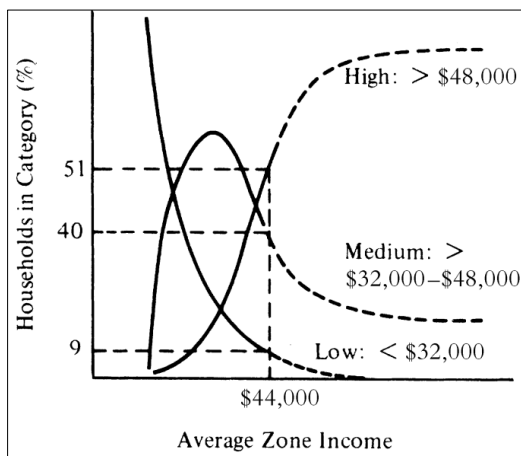


Figure 12.2

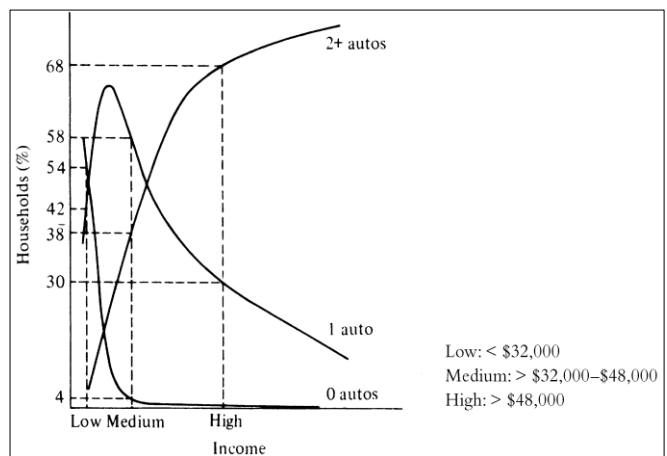


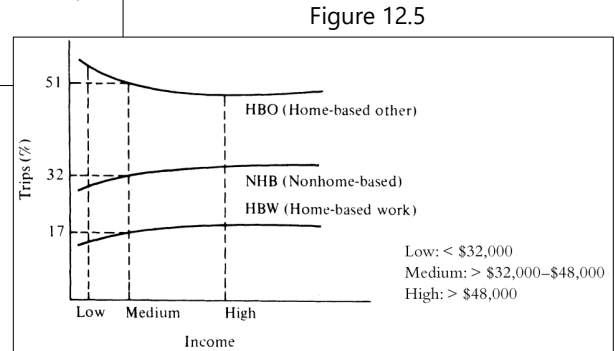
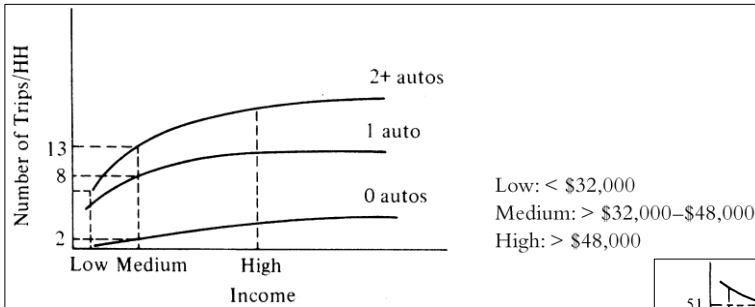
Figure 12.3

39

39

## Cross – Classification

Solution of Example No .2

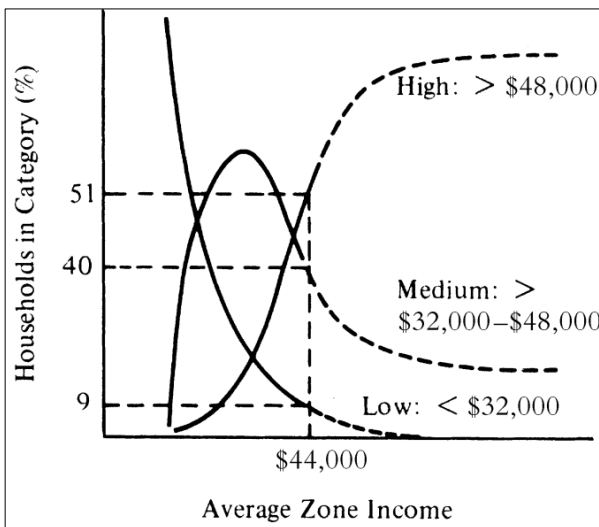


40

## Cross – Classification

Solution of Example No .2

**Step 1 :** Determine the percentage of households in each economic category



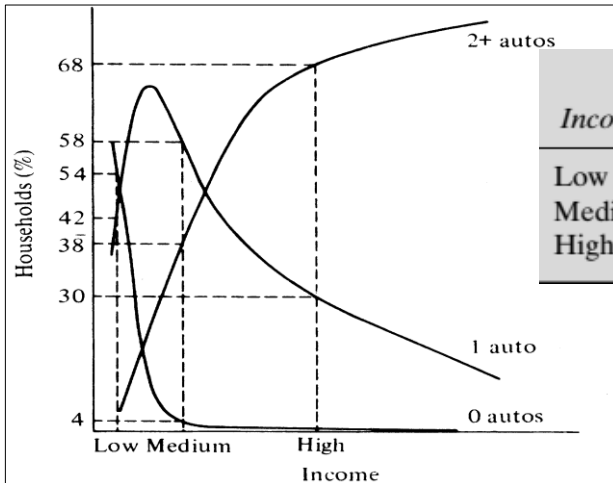
Income (\$)	Households (%)
Low (under 32,000)	9
Medium (32,000 – 48,000)	40
High (over 48,000)	51

41

## Cross – Classification

*Solution of Example No .2*

**Step 2 :** Determine the number of trips per household per day for each income–auto ownership category.



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

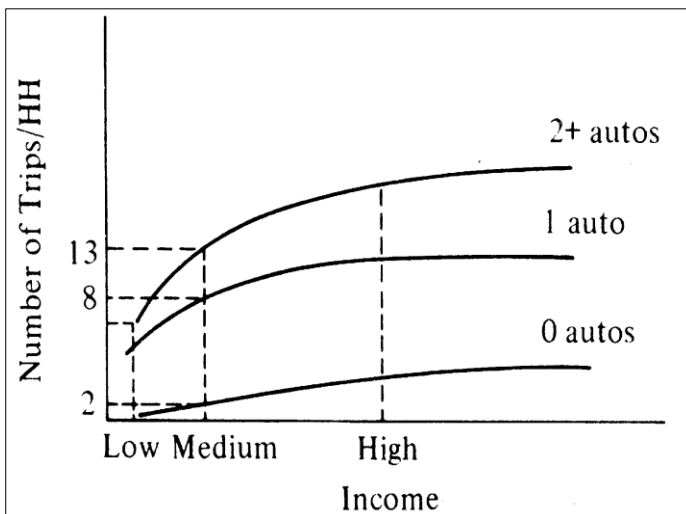
42

42

## Cross – Classification

*Solution of Example No .2*

**Step 3:** Determine the number of trips per household per day for each income–auto ownership category



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

58% of medium-income families own one auto per household.

43

43

## Cross – Classification

### Solution of Example No .2

**Step 4:** Calculate the total number of trips per day generated in the zone

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

$$P_T = \sum_g^3 \sum_h^3 P_{gh}$$

$HH$  = number of households in the zone

$I_g$  = percentage of households (decimal) in zone with income level  $g$  (low, medium, or high)

$A_{gh}$  = percentage of households (decimal) in income level  $g$  with  $h$  autos per household ( $h = 0, 1, \text{ or } 2+$ )

$P_{gh}$  = number of trips per day generated in the zone by householders with income level  $g$  and auto ownership  $h$

$(P_H)_{gh}$  = number of trips per day produced in a household at income level  $g$  and auto ownership  $h$

$P_T$  = total number of trips generated in the zone

44

44

## Cross – Classification

### Solution of Example No .2

**Step 4:** Calculate the total number of trips per day generated in the zone

**Table 12.6** Number of Trips per Day Generated by Sixty Households

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

46

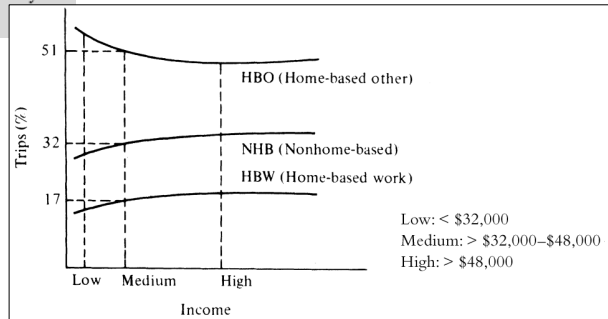
46

## Cross – Classification

### *Solution of Example No .2*

#### **Step 5 :** Determine the percentage of trips by trip purpose

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



47

47

## Trip generation

### *by Trip types*

48

48

## Trip generation

### *Trip types*

#### ↳ Trip production

- All the trips of home based
- The origin of the non home-based trips

#### ↳ Trip attraction

- Trips do not classify as trip production

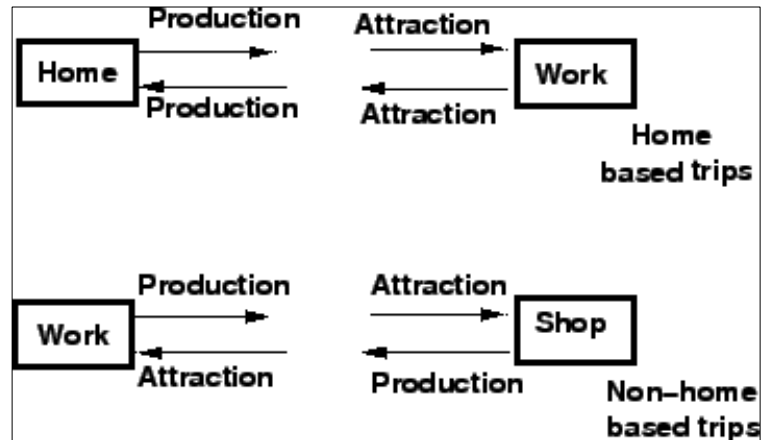


Image source: [https://www.civil.iitb.ac.in/~vmtom/1100\\_LnTse/203\\_InTse/plain/](https://www.civil.iitb.ac.in/~vmtom/1100_LnTse/203_InTse/plain/)

49

49

## Trip generation

### *Trip types*

#### ↳ Attracted ( $T_a$ ) trips

- $T_a$  is function with **land use**

#### ↳ Produced ( $T_p$ ) trips?

- $T_p$  is function with
  - ❖ Population
  - ❖ Income
  - ❖ Household size
  - ❖ Number of household size
  - ❖ Vehicle owned

50

50

## Trip generation

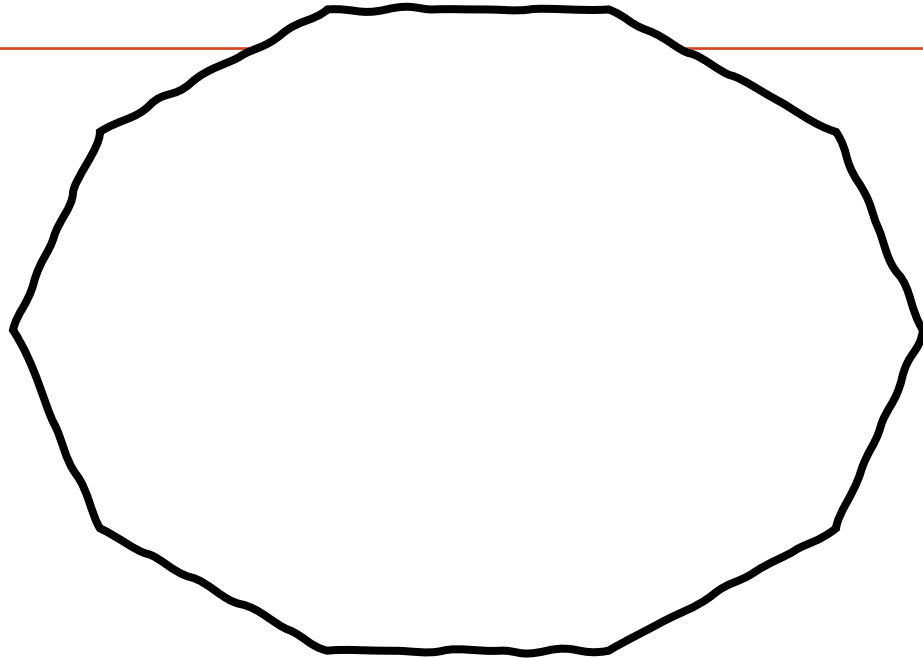
TRIP PURPOSE	MODEL TYPE	INDEPENDENT VARIABLES	REGRESSION	R <sup>2</sup>
TO HOME	PRODUCED	POPULATION	$P = 0.514X_1 - 9.717$	0.745
	ATTRACTED	WORKERS PER ZONE & STUDENTS PER ZONE	$A = 0.812X_6 + 0.943X_{13} - 84.621$	0.983
TO WORK	PRODUCED	NO. OF HOUSEHOLDS	$P = 1.368X_2 - 225.047$	0.868
	ATTRACTED	WORKERS PER ZONE	$A = 0.8698X_6 - 192.25$	0.987
TO SCHOOL	PRODUCED	NO. OF HOUSEHOLDS	$P = 0.9851X_2 + 43.649$	0.737
	ATTRACTED	STUDENTS PER ZONE	$A = 0.8355X_{13} + 41.39$	0.972

Image source: Aloc, D. S. & Amar, J. A. N. A. C. Trip Generation Modeling of Lipa City Trip Generation Modelling of Lipa City. (2014). doi:10.13140/2.1.2171.7126

51

51

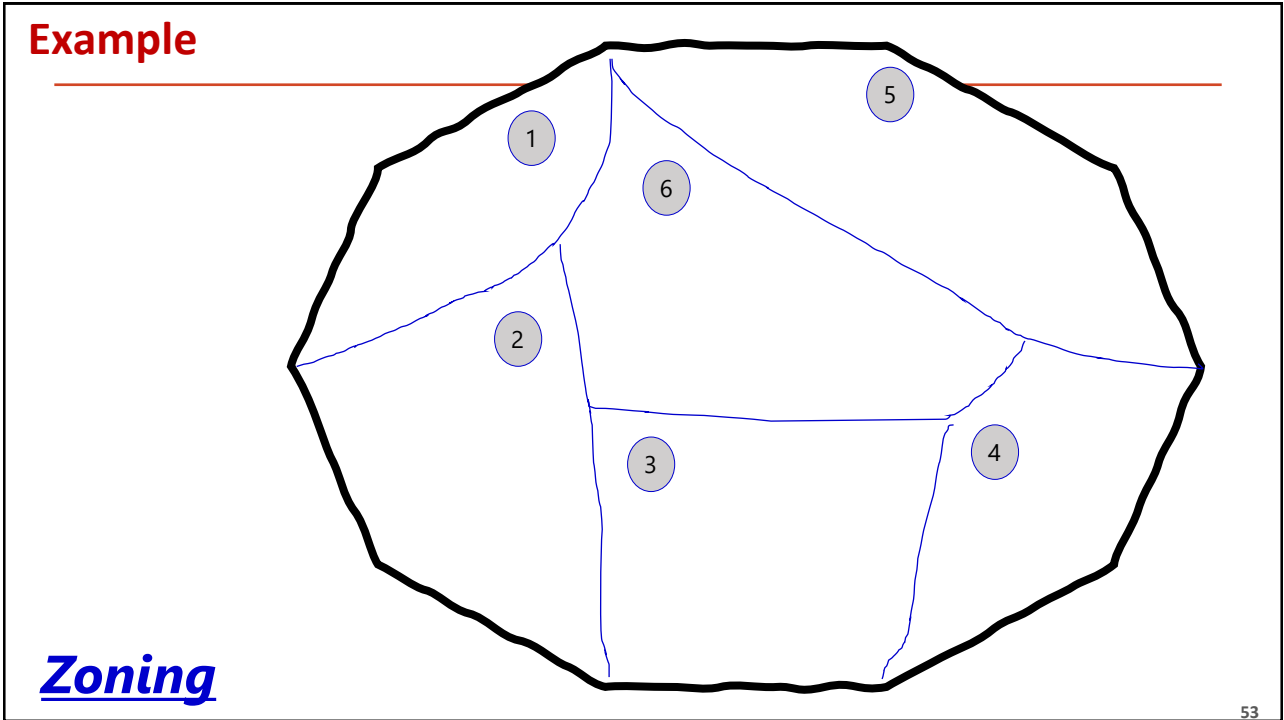
## Example



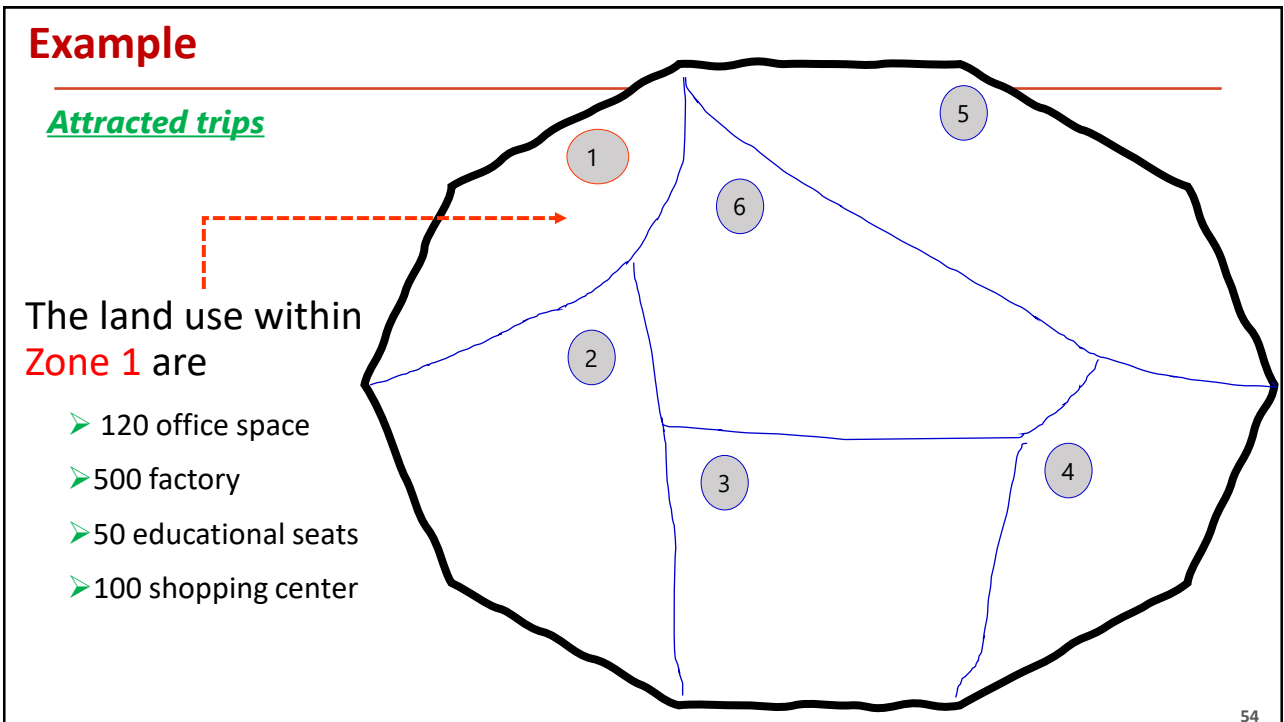
**Study**  
**area**

52

52



53



54

## Example

How many trips are attracted ( $T_a$ ) and produced to a zone 1?

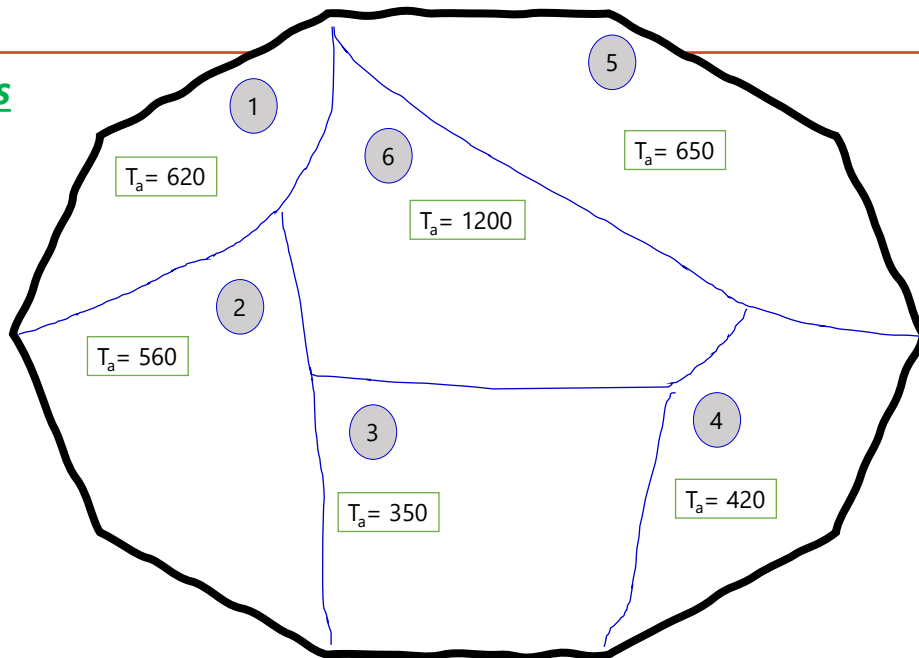
Land use ( By survey)	Number of units ( By survey)	Trip rates (manual)	Attracted ( $T_a$ ) trips (column 2 X column 3)
office space	120	1.18	472
factory	500	0.43	64.5
educational seats	50	1.2	108
shopping center	100	2.1	630
Total attracted trips ( $T_a$ )			<b>626</b>

55

55

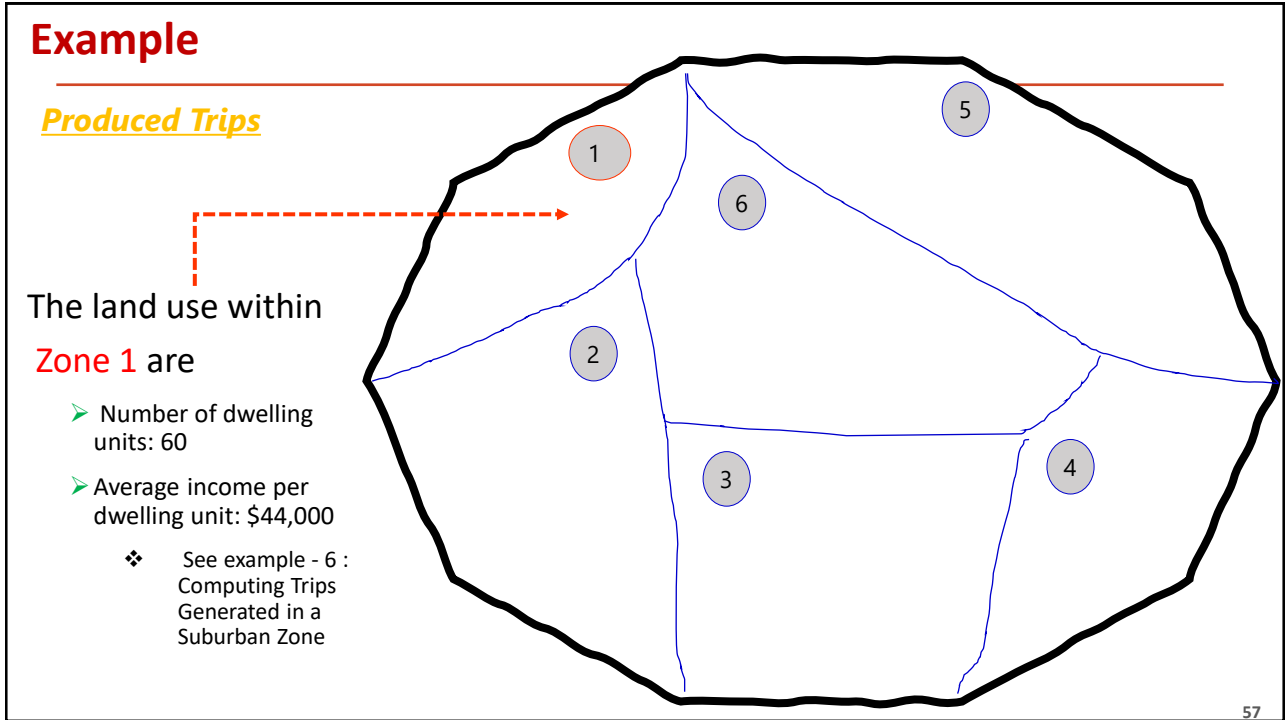
## Example

Attracted trips

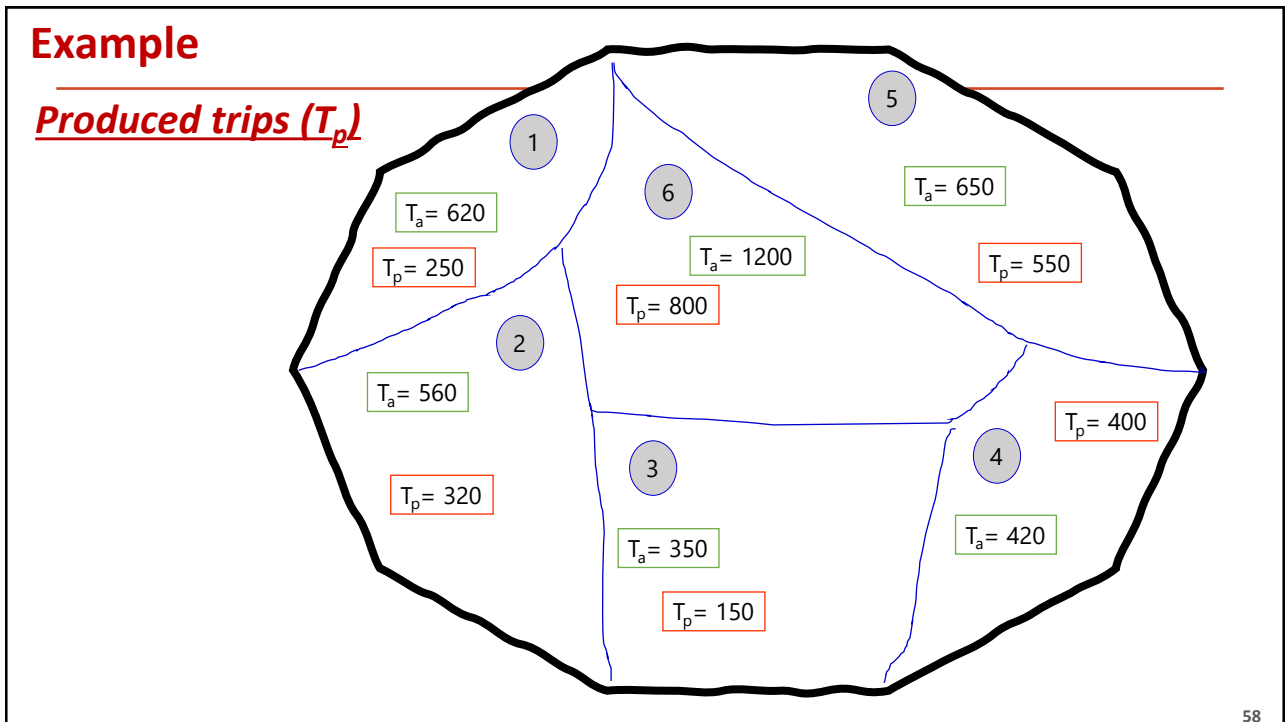


56

56



57



58

## Balancing Trip Productions and Attraction



- ↪ A likely result of the trip generation process is that the number of trip productions **may not be** equal to the number of trip attractions
- ↪ Trip productions
  - which are *based on census data*, are considered to be more accurate than trip attractions
  - Therefore,
    - Trip attractions are usually modified so that they are equal to trip productions

59

59

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## Balancing Trip Productions and Attraction

*Example No.1 : Balancing the Home-based trips*

60

60

## Balancing Trip Productions and Attraction

### Example No.1 : Balancing the Home-based trips

- ↪ The trip generation process between zone 1 through zone 3 has produced
  - 600 HBW productions trips
  - 800 HBW attraction trips
- It requires to balancing trip productions and attraction in this zone

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

61

61

## Balancing Trip Productions and Attraction

### Solution of Example No.1

- ↪ Trip correction factor =  $\frac{\text{Total Unbalanced Production trips}}{\text{Total Unbalanced Attraction trips}}$
- ↪ Trip correction factor =  $\frac{600}{800} = 0.75$

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

62

62

## Balancing Trip Productions and Attraction

*Solution of Example No.1*

↳  $Balanced\ attraction\ trips = Trip\ correction\ factor \times Unbalanced\ attractions\ trips$

**Table 12.8a** Balancing Home-Based Work Trips

Zone	Unbalanced HBW Trips		Balanced HBW Trips		
	Productions	Attractions	Productions	Attractions	
1	100	240	100	180	= (240*0.75) = 180
2	200	400	200	300	
3	300	160	300	120	
Total	600	800	600	600	

63

63

## Balancing Trip Productions and Attraction

*Example No.2 : Balancing the NON-Home-based trips*

64

64

## Balancing Trip Productions and Attraction

*Example No.2 : Balancing the Home-based trips*

- ↪ The trip generation process between zone 1 through zone 3 has produced
  - 600 NHB productions trips
  - 800 NHB attraction trips
- It requires to balancing trip productions and attraction in this zone

**Table 12.8b** Balancing Non-Home-Based Trips

Zone	Unbalanced NHB Trips	
	NHB Productions	NHB Attractions
1	100	240
2	200	400
3	300	160
<b>Total</b>	<b>600</b>	<b>800</b>

65

65

## Balancing Trip Productions and Attraction

*Solution of Example No.2*

- ↪  $Trip\ correction\ factor = \frac{Total\ Unbalanced\ PRODUCTION\ trips}{Total\ Unbalanced\ attraction\ trips}$
- ↪  $Trip\ correction\ factor = \frac{600}{800} = 0.75$

**Table 12.8b** Balancing Non-Home-Based Trips

Zone	Unbalanced NHB Trips	
	NHB Productions	NHB Attractions
1	100	240
2	200	400
3	300	160
<b>Total</b>	<b>600</b>	<b>800</b>

66

66

## Balancing Trip Productions and Attraction

### Solution of Example No.2

↪  $Balanced\ attraction\ trips = Trip\ correction\ factor \times Unbalanced\ attractions\ trips$

**Table 12.8b** Balancing Non-Home-Based Trips

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

$= (240 \times 0.75) = 180$

67

67

## Balancing Trip Productions and Attraction

### Solution of Example No.2

↪ An extra step is required for balancing NHB trips.

➤ This extra step is that after total productions and total attractions are equal, the productions for each zone are set equal to the attractions for each zone.

➤ The rationale behind this extra step is that

- ❖ the true origin of non-home based trips is not provided by survey or census data.
- ❖ thus the best estimate of the number of NHB trips produced in each zone is the number of NHB trips attracted to each zone.

**Table 12.8b** Balancing Non-Home-Based Trips

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

68

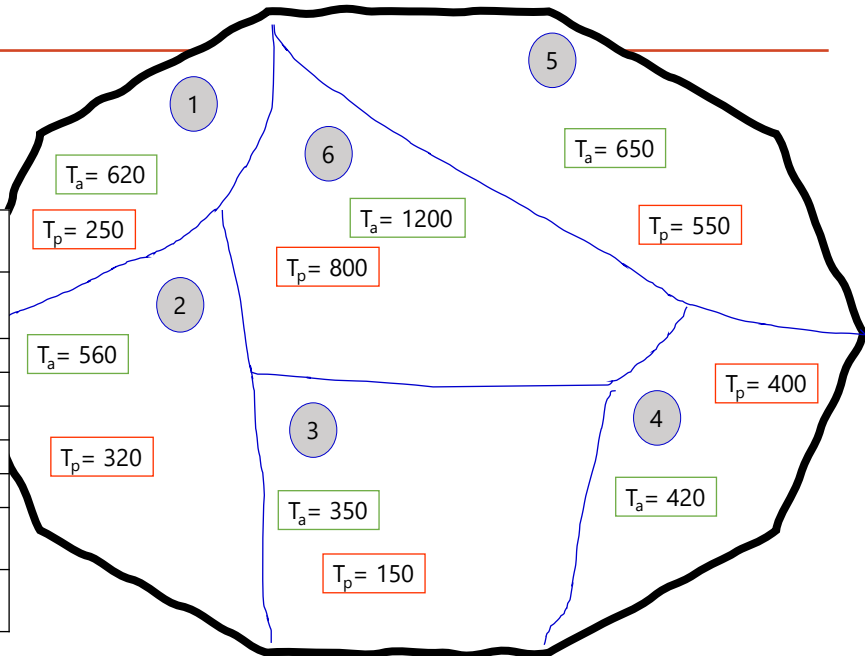
68

# Balancing Trip Productions and Attraction

## Example No.3 :

### Unbalanced Trip Productions and Attractions

Zone ID	Unbalanced trips	
	Production	Attraction
1	250	620
2	320	560
3	150	350
4	400	420
5	550	650
6	800	1200
Total trips	2470	3800



### Balancing Trip Productions and Attractions

↳ Trip correction factor =  $\frac{\text{Total Unbalanced production trips}}{\text{Total Unbalanced attractions trips}}$

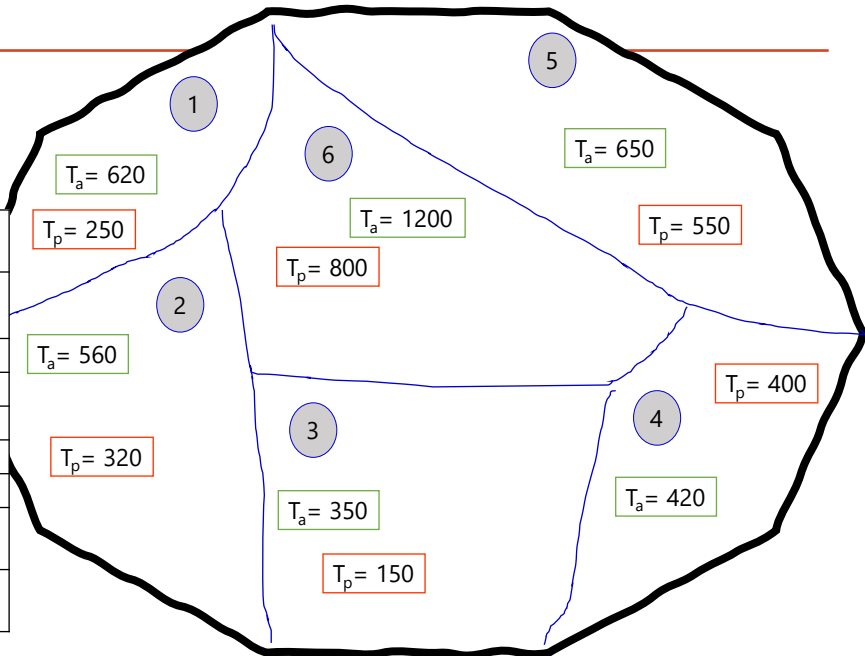
➤ Trip correction factor =  $\frac{2470}{3800} = 0.65$

Zone ID	Unbalanced trips		Balanced trips	
	Production	Attraction	Production	Attraction
1	250	620	250	403
2	320	560	320	364
3	150	350	150	228
4	400	420	400	273
5	550	650	550	423
6	800	1200	800	780
Total trip	<b>2470</b>	<b>3800</b>	<b>2470</b>	<b>2470</b>

71

### Balanced Trip Productions and Attractions

Zone ID	Balanced trips	
	Production	Attraction
1	250	403
2	320	364
3	150	228
4	400	273
5	550	423
6	800	780
Total trips	<b>2470</b>	<b>2470</b>



72

# *Transportation Engineering and Planning*

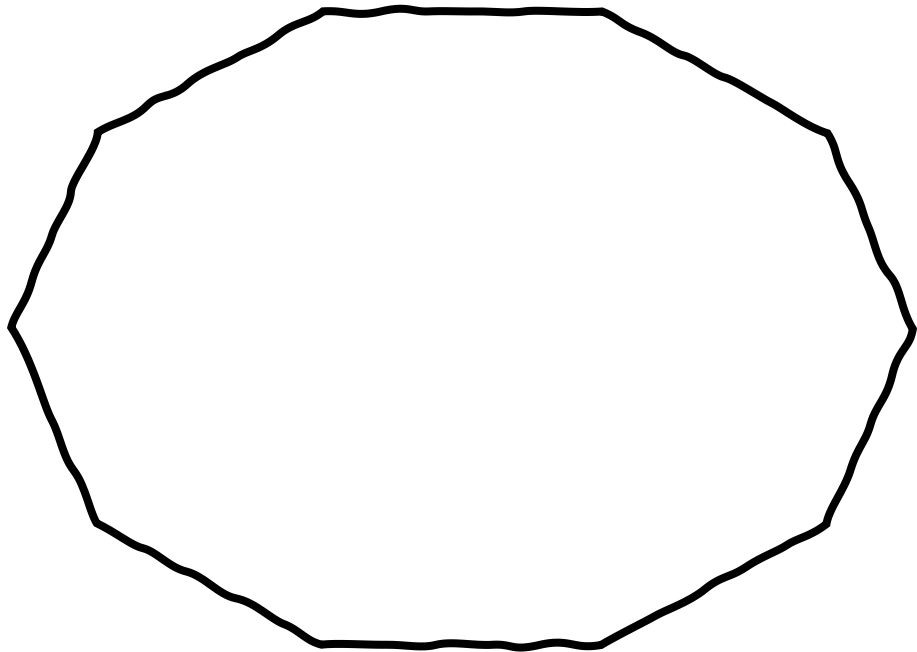
Module | 3 | Forecasting Travel in Urban Transportation Planning

## 3.6 | Trip Distribution

*Dr. Hamza Mohammad Alkuime*

1

**Review**

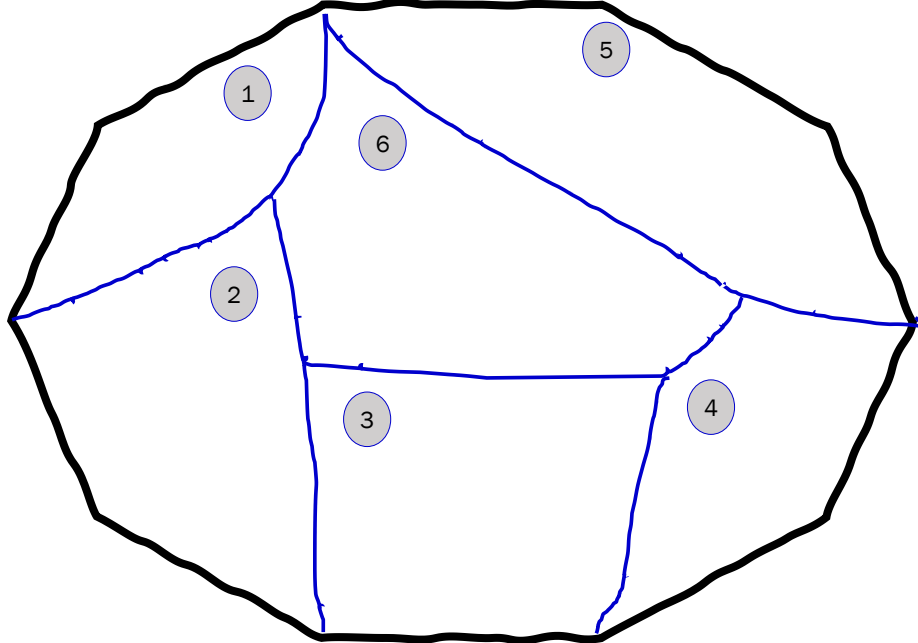


**Study area**

2

2

## Review



## Zoning

3

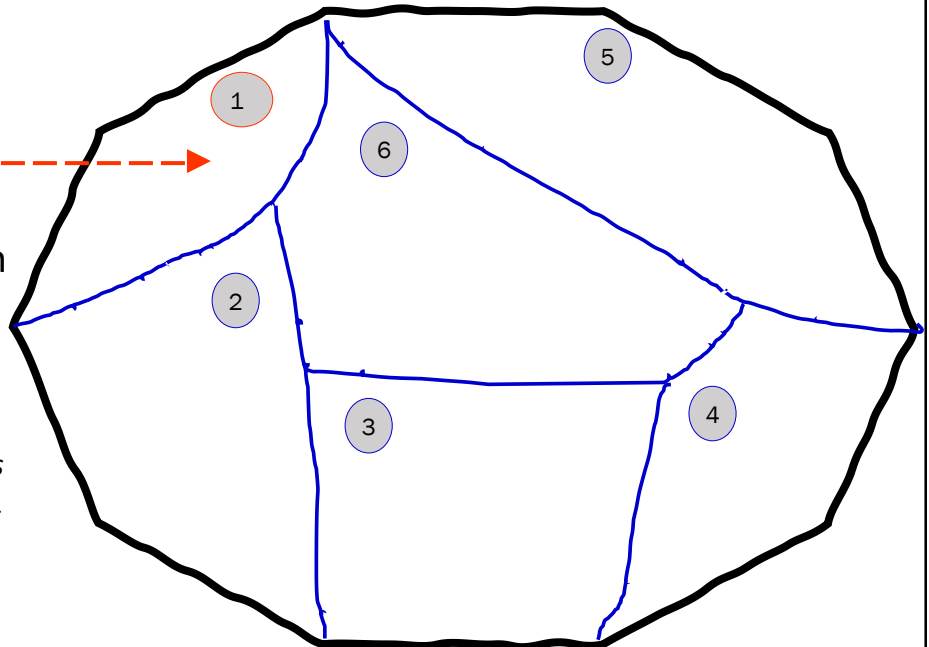
3

## Review

### Attracted trips

The land use within  
**Zone 1** are

- 120 office space
- 500 factory
- 50 educational seats
- 100 shopping center



4

4

## Review

How many trips are attracted ( $T_a$ ) and produced to a zone 1?

Land use ( By survey)	Number of units ( By survey)	Trip rates (manual)	Attracted ( $T_a$ ) trips (column 2 X column 3)
office space	120	1.18	472
factory	500	0.43	64.5
educational seats	50	1.2	108
shopping center	100	2.1	630
Total attracted trips ( $T_a$ )			<b>626</b>

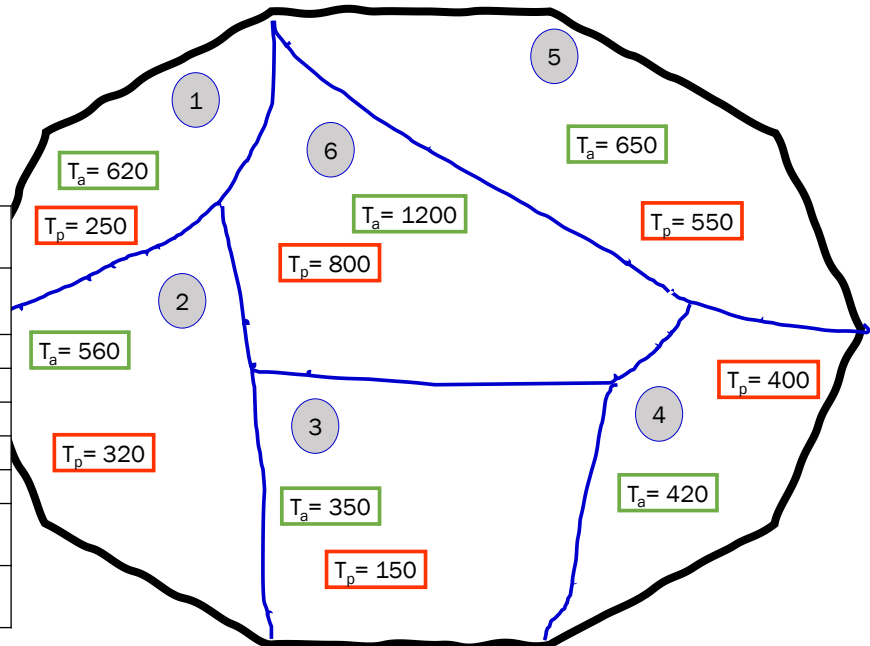
5

5

## Review

### Balanced Trip Productions and Attractions

Zone ID	Balanced trips	
	Production	Attraction
1	250	403
2	320	364
3	150	228
4	400	273
5	550	423
6	800	780
Total trips	<b>2470</b>	<b>2470</b>



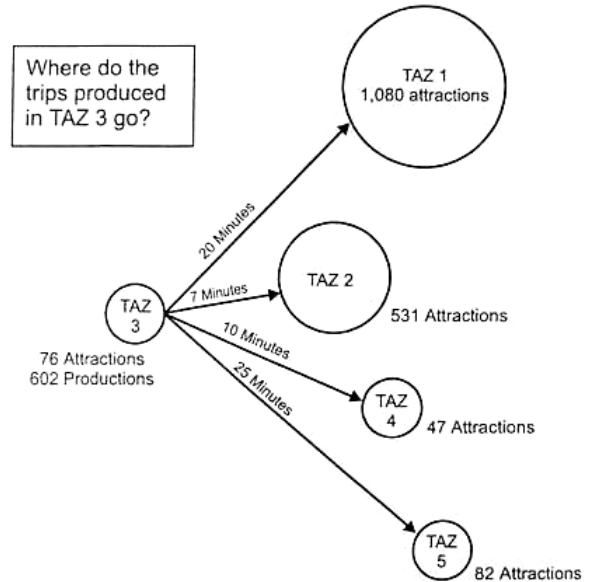
6

# Review

## Travel Forecasting Process

Four-step process”

- Trip generation
  - ❖ [How many trips](#)
- Trip distribution
  - ❖ [From where to where](#)
- Modal choice
  - ❖ [On what mode](#)
- Traffic assignment
  - ❖ [On what route](#)



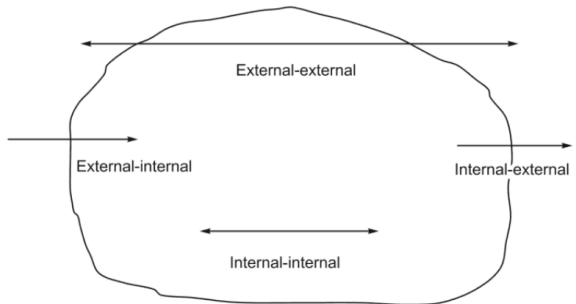
# Trip Distribution

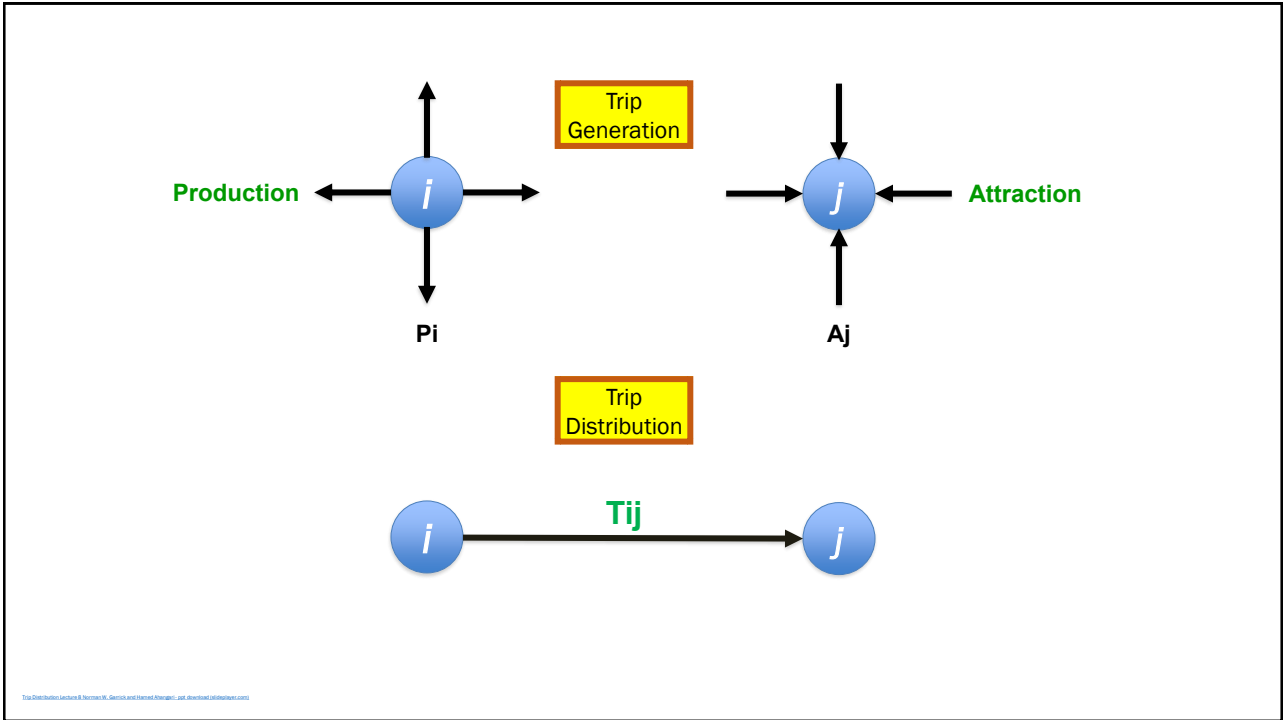
## Definition

is a process by which the trips generated in one zone are allocated to other zones in the study area.

These trips may be

- Internal-internal
  - ❖ within the study area
- Internal-external
  - ❖ between the study area and areas outside the study area





9

# Trip Distribution

- ↪ **Goal**
  - Where the trips are traveling
  - What affect the destination
    - ❖ Type of land use
    - ❖ Costs of travel between zones (Time, distance, speed )
- ↪ **Inputs**
  - Trip generated within the study area and zones
- ↪ **Output**
  - Origin- destination matrix

Origins	Destinations				$\sum_j T_{ij}$
	1	2	...	n	
1					P1
2		?			P2
...					...
m					Pm
$\sum_i T_{ij}$	A1	A2	...	An	

10

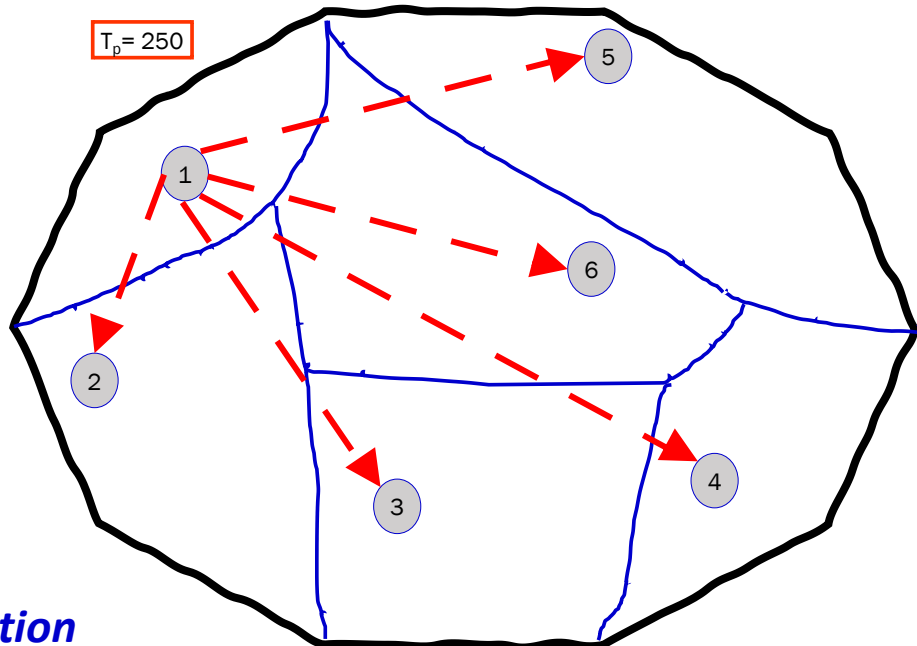
## Trip Generation $\Rightarrow$ Trip Distribution

The question is... how do we allocate all the trips among all the potential destinations?

TAZ	Prod.	TAZ	1	2	3	4	5	6	7	8	Attractions
1		1	Trip Matrix or Trip Table								9
2		2									12
3		3									4
4		4									38
5		5									45
6		6									6
7		7									4
8		8									2

11

### Example

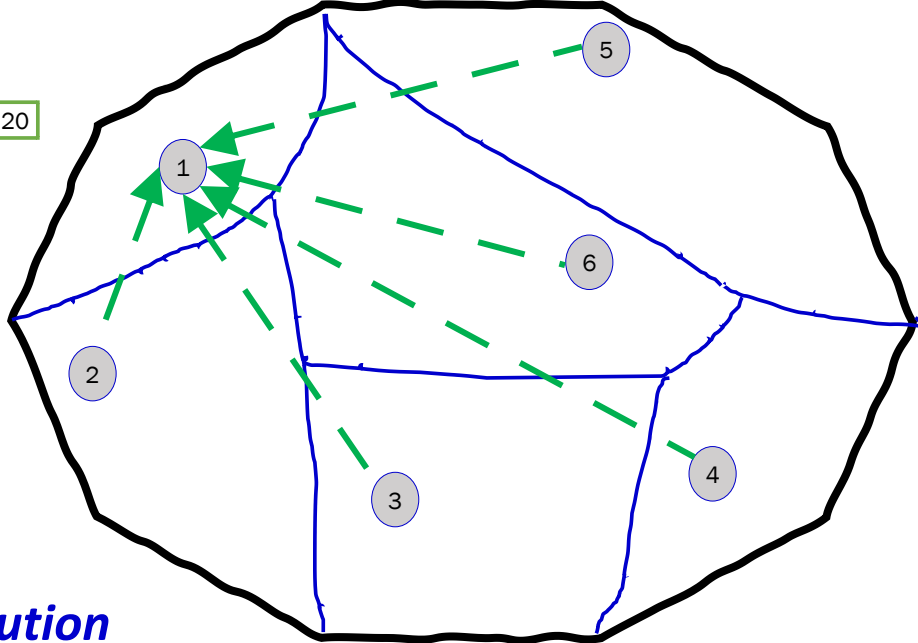


12

12

## Example

$$T_a = 620$$



Trip distribution

13

13

## Basic Assumptions of Trip Distribution

- ↪ Number of trips
  - *decrease* with *COST* between zones
  - *increase* with zone "attractiveness"

Trip Distribution Lecture 8: Homework 8, Section 8 and Homework 8 (page 1) - download | slideshare.net

14

# Trip Distribution

## Methods

### 1. Gravity model

➤ *Preferred to be used because*

- ❖ Simple and accurate
- ❖ Uses the **attributes of the transportation system** and **land-use characteristics**
- ❖ Has been **calibrated extensively for many urban areas**

### 2. Growth factor models

- *Uniform Growth Factor*
- *Singly-Constrained Growth Factor*
- *Average Factor*
- *Detroit Factor*
- *Fratar Method*

15

15

# Trip Distribution Models

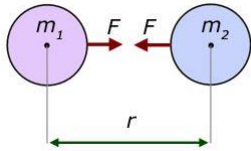
## Gravity model

16

16

## The Inspiration for the Gravity Model

- The big idea behind the gravity model is Newton's law of gravitation...



$$F = G \frac{m_1 m_2}{r^2}$$

- The force of attraction between 2 bodies is
  - *directly proportional to the product of masses between the two bodies*
  - *inversely proportional to the square of the distance*

17

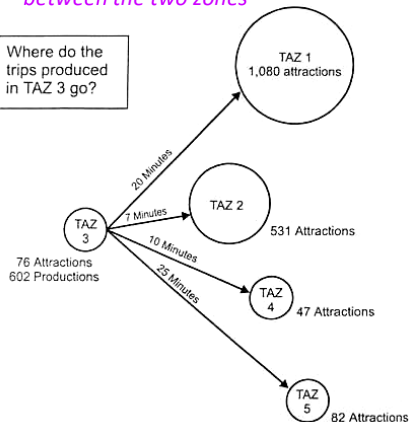
## Gravity Model

### Definition

- ↪ The number of trips between **two zones** is
  - *Directly proportional to the number of trip attractions generated by the zone of destination*
  - *Inversely proportional to a function of time of travel between the two zones*

*i is origin zone number  
j is destination zone  
n is total number of zones*

Where do the trips produced in TAZ 3 go?



$$\text{Attractiveness}_j = \frac{\# \text{ Attractions}_j}{\text{Travel Time between zone } i \text{ and zone } j}$$

$$\text{Attractiveness}_j = \frac{A_j}{t_{ij}}$$

18

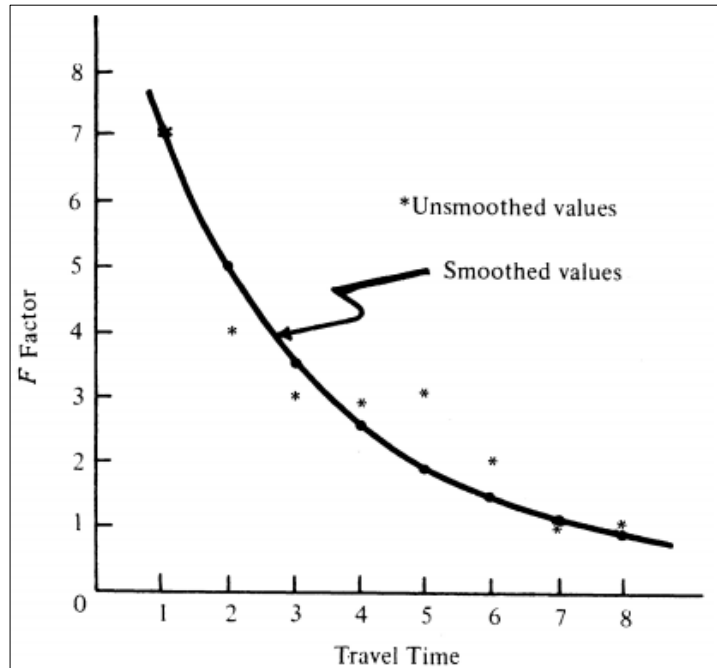
18

## Trip Distribution

### *F values for calibration*

- ↪ **What is the F-Factor?**
- ↪ Represents the **willingness** to travel between two zones.
- **High F-value** = High willingness to make the trip.
- **Low F-value** = Discouraged from making the trip.
- ↪ **The Golden Rule of Trip Distribution**
- **Inverse relationship:** As Travel Time INCREASES, the F-Factor DECREASES.

$$: F_{ij} = \frac{1}{t_{ij}}$$



19

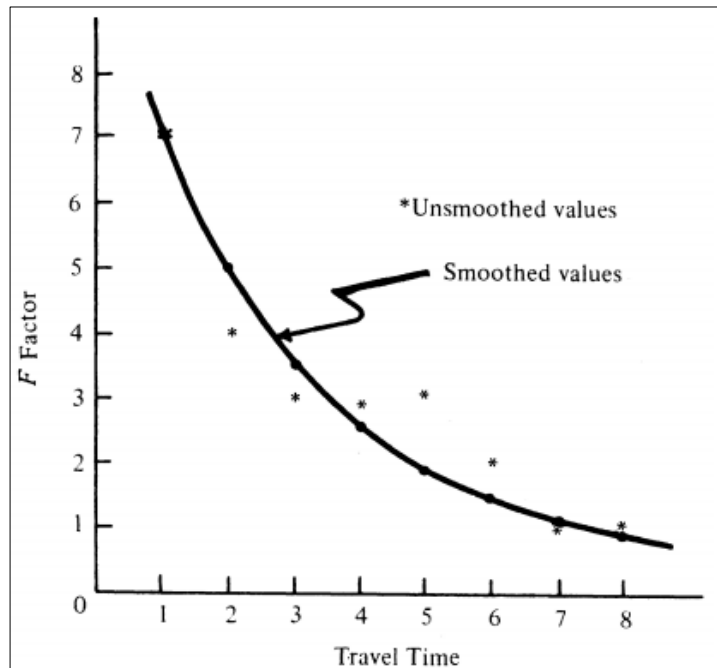
19

## Trip Distribution

### *F values for calibration*

$$Attractiveness_j = \frac{A_j}{t_{ij}}$$

$$: F_{ij} = \frac{1}{t_{ij}}$$



20

20

# Gravity Model

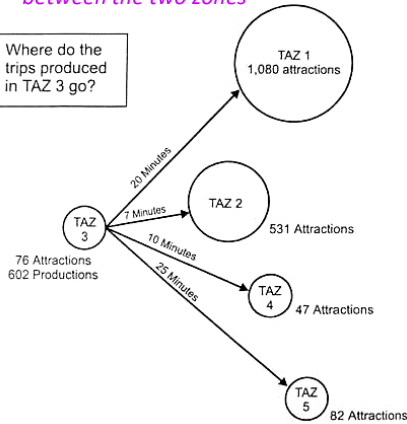
## Definition

↪ The number of trips between two zones is

- *Directly* proportional to the *number of trip attractions generated by the zone of destination*
- *Inversely* proportional to a *function of time of travel between the two zones*

*i* is origin zone number  
*j* is destination zone  
*n* is total number of zones

Where do the trips produced in TAZ 3 go?



$$\text{Attractiveness}_j = \frac{\# \text{ Attractions}_j}{\text{Travel Time between zone } i \text{ and zone } j}$$

$$\text{Attractiveness}_j = \frac{A_j}{t_{ij}}$$

$$\text{Attractiveness}_j = \# \text{ Attractions}_j \times FF_{ij}$$

21

21

# Gravity Model

## Relative Attractiveness: How Trips Choose Their Destinations

### The Concept: It's a Competition

Trips are not distributed to a destination in isolation. Destinations **compete** for trips based on their combined size and accessibility.

$$\text{Attractiveness}_j = \# \text{ Attractions}_j \times FF_{ij}$$

### How to Calculate Relative Attractiveness

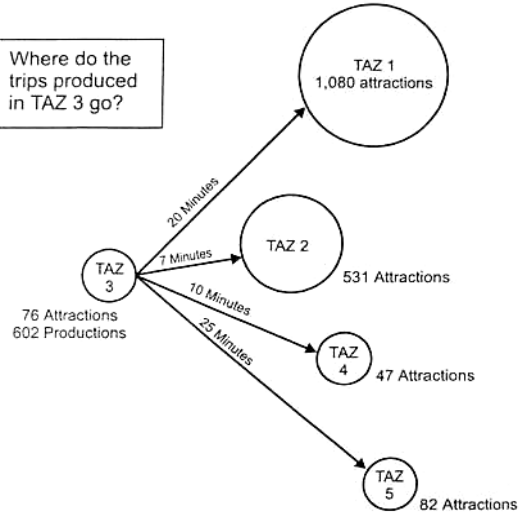
The probability that a trip produced in Zone *i* will go to Zone *j* is the **ratio** of that zone's attractiveness to the sum of attractiveness for all possible destinations:

$$\text{Probability}_{ij} = \frac{\text{Attractiveness}_j}{\sum \text{ Attractiveness of all TAZs}}$$

### Key Components

- **Attractiveness<sub>j</sub>**: The raw "pull" of a zone (e.g., jobs, retail space) adjusted by friction.
- **Numerator**: How desirable Zone *j* is.
- **Denominator (Σ)**: The total desirability of the entire region.
- **Result**: A percentage (or fraction) of total trips that will head to Zone *j*.

Where do the trips produced in TAZ 3 go?



22

# Gravity Model

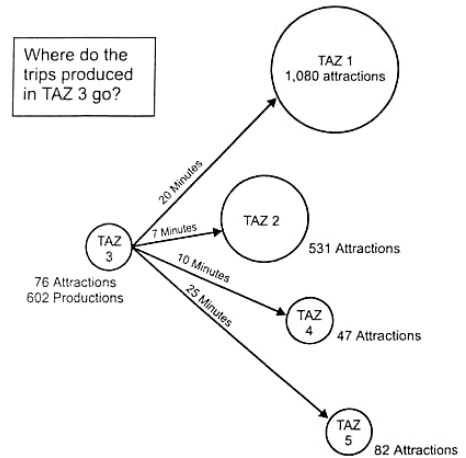
## Relative Attractiveness: How Trips Choose Their Destinations

$$Probability_{ij} = \frac{Attractiveness_j}{\sum \text{Attractiveness of all TAZs}}$$

$$Attractiveness_j = \# \text{ Attractions}_j \times FF_{ij}$$

$$Probability_{ij} = \frac{A_j \times FF_{ij}}{\sum (A_z \times FF_{iz})}$$

$$Attractiveness_j = \# \text{ Attractions}_j \times FF_{ij}$$



23

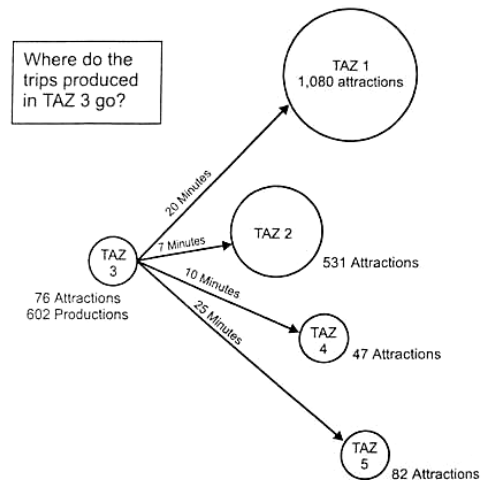
23

# Gravity Model

## The Probability-to-Trips Formula

$$Trips_{ij} = Productions_i \times Probability_{ij}$$

$$Probability_{ij} = \frac{A_j \times FF_{ij}}{\sum (A_z \times FF_{iz})}$$



### Gravity Model Equation

$$Trips_{ij} = Productions_i \times \frac{Attractions_j \times FF_{ij} \times K_{ij}}{\sum Attractions_z \times FF_{iz} \times K_{iz}}$$

24

24

## Gravity Model

Mathematically

$$\text{Relative attractiveness} = \frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$$

Attractiveness of "TO" TAZ

Attractiveness of all TAZs

Trips between TAZ 3 and "TO" TAZ =

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

Trips produced in TAZ 3

Attractiveness<sub>j</sub> = # Attractions<sub>j</sub> × FF<sub>ij</sub>

Where do the trips produced in TAZ 3 go?

Trips between TAZ 3 and "TO" TAZ = Trips produced in TAZ 3 ×  $\frac{\text{Attractiveness of "TO" TAZ}}{\text{Attractiveness of all TAZs}}$

26

26

## Gravity Model

Mathematically

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

i is origin zone number  
j is destination zone  
n is total number of zones

- ↪  $T_{ij}$  = number of trips that are produced in zone i and attracted to zone j
- ↪  $P_i$  = total number of trips produced in zone i
  - Determined from trip generation step
- ↪  $A_j$  = number of trips attracted to zone j
  - Determined from trip generation step
  - The sum of  $P_i$  for all zones must equal the sum of  $A_j$  for all zone
- ↪  $F_{ij}$  = a value which is an inverse function of travel time
  - Determined by a calibrating process
- ↪  $K_{ij}$  = Socioeconomic adjustment factor for interchange ij
  - Determined by a calibrating process

Where do the trips produced in TAZ 3 go?

27

27

## Trip Distribution

$K_{ij}$  = Socioeconomic adjustment factor

◆ Definition:

$K_{ij}$  = Socioeconomic adjustment factor

◆ Purpose:

- Used to adjust the number of trips between zone  $i$  and zone  $j$  after initial gravity model calculations.
- Applied when there's a significant difference between:
  - Estimated trips (from the model)
  - Actual observed trips

30

30

## Trip Distribution

*Example No. 1*

31

31

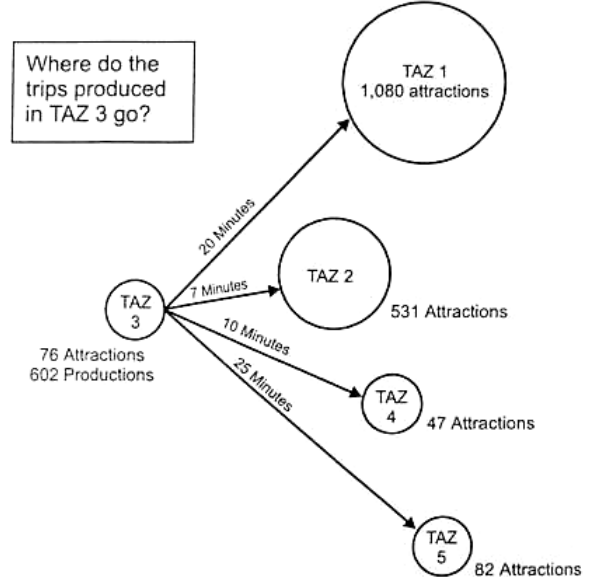
## Example: Calculate the Attractiveness of Each Zone

From Trip Generation:  
HBW Productions and Attractions

TAZ	Productions	Attractions
1	234	1080
2	76	531
3	602	76
4	432	47
5	472	82

HBW  
Friction  
Factors

Travel Time (min)	Friction Factor
3	87
4	45
7	29
10	18
15	10
20	6
25	4



32

32

## Calculate the Attractiveness of Each Zone

$$\text{Attractiveness}_j = \# \text{Attractions}_j \times \text{FF}_{ij}$$

i = production TAZ

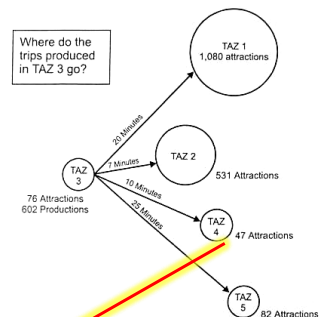
j = attraction TAZ

Attraction TAZ →	1	2	3	4	5
# Attractions ( $A_j$ )	1,080	531	76	47	82
Friction Factor ( $\text{FF}_{ij}$ )	6	29	45	18	4
Attractiveness ( $A_j * \text{FF}_{ij}$ )	6,480	15,399	3,420	846	328

Which zone is the most attractive?

For TAZ 3:

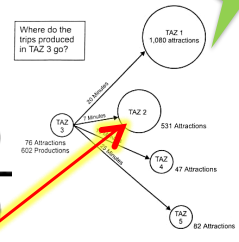
Attraction TAZ	1	2	3	4	5
Travel Time	20	7	4	10	25
Friction Factor	6	29	45	18	4



33

# Calculate the Relative Attractiveness of Each Zone

Make sense?

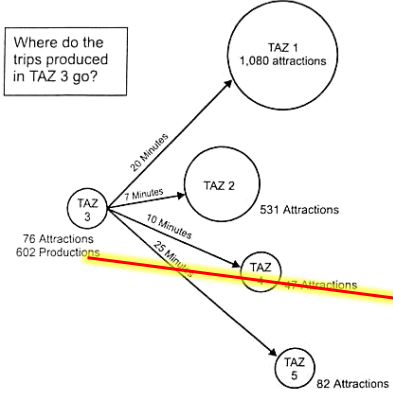


$$\text{Relative attractiveness} = \frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$$

Attraction TAZ→	1	2	3	4	5	Sum of Attractiveness
Attractiveness (A <sub>j</sub> × FF <sub>ij</sub> )	6,480	15,399	3,420	846	328	26,473
Relative Attractiveness (A <sub>j</sub> × FF <sub>ij</sub> ) / ∑ (A <sub>j</sub> × FF <sub>ij</sub> )	6,480 / 26,473 or 0.2448	0.5817	0.1292	0.0319	0.0124	1.0000

34

# Distribute Productions to TAZs

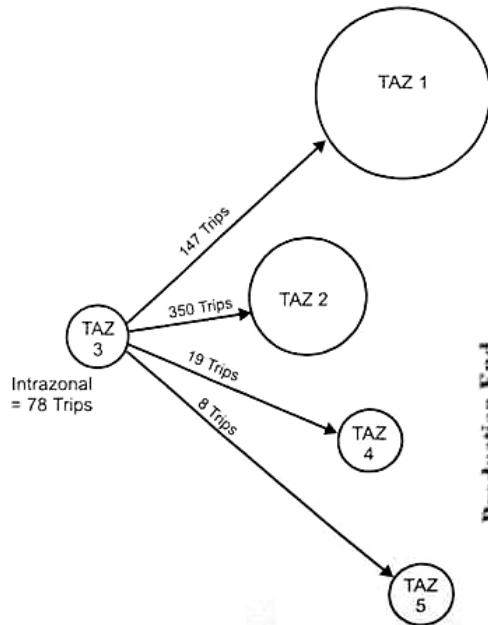


$$T_{ij} = P_i \times \frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$$

TAZ	Productions from TAZ 3	Relative Attractiveness (A <sub>j</sub> × FF <sub>ij</sub> ) / ∑ (A <sub>j</sub> × FF <sub>ij</sub> )	Distributed Trips P <sub>i</sub> × (A <sub>j</sub> × FF <sub>ij</sub> ) / ∑ (A <sub>j</sub> × FF <sub>ij</sub> )
1	602	0.2448	147
2	602	0.5817	350
3	602	0.1292	78
4	602	0.0319	19
5	602	0.0124	8
<b>Total</b>		<b>1.000</b>	<b>602</b>

35

## First Iteration Distribution



HBW Trip Table  
Attraction End

TAZ	1	2	3	4	5
1	199	2	15	2	16
2	35	25	12	3	1
3	147	350	78	19	8
4	330	90	4	6	2
5	369	90	7	5	1

Production End

36

## Trip Distribution

*Example No. 1 (Example 12.4) : Use of Calibrated F Values and Iteration*

37

37

## Trip Distribution

### Example -1 (Example 12.4): Use of Calibrated $F$ Values and Iteration

- ↪ A study area consisting of **three zones**
- ↪ Trip Productions and Attractions for a Three-Zone Study Area
  - Determined from trip generation step are provided in Table 12.9
- ↪ Average travel times between each zone
  - Determined ( Table 12.10)
- ↪ Determine the **number of zone-to-zone trips** through **two iterations**.

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

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

**Table 12.10** Travel Time between Zones (min)

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

38

38

## Solution of Example -1 (Example 12.4)

- ↪ **Step -1: Balanced** Attracted and produced trips for a Three-Zone Study Area

Zone	Balanced Trip	
	Production( $P_i$ )	Attraction ( $A_j$ )
1	140	300
2	330	270
3	280	180
<u>Total</u>	<u>750</u>	<u>750</u>

39

39

## Solution of Example -1 (Example 12.4)

### Use of Calibrated $F$ Values and Iteration

↪ Step -2: Average travel times between each zone

Average travel time			
Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	5	2	3
<u>2</u>	2	6	6
<u>3</u>	3	6	5

Orange cells are internal-internal

green cell are internal-external

40

40

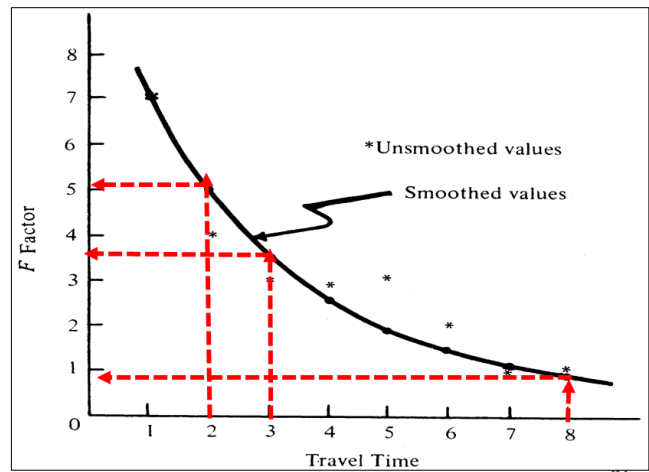
## Solution of Example -1 (Example 12.4)

### Use of Calibrated $F$ Values and Iteration

↪ Step -3: Determination of  $F$  factors based on travel time (Calibration process)

Average travel time			
Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	5	2	3
<u>2</u>	2	6	6
<u>3</u>	3	6	5

Note that the book use another chart to determine the  $f$  factors for the example



41

## Solution of Example -1 (Example 12.4)

### Use of Calibrated $F$ Values and Iteration

↳ **Step -3:** Determination of  $F$  factors based on travel time (Calibration process)

Travel time (Min)	1	2	3	4	5	6	7	8
f factor	82	52	50	41	39	26	20	13

42

42

## Solution of Example -1 (Example 12.4)

### Use of Calibrated $F$ Values and Iteration

↳ **Step -4:** Determine  $f$  factor between zones

Travel time (Min)	1	2	3	4	5	6	7	8
f factor	82	52	50	41	39	26	20	13

Average travel time			
Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	5	2	3
<u>2</u>	2	6	6
<u>3</u>	3	6	5

F factor ( $F_{ij}$ )			
Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	39	52	50
<u>2</u>	52	26	26
<u>3</u>	50	26	39

43

43

F factor (F <sub>ij</sub> )			
Zone (i)	Zone (j)		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	39	52	50
<u>2</u>	52	26	26
<u>3</u>	50	26	39

Zone	Balanced Trip	
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )
1	<b>140</b>	<b>300</b>
2	330	270
3	280	180
<u>Total</u>	<u>750</u>	<u>750</u>

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

i is origin zone number  
j is destination zone number  
n is total number of zones

Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	1	1	1
<u>2</u>	1	1	1
<u>3</u>	1	1	1

**K<sub>ij</sub>=1** for all zones

44

44

F factor (F <sub>ij</sub> )			
Zone (i)	Zone (j)		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	39	52	50
<u>2</u>	52	26	26
<u>3</u>	50	26	39

Zone	Balanced Trip	
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )
1	<b>140</b>	<b>300</b>
2	330	270
3	280	180
<u>Total</u>	<u>750</u>	<u>750</u>

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

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

i is origin zone number  
j is destination zone number  
n is total number of zones

Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	1	1	1
<u>2</u>	1	1	1
<u>3</u>	1	1	1

**K<sub>ij</sub>=1** for all zones

45

38

45

## Solution of Example -1 (Example 12.4)

Use of Calibrated  $F$  Values and Iteration

Step -5: Solve

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

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

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

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

$P_1 = 140$

Make similar calculations for zones 2 and 3.

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

48

48

## Solution of Example -1 (Example 12.4)

Step -5: Solve

F factor ( $F_{ij}$ )			
Zone (i)	Zone (j)		
	1	2	3
1	39	52	50
2	52	26	26
3	50	26	39

Balanced Trip		
Zone	Production ( $P_j$ )	Attraction ( $A_j$ )
1	140	300
2	330	270
3	280	180
Total	750	750

$i$  and  $j$  are zones number  
 $n$  is total number of zones

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

$K_{ij} = 1$ for all zones			
Zone	Zone		
	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1

$T_{2-3} \quad i=2, j=3, A=3$

$$T_{2-3} = P_2 \left[ \frac{A_3 \times F_{23} \times K_{23}}{\sum_{j=1}^n A_j \times F_{2j} \times K_{2j}} \right]$$

$$= 330 \left[ \frac{180 \times 26 \times 1}{300 \times 52 \times 1 + 270 \times 26 \times 1 + 180 \times 26 \times 1} \right]$$

$$= 330 \times \frac{4680}{2730}$$

$$= 56.5 \approx 57$$

49

49

$$T_{2-3} \quad \text{Zone } i=2, j=3, A=3$$

$$T_{2-3} = P_2 \left[ \frac{A_3 \times F_{23} \times k_{23}}{\sum_{j=1}^{j=n} A_j \times F_{2j} \times k_{2j}} \right]$$

$$\rightarrow A_1 \times F_{21} \times k_{21} + A_2 \times F_{22} \times k_{22} + A_3 \times F_{23} \times k_{23}$$

$$\rightarrow T_{2-3} = P_2 \left[ \frac{A_3 \times F_{23} \times k_{23}}{A_1 \times F_{21} \times k_{21} + A_2 \times F_{22} \times k_{22} + A_3 \times F_{23} \times k_{23}} \right]$$

$$= 330 \left[ \frac{180 \times 26 \times 1}{300 \times 52 \times 1 + 270 \times 26 \times 1 + 180 \times 26 \times 1} \right]$$

$$= 330 \times \frac{4680}{2730}$$

$$= 56.5 \approx 57$$

50

50

## Solution of Example -1 (Example 12.4)

↪ Step -5: Solve

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

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

51

51

## Solution of Example -1 (Example 12.4)

↪ Step -5: Solve

↪ The results summarized in Table 12.12 represent a **singly constrained gravity model**.

- This constraint is that the **sum of the productions in each zone is equal** to the number of productions given in the problem statement.

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

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

52

52

## Solution of Example -1 (Example 12.4)

↪ Step -5: Solve

↪ To create a **doubly constrained gravity model**

- where the **computed attractions equal** the given attractions,
- **You have to adjust attraction trips as presented in step-6**

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

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

53

53

## Solution of Example -1 (Example 12.4)

$j$  is destination zone number  
 $k$  is iteration number

Step -6: Adjusted attraction trip factors

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

Adjusted Attraction at iteration  $k$  for zone  $j = \left( \frac{\text{Desired Attraction for zone } j}{\text{Actual total trips attracted to zone } j \text{ in iteration } (k-1)} \right) \times \text{Adjusted Attraction used in iteration } (k-1)$

$A_{jk}$  = adjusted attraction factor for attraction zone (column)  $j$ , iteration  $k$

$A_{jk} = A_j$  when  $k = 1$

$C_{jk}$  = actual attraction (column) total for zone  $j$ , iteration  $k$

$A_j$  = desired attraction total for attraction zone (column)  $j$

$j$  = attraction zone number,  $j = 1, 2, \dots, n$

$n$  = number of zones

$k$  = iteration number,  $k = 1, 2, \dots, m$

$m$  = number of iterations

54

54

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

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

Zone	Balanced Trip	
	Production ( $P_i$ )	Attraction ( $A_j$ )
1	140	300
2	330	270
3	280	180
Total	750	750

$k = 1$

Adjusted Attraction at iteration  $k$  for zone  $j = \left( \frac{\text{Desired Attraction for zone } j}{\text{Actual total trips attracted to zone } j \text{ in iteration } (k-1)} \right) \times \text{Adjusted Attraction used in iteration } (k-1)$

55

55

Table 12.12 Zone-to-Zone Trips: First Iteration, Singly Constrained						Zone	Balanced Trip	
Zone	1	2	3	Computed P	Given P		Production(P <sub>j</sub> )	Attraction (A <sub>j</sub> )
1	47	57	36	140	140	1	140	300
2	188	85	57	330	330			
3	144	68	68	280	280			
Computed A	379	210	161	750	750	2	330	270
Given A	300	270	180	750	750	3	280	180
						Total	750	750

Adjusted Attraction at iteration  $k$  for zone  $j = \left( \frac{\text{Desired Attraction for zone } j}{\text{Actual total trips attracted to zone } j \text{ in iteration } (k-1)} \right) \times \text{Adjusted Attraction used in iteration } (k-1)$

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

Zone 1:  $A_{12} = 300 \times \frac{300}{379} = 237$   
 Zone 2:  $A_{22} = 270 \times \frac{270}{210} = 347$   
 Zone 3:  $A_{32} = 180 \times \frac{180}{161} = 201$

where

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

## Solution of Example -1 (Example 12.4)

↪ Step -6: Adjusted attraction trip factors

Adjusted Attraction at iteration  $k$  for zone  $j = \left( \frac{\text{Desired Attraction for zone } j}{\text{Actual total trips attracted to zone } j \text{ in iteration } (k-1)} \right) \times \text{Adjusted Attraction used in iteration } (k-1)$

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

Zone 1:  $A_{12} = 300 \times \frac{300}{379} = 237$   
 Zone 2:  $A_{22} = 270 \times \frac{270}{210} = 347$   
 Zone 3:  $A_{32} = 180 \times \frac{180}{161} = 201$

## Solution of Example -1 (Example 12.4)

↳ Step -5: Use the adjusted factors (iteration No.2)

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

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

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

58

58

F factor ( $F_{ij}$ )				Balanced Trip			Adjusted Attraction ( $A_j$ ) at $k=2$
Zone (i)	Zone (j)			Zone	Production ( $P_i$ )	Attraction ( $A_j$ )	
	<u>1</u>	<u>2</u>	<u>3</u>				
<u>1</u>	39	52	50	1	140	300	237
<u>2</u>	52	26	26	2	330	270	347
<u>3</u>	50	26	39	3	280	180	201
				<u>Total</u>	<u>750</u>	<u>750</u>	<u>750</u>

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

$i$  is origin zone number  
 $j$  is destination zone number  
 $n$  is total number of zones

$K_{ij} = 1$  for all zones

Zone	Zone		
	<u>1</u>	<u>2</u>	<u>3</u>
<u>1</u>	1	1	1
<u>2</u>	1	1	1
<u>3</u>	1	1	1

59

59

## Solution of Example -1 (Example 12.4)

↪ Step -5: Use the adjusted factors (iteration No.2)

Perform a second iteration using the adjusted attraction values.

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

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

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

$$P_1 = 140$$

Make similar calculations for zones 2 and 3.

$$T_{2-1} = 153 \quad T_{2-2} = 112 \quad T_{2-3} = 65 \quad P_2 = 330$$

$$T_{3-1} = 116 \quad T_{3-2} = 88 \quad T_{3-3} = 76 \quad P_3 = 280$$

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

60

60

## Solution of Example -1 (Example 12.4)

↪ Step -5: Use the adjusted factors (iteration No.2)

↪ The results are summarized in Table 12.13.

↪ Note that, in each case, the sum of the attractions is now much closer to the given value.

↪ The process will be continued until there is a reasonable agreement (within 5%) between the  $A$  that is estimated using the gravity model and the values that are furnished in the trip generation phase

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

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

61

61

# Trip Distribution

## *New Example*

62

62

✚ In trip distribution, the Gravity Model ensures the total trips *leaving* a zone (Productions) match our data, but trips *arriving* (Attractions) often do not. We must iterate to balance them.

✚ Our Study Area Data:

Zone	Balanced Trip	
	Production( $P_i$ )	Attraction ( $A_j$ )
1	<u>100</u>	<u>240</u>
2	200	200
3	300	160
<b>Total</b>	<b><u>600</u></b>	<b><u>600</u></b>

63

63

## Iteration 1 - Initial Run ( k= 1)

↳ **Action:** We run the standard Gravity Model using travel times (friction factors) and initial Target Attractions.

Origin \ Dest	Zone 1	Zone 2	Zone 3	Row Sum (P)	Target P
Zone 1	50	30	20	100	100
Zone 2	80	90	30	200	200
Zone 3	150	50	100	300	300
Col Sum	280	170	150	600	600
Target	240	200	160		600

64

64

## Iteration 1 - Calculating New Attraction Factors ( K=2)

Zone	Balanced Trip	
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )
1	<u>100</u>	<u>240</u>
2	200	200
3	300	160
<b>Total</b>	<b><u>600</u></b>	<b><u>600</u></b>

Origin \ Dest	Zone 1	Zone 2	Zone 3	Row Sum (P)	Target P
Zone 1	50	30	20	100	100
Zone 2	80	90	30	200	200
Zone 3	150	50	100	300	300
Col Sum	280	170	150	600	600
Target	240	200	160		600

Formula:  $A_{jk} = A_{j(k-1)} \times \frac{A_j}{C_{j(k-1)}}$

Calculations for Iteration 2 Inputs (A<sub>j2</sub>):

- **Zone 1:**  $A_{1,2} = 240 \times \frac{240}{280} = 240 \times 0.857 = 205.7$
- **Zone 2:**  $A_{2,2} = 200 \times \frac{200}{170} = 200 \times 1.176 = 235.3$
- **Zone 3:**  $A_{3,2} = 160 \times \frac{160}{150} = 160 \times 1.067 = 170.7$

65

65

## Iteration 2 - Second Run

Zone	Balanced Trip	
	Production ( $P_i$ )	Attraction ( $A_j$ )
1	100	240
2	200	200
3	300	160
<b>Total</b>	<b>600</b>	<b>600</b>

Adjusted Attraction ( $A_j$ ) at $k=2$
205.7
235.3
170.7
750

66

66

## Iteration 2 - Second Run

Origin \ Dest	Zone 1	Zone 2	Zone 3	Row Sum (P)	Target P
Zone 1	43	35	22	100	100
Zone 2	67	101	32	200	200
Zone 3	122	63	115	300	300
Col Sum	232	199	169	600	
Target	240	200	160		600

67

67

## Iteration 3 - Calculating Attraction Factors ( K=3)

Origin \ Dest	Zone 1	Zone 2	Zone 3	Row Sum (P)	Target P
Zone 1	43	35	22	100	100
Zone 2	67	101	32	200	200
Zone 3	122	63	115	300	300
Col Sum	232	199	169	600	
Target	240	200	160		600

Zone	Balanced Trip ( From trip generation)	
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )
1	<u>100</u>	<u>240</u>
2	200	200
3	300	160
<b>Total</b>	<b><u>600</u></b>	<b><u>600</u></b>

$$\text{Formula: } A_{jk} = A_{j(k-1)} \times \frac{A_j}{C_{j(k-1)}}$$

Calculations for Iteration 3 Inputs (A<sub>j3</sub>):

- **Zone 1:**  $A_{1,3} = 205.7 \times \frac{240}{232} = 205.7 \times 1.034 = 212.8$
- **Zone 2:**  $A_{2,3} = 235.3 \times \frac{200}{199} = 235.3 \times 1.005 = 236.5$
- **Zone 3:**  $A_{3,3} = 170.7 \times \frac{160}{169} = 170.7 \times 0.947 = 161.6$

Zone	Balanced Trip		Adjusted Attraction (A <sub>j</sub> ) at k =2
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )	
1	<u>100</u>	<u>240</u>	205.7
2	200	200	235.3
3	300	160	170.7
<b>Total</b>	<b>600</b>	<b>600</b>	<b>750</b>

68

68

## Iteration 2 - Second Run

Zone	Balanced Trip	
	Production(P <sub>i</sub> )	Attraction (A <sub>j</sub> )
1	<u>100</u>	<u>240</u>
2	200	200
3	300	160
<b>Total</b>	<b><u>600</u></b>	<b><u>600</u></b>

Adjusted Attraction (A <sub>j</sub> ) at k =2
205.7
235.3
170.7
750

Adjusted Attraction (A <sub>j</sub> ) at k =3
212.8
236.5
161.6
600

$$\text{Formula: } A_{jk} = A_{j(k-1)} \times \frac{A_j}{C_{j(k-1)}}$$

Calculations for Iteration 3 Inputs (A<sub>j3</sub>):

- **Zone 1:**  $A_{1,3} = 205.7 \times \frac{240}{232} = 205.7 \times 1.034 = 212.8$
- **Zone 2:**  $A_{2,3} = 235.3 \times \frac{200}{199} = 235.3 \times 1.005 = 236.5$
- **Zone 3:**  $A_{3,3} = 170.7 \times \frac{160}{169} = 170.7 \times 0.947 = 161.6$

69

69

## Iteration 3: Final

Origin \ Dest	Zone 1	Zone 2	Zone 3	Row Sum (P)	Target P
Zone 1	44	35	21	100	100
Zone 2	69	100	31	200	200
Zone 3	127	65	108	300	300
Col Sum (\$C_{j3}\$)	240	200	160	600	
Target \$A_j\$	240	200	160		600

70

70

## Trip Distribution

*Example No. 2 (Example 12.5) : Selecting  
Singly or Doubly Constrained Gravity  
Model Results*

71

71

## Trip Distribution

### Example No. 2 (Example 12.5) : Selecting Singly or Doubly Constrained Gravity Model Results

#### Example 12.5 Selecting Singly or Doubly Constrained Gravity Model Results

A three-zone system with 900 home-based shopping productions is shown in Table 12.14. Zones 1 and 2 each generate 400 productions, while zone 3 generates 100 productions. Each zone contains a shopping mall with 300 attractions. The shopping mall in zone 1 can be easily reached due to the parking availability and transit service. Thus,  $F_{11}$ ,  $F_{21}$ , and  $F_{31} = 1.0$ . Parking costs at the shopping mall in zone 2 are moderate with some transit service. Thus,  $F_{12}$ ,  $F_{22}$ , and  $F_{32} = 0.5$ . Parking costs at the mall in zone 3 is high and transit service is unavailable. Thus,  $F_{13}$ ,  $F_{23}$ , and  $F_{33} = 0.2$ .

Application of the singly constrained gravity model yields the results shown in Table 12.15 and application of the doubly constrained gravity model yields the results shown in Table 12.16.

72

72

## Trip Distribution

### Example No. 2 (Example 12.5) : Selecting Singly or Doubly Constrained Gravity Model Results

- ↪ A three-zone system with 900 home-based shopping productions
- ↪ Zones 1 and 2 each generate 400 productions, while zone 3 generates 100 productions
- ↪ Each zone contains a shopping mall with 300 attractions

**Table 12.14** Home-Based Shopping Productions and Attractions

<i>Zone</i>	<i>Productions</i>	<i>Attractions</i>
1	400	300
2	400	300
3	100	300
Total	900	900

73

73

## Solution of Example -2 (Example 12.5)

### Selecting Singly or Doubly Constrained Gravity Model Results

#### F factors

➤ The shopping mall in **zone 1** can be easily reached due to the parking availability and transit service.

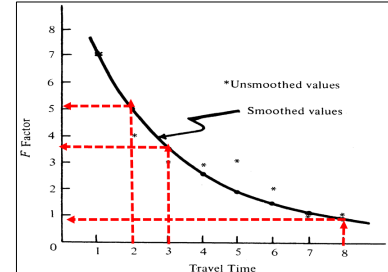
❖ Thus,  $F_{11}$ ,  $F_{21}$ , and  $F_{31} = 1.0$

➤ Parking costs at the shopping mall in **zone 2** are moderate with some transit service.

❖ Thus,  $F_{12}$ ,  $F_{22}$ , and  $F_{32} = 0.5$

➤ Parking costs at the mall in **zone 3** is high and transit service is unavailable.

❖ Thus,  $F_{13}$ ,  $F_{23}$ , and  $F_{33} = 0.2$



74

74

## Solution of Example -2 (Example 12.5)

### Selecting Singly or Doubly Constrained Gravity Model Results

**Table 12.15** Zone-to-Zone Trips: Singly Constrained Gravity Model

Zone	1	2	3	Computed P	Given P
1	235	118	47	400	400
2	235	118	47	400	400
3	<u>59</u>	<u>29</u>	<u>12</u>	<u>100</u>	<u>100</u>
Computed A	529	265	106	900	900
Given A	300	300	300	900	

**Table 12.16** Zone-to-Zone Trips: Doubly Constrained Gravity Model

Zone	1	2	3	Computed P	Given P
1	133	133	133	400	400
2	133	133	133	400	400
3	<u>33</u>	<u>33</u>	<u>33</u>	<u>100</u>	<u>100</u>
Computed A	300	300	300	900	900
Given A	300	300	300	900	

75

75

## Solution of Example -2 (Example 12.5)

### Selecting Singly or Doubly Constrained Gravity Model Results

Which of the results shown for the singly constrained gravity model and for the doubly constrained gravity model are more likely to be the most accurate?

**Solution:** Table 12.15 is more likely to be accurate if engineering judgment suggests the occurrence of travel impedances and thus the friction factors are more accurate than trip attractions. Table 12.16 is more likely to be accurate if the attractions are more accurate than the friction factors.

In practice, these judgments must be made based on the quality of the data set. For example, if local land-use data had been recently used to develop trip attraction rates whereas friction factors had been borrowed from another area, then the selection of the doubly constrained gravity model results in Table 12.16 is recommended.

**Table 12.15** Zone-to-Zone Trips: Singly Constrained Gravity Model

Zone	1	2	3	Computed P	Given P
1	235	118	47	400	400
2	235	118	47	400	400
3	59	29	12	100	100
Computed A	529	265	106	900	900
Given A	300	300	300	900	900

**Table 12.16** Zone-to-Zone Trips: Doubly Constrained Gravity Model

Zone	1	2	3	Computed P	Given P
1	133	133	133	400	400
2	133	133	133	400	400
3	33	33	33	100	100
Computed A	300	300	300	900	900
Given A	300	300	300	900	900

76

## Trip Distribution

### Calibration of the Gravity Model

77

77

## Calibration of the Gravity Model for Estimation of UPLB Employee Trips using Origin-Destination Data

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DOI 10.1007/s10958-025-08161-w  
*Journal of Mathematical Sciences, Vol. 295, No. 2, December, 2025*

### CALIBRATION OF GRAVITY MODELS

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78

78

# Trip Distribution

## Reading assignment

79

79

## Reading Assignment: Trip Distribution Models in Practice

### Reading Material

- **Title:** *Modelling Trip Distribution Using the Gravity Model and Fratar's Method*
- **Authors:** *Areeq T. Al-Rubaie, et al.*
- **Published In:** *International Journal of Design & Nature and Ecodynamics (2020)*

80

80

## Trip Distribution Models

### *Growth Factor Model*

89

89

## Growth Factor Models

- ❑ Growth Factor Models assume that we already have a **basic trip matrix**

TAZ	1	2	3	4
1	5	50	100	200
2	50	5	100	300
3	50	100	5	100
4	100	200	250	20

- ❑ Usually obtained from *a previous study* or *recent survey data*

90

## What is a Growth Factor Model?

- ❑ The goal is then to estimate the matrix at some point in the future
  - ❑ For example, what would the trip matrix look like in 10 years time?

TAZ	1	2	3	4
1	5	50	100	200
2	50	5	100	300
3	50	100	5	100
4	100	200	250	20

Trip Matrix, t  
(2008)

→

TAZ	1	2	3	4
1	?	?	?	?
2	?	?	?	?
3	?	?	?	?
4	?	?	?	?

Trip Matrix, T  
(2018)

- ❑ Idea: **Future trips = Base trips × Growth factor**

91

# Some of the More Popular Growth Factor Models

- Uniform Growth Factor
- Singly-Constrained Growth Factor
- Average Factor
- Detroit Factor
- Fratar Method

92

## Growth Factor Models

### Fratar method

It is a mathematical formula that proportions future trip generation estimates to each zone as a function of the product of

- the current trips between the two zones  $T_{ij}$
- The growth factor of the attracting zone  $G_j$

If we assume  $\tau = 1.2$  (growth rate), then...

TAZ	1	2	3	4
1	5	50	100	200
2	50	5	100	300
3	50	100	5	100
4	100	200	250	20

Trip Matrix,  $t$   
(2013)

$$\begin{aligned}
 T_{ij} &= \tau t_{ij} \\
 &= (1.2)(5) \\
 &= 6
 \end{aligned}$$

TAZ	1	2	3	4
1	6	60	120	240
2	60	6	120	360
3	60	120	6	120
4	120	240	300	24

Trip Matrix,  $T$   
(2018)

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93

93

# Growth Factor Models

## Fratar method

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and other **zones x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

i is origin zone number  
j is destination zone number

x are all zones in the study area **except** the origin zone i

94

94

# Fratar method

## Mathematically

Relative attractiveness =  $\frac{t_{ij} G_j}{\sum_x t_{ix} G_x}$

Attractiveness of "TO" TAZ (points to numerator)

Attractiveness of all TAZs (points to denominator)

Future Trips by two zones

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

Future Trips generated by Origin zone (points to  $t_i G_i$ )

Present Trips between zone i and zone j ( $t_{ij}$ )					Total
Zone (i)	Zone (j)				
	A	B	C	D	
A	-	400	100	100	600

Zone (i)	Growth factor ( $G_j$ )
A	1.2

Attractiveness = [Present trips between zone i and zone j] \* [The growth factor of the attracting zone  $G_j$ ]

97

97

## Trip Distribution

### *Example No. 3 (Example 12.6) :* Forecasting Trips Using the Fratar Model

98

98

### **Example No. 3 (Example 12.6) :** Forecasting Trips Using the Fratar Model

#### **Example 12.6** Forecasting Trips Using the Fratar Model

A study area consists of four zones (A, B, C, and D). An O-D survey indicates that the number of trips between each zone is as shown in Table 12.17. Planning estimates for the area indicate that in five years the number of trips in each zone will increase by the growth factor shown in Table 12.18 on page 612 and that trip generation will be increased to the amounts shown in the last column of the table.

Determine the number of trips between each zone for future conditions.

99

99

### Example No. 3 (Example 12.6) :

#### Forecasting Trips Using the Fratar Model

- ↪ A study area consists of **four zones** (A, B, C, and D)
- ↪ An O-D survey indicates that the **number of trips between** each zone is as shown in Table 12.17.
- ↪ Planning estimates for the area indicate that **in five years** the number of trips in each zone will increase by **the growth factor** shown in Table 12.18 on page 612
  - *That trip generation will be increased to the amounts shown in the last column of the table 12.18*
- ↪ **Determine** the number of **trips between each zone** for future conditions.

100

100

### Solution of Example No. 3 (Example 12.6) :

#### Forecasting Trips Using the Fratar Model

↪ Present Trips between Zone

**Table 12.17** Present Trips between Zones

<i>Zone</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
A	—	400	100	100
B	400	—	300	—
C	100	300	—	300
D	100	—	300	—
Total	600	700	700	400

101

101

## Solution of Example No. 3 (Example 12.6) :

### Forecasting Trips Using the Fratar Model

#### ↳ Present Trip Generation and Growth Factors

**Table 12.18** Present Trip Generation and Growth Factors

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

102

102

**Present** Trips between zone **i** and zone **j** ( $t_{ij}$ )

Zone (i)	Zone (j)			
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
<u>A</u>	-	400	100	100
<u>B</u>	400	-	300	-
<u>C</u>	100	300	-	300
<u>D</u>	100	-	300	-
<b>Total</b>	<b>600</b>	<b>700</b>	<b>700</b>	<b>400</b>

**Present** Trip Generation and Growth Factors

Zone	Present Trip Generation (Trips/ day) ( $T_i$ )	Growth factor ( $G_j$ )	Trip Generation in Five Years (= column 2 X column 3)
<u>A</u>	600	1.2	720 = 1.2*600
<u>B</u>	700	1.1	770
<u>C</u>	700	1.4	980
<u>D</u>	400	1.3	520

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

$i$  is origin zone number  
 $j$  is destination zone number

$x$  are all zones in the study area except the origin zone  $i$

103

103

# Growth Factor Models

## Fratar method

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

i is origin zone number  
j is destination zone number

x are all zones in the study area except the origin zone i

104

104

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

Zone (i)	Zone (j)			
	A	B	C	D
A	-	400	100	100
B	400	-	300	-
C	100	300	-	300
D	100	-	300	-
Total	600	700	700	400

Zone	Present Trip Generation (Trips/day) ( $T_i$ )	Growth factor ( $G_i$ )	Trip Generation in Five Years (= column 2 X column 3)
A	600	1.2	720 = 1.2*600
B	700	1.1	770
C	700	1.4	980
D	400	1.3	520

i is origin zone number  
j is destination zone number

x are all zones in the study area except the origin zone i

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

105

105

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

Zone (i)	Zone (j)			
	A	B	C	D
A	-	400	100	100
B	400	-	300	-
C	100	300	-	300
D	100	-	300	-
Total	600	700	700	400

Zone	Present Trip Generation (Trips/ day) ( $T_i$ )	Growth factor ( $G_i$ )	Trip Generation in Five Years (= column 2 X column 3)
A	600	1.2	720 = 1.2*600
B	700	1.1	770
C	700	1.4	980
D	400	1.3	520

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

$i$  is origin zone number  
 $j$  is destination zone number

$x$  are all zones in the study area except the origin zone  $i$

106

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

Zone (i)	Zone (j)			
	A	B	C	D
A	-	400	100	100
B	400	-	300	-
C	100	300	-	300
D	100	-	300	-
Total	600	700	700	400

Zone	Present Trip Generation (Trips/ day) ( $T_i$ )	Growth factor ( $G_i$ )	Trip Generation in Five Years (= column 2 X column 3)
A	600	1.2	720 = 1.2*600
B	700	1.1	770
C	700	1.4	980
D	400	1.3	520

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

$i$  is origin zone number  
 $j$  is destination zone number

$x$  are all zones in the study area except the origin zone  $i$

107

## Solution of Example No. 3 (Example 12.6) :

### Forecasting Trips Using the Fratar Model

**Solution:** Using the Fratar formula (Eq. 12.5), calculate the number of trips between zones A and B, A and C, A and D, and so forth. Note that two values are obtained for each zone pair (that is,  $T_{AB}$  and  $T_{BA}$ ). These values are averaged, yielding a value for  $T_{AB} = (T_{AB} + T_{BA})/2$ .

The calculations are as follows.

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

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

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

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

Similar calculations yield

$$\bar{T}_{AC} = 141 \quad \bar{T}_{AD} = 124 \quad \bar{T}_{BC} = 372 \quad \bar{T}_{CD} = 430$$

108

108

⇒ Find the trips between Zone A and Zone B  
step

① Trips from Zone A to Zone B

$\dot{o}$  = origin Zone ⇒  $\dot{o} = A$

$\dot{j}$  = Destination Zone ⇒  $\dot{j} = B$

$x$  = All Zones except the origin Zone ⇒  $x = B, C, \text{ and } D$

$$\Rightarrow T_{\dot{o}\dot{j}} = t_{\dot{o}\dot{j}} G_{\dot{j}} * \frac{t_{\dot{o}x} G_x}{\sum_x t_{\dot{o}x} G_x}$$

$$\rightarrow T_{AB} = (t_A G_A) * \frac{t_{AB} G_B}{\sum_{x=B}^{x=D} t_{Ax} G_x}$$

$$L = \underbrace{t_{AB} G_B}_{\substack{\dot{o}=A \\ x=B}} + \underbrace{t_{AC} G_C}_{\substack{\dot{o}=A \\ x=C}} + \underbrace{t_{AD} G_D}_{\substack{\dot{o}=A \\ x=D}}$$

$T_{AB} = ,$

109

109

$$\rightarrow T_{AB} = (E_A G_A) + \frac{E_{AB} G_B}{\sum_{x=B}^{x=D} E_{Ax} G_x}$$

$$L = \underbrace{E_{AB} G_B}_{\substack{\dot{c}=A \\ x=B}} + \underbrace{E_{AC} G_C}_{\substack{\dot{c}=A \\ x=C}} + \underbrace{E_{AD} G_D}_{\substack{\dot{c}=A \\ x=D}}$$

$$T_{AB} = E_A G_A + \frac{E_{AB} G_B}{E_{AB} G_B + E_{AC} G_C + E_{AD} G_D}$$

$$= (600 \times 1.2) + \frac{(400)(1.0)}{(400 \times 1.1 + 100 \times 1.4 + 100 \times 1.3)} = 4116$$

$$\Rightarrow \boxed{T_{AB} = 4116}$$

110

110

step

② Trips from Zone B to Zone A

 $\dot{c}$  = origin zone  $\rightarrow \dot{c} = B$  $\dot{u}$  = Destination zone  $\rightarrow \dot{u} = A$  $x$  = All zones except the origin zone  $\rightarrow x = A, C, \text{ and } D$ 

$$\rightarrow T_{BA} = E_B G_B + \frac{E_{BA} G_A}{\sum_{x=A}^{x=D} E_{Bx} G_x}$$

$$L = \underbrace{E_{BA} G_A}_{\substack{\dot{c}=B \\ x=A}} + \underbrace{E_{BC} G_C}_{\substack{\dot{c}=B \\ x=C}} + \underbrace{E_{BD} G_D}_{\substack{\dot{c}=B \\ x=D}}$$

111

111

$$\rightarrow T_{BA} = \cancel{t_B} G_B + \frac{t_{BA} G_A}{\sum_{n=A}^{n=D} t_{Bn} G_n}$$

$\rightarrow = \frac{t_{BA} G_A + t_{BC} G_C + t_{BD} G_D}{\substack{i=B \\ n=A} \quad \substack{i=A \\ n=C} \quad \substack{i=B \\ n=D}}$

$$T_{BA} = t_B G_B + \frac{t_{BA} G_A}{t_{BA} G_A + t_{BC} G_C + t_{BD} G_D}$$

$$= (700 \times 1.1) \times \frac{400 \times 1.2}{400 \times 1.2 + \cancel{300 \times 1.4} + \cancel{0 \times 1.3} \text{ zero}}$$

$$= (700 \times 1.1) \times \frac{400 \times 1.2}{400 \times 1.2 + 300 \times 1.4} = 416$$

$\Rightarrow T_{BA} = 416$

112

112

step (3) Average trips between Zone A and Zone B ( $\bar{T}_{AB}$ )

$$\bar{T}_{AB} = \frac{T_{AB} + T_{BA}}{2} = \frac{416 + 411}{2} = 428$$

$$\Rightarrow \bar{T}_{AB} = 428$$

113

113

## Solution of Example No. 3 (Example 12.6) :

The results of the preceding calculations have produced the first estimate (or iteration) of future trip distribution and are shown in Table 12.19. The totals for each zone do not equal the values of future trip generation. For example, the trip

**Table 12.19** First Estimate of Trips between Zones

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

114

114

## Trip Distribution

### *New Example*

### Forecasting Trips Using the Fratar Model

117

117

## Example

- ↪ If the number of present trips between zones and the growth factors for a three-zone study area are as shown in Table 2.69,
- ↪ Estimate the future zone-to-zone trips (trip distribution) using the Fratar model and **after two iterations**

**TABLE 2.69**  
**Present Trip Matrix and Growth Factors for a Three-Zone Study Area for Problem 2.33**

Zone	1	2	3	Growth Factor
1	–	100	300	1.2
2	100	–	200	1.5
3	300	200	–	2.0
Total	400	300	500	

118

118

## Calculate future trip generation

- ↪ The present trip generation (productions) and future trips are computed for each zone based on the given data

**TABLE 2.70**  
**Calculated Present and Future Trip Generation**

Zone	1	2	3	Present Trip Generation
1	–	100	300	
2	100	–	200	
3	300	200	–	
Total	400	300	500	

119

119

## Present trip generation

↪ The present trip generation (productions) and future trips are computed for each zone based on the given data

**TABLE 2.70**

### Calculated Present and Future Trip Generati

Zone	1	2	3	Present Trip Generation
1	–	100	300	400
2	100	–	200	300
3	300	200	–	500
Total	400	300	500	

120

120

## Calculate future trip generation

↪ The present trip generation (productions) and future trips are computed for each zone based on the given data

**TABLE 2.70**

### Calculated Present and Future Trip Generation Results for Problem 2.33

Zone	1	2	3	Present Trip Generation	Growth Factor	Future Trip Generation
1	–	100	300	400	1.2	
2	100	–	200	300	1.5	
3	300	200	–	500	2.0	
Total	400	300	500			

121

121

## Calculate future trip generation



↪ The present trip generation (productions) and future trips are computed for each zone based on the given data

TABLE 2.70

Calculated Present and Future Trip Generation Results for Problem 2.33

Zone	1	2	3	Present Trip Generation	Growth Factor	Future Trip Generation
1	–	100	300	400	1.2	480
2	100	–	200	300	1.5	450
3	300	200	–	500	2.0	1000
Total	400	300	500			

122

122

## Growth Factor Models

### *Fratar method*

- ↪  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↪  $t_i$  = Present trip generation in **zone i**
- ↪  $G_i$  = Growth factor of **zone i**
- ↪  $G_j$  = Growth factor of **zone j**
- ↪  $G_x$  = growth factor of **zones x**
- ↪  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↪  $t_{ix}$  = Number of trips between **zone i** and other zones **x**
- ↪  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

$i$  is origin zone number  
 $j$  is destination zone number

$x$  are all zones in the study area except the origin zone  $i$

123

123

- ↻  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↻  $t_i$  = Present trip generation in **zone i**
- ↻  $G_i$  = Growth factor of **zone i**
- ↻  $G_j$  = Growth factor of **zone j**
- ↻  $G_x$  = growth factor of **zones x**
- ↻  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↻  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↻  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
<b>1</b>	–	100	300	400	480	<b>1.2</b>
<b>2</b>	100	–	200	300	450	<b>1.5</b>
<b>3</b>	300	200	–	500	1000	<b>2.0</b>
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

area except the origin zone i

$T_{3-1} =$

124

124

- ↻  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↻  $t_i$  = Present trip generation in **zone i**
- ↻  $G_i$  = Growth factor of **zone i**
- ↻  $G_j$  = Growth factor of **zone j**
- ↻  $G_x$  = growth factor of **zones x**
- ↻  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↻  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↻  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
<b>1</b>	–	100	300	400	480	<b>1.2</b>
<b>2</b>	100	–	200	300	450	<b>1.5</b>
<b>3</b>	300	200	–	500	1000	<b>2.0</b>
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

area except the origin zone i

$$T_{3-1} = (t_3 G_3) \left[ \frac{t_{31} G_1}{\sum_j t_{3j} G_j} \right] = (t_3 G_3) \left[ \frac{t_{31} G_1}{t_{31} G_1 + t_{32} G_2} \right]$$

$$T_{3-1} = (500 \times 2.0) \left[ \frac{(300)(1.2)}{(300)(1.2) + (200)(1.5)} \right] = 545.5 \text{ trips} \cong 546 \text{ trips}$$

125

125

- ☞  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ☞  $t_i$  = Present trip generation in **zone i**
- ☞  $G_i$  = Growth factor of **zone i**
- ☞  $G_j$  = Growth factor of **zone j**
- ☞  $G_x$  = growth factor of **zones x**
- ☞  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ☞  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ☞  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
1	–	100	300	400	480	1.2
2	100	–	200	300	450	1.5
3	300	200	–	500	1000	2.0
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

*area except the origin zone i*

$$T_{1-3} = ($$

126

126

- ☞  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ☞  $t_i$  = Present trip generation in **zone i**
- ☞  $G_i$  = Growth factor of **zone i**
- ☞  $G_j$  = Growth factor of **zone j**
- ☞  $G_x$  = growth factor of **zones x**
- ☞  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ☞  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ☞  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
1	–	100	300	400	480	1.2
2	100	–	200	300	450	1.5
3	300	200	–	500	1000	2.0
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

*area except the origin zone i*

$$T_{1-3} = (t_1 G_1) \left[ \frac{t_{13} G_3}{\sum_j t_{1j} G_j} \right] = (t_1 G_1) \left[ \frac{t_{13} G_3}{t_{12} G_2 + t_{13} G_3} \right]$$

$$T_{1-3} = (400 \times 1.2) \left[ \frac{(300)(2.0)}{(100)(1.5) + (300)(2.0)} \right] = 384.0 \text{ trips}$$

127

127

- ↳  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↳  $t_i$  = Present trip generation in **zone i**
- ↳  $G_i$  = Growth factor of **zone i**
- ↳  $G_j$  = Growth factor of **zone j**
- ↳  $G_x$  = growth factor of **zones x**
- ↳  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↳  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↳  $t_{ij}$  = Present trips between **zone i** and **zone j**

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

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
1	–	100	300	400	480	1.2
2	100	–	200	300	450	1.5
3	300	200	–	500	1000	2.0
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

Procedure	Value
$T_{1-2} = (400 \times 1.2) \left[ \frac{(100)(1.5)}{(100)(1.5) + (300)(2.0)} \right] =$	96.0
$T_{2-1} = (300 \times 1.5) \left[ \frac{(100)(1.2)}{(100)(1.2) + (200)(2.0)} \right] =$	103.8

128

128

- ↳  $T_{ij}$  = Number of trips estimated from **zone i** to **zone j**
- ↳  $t_i$  = Present trip generation in **zone i**
- ↳  $G_i$  = Growth factor of **zone i**
- ↳  $G_j$  = Growth factor of **zone j**
- ↳  $G_x$  = growth factor of **zones x**
- ↳  $T_i = t_i G_i$  = Future trip generation in **zone i**
- ↳  $t_{ix}$  = Number of trips between **zone i** and **other zones x**
- ↳  $t_{ij}$  = Present trips between **zone i** and **zone j**

Zone	To Zone 1	To Zone 2	To Zone 3	Present Trip Generation	Future Trip Generation	Growth Factor
1	–	100	300	400	480	1.2
2	100	–	200	300	450	1.5
3	300	200	–	500	1000	2.0
<b>Total</b>	<b>400</b>	<b>300</b>	<b>500</b>			

area except the origin zone i

$T_{2-3} = (300 \times 1.5) \left[ \frac{(200)(2.0)}{(100)(1.2) + (200)(2.0)} \right] =$	346.2
$T_{3-2} = (500 \times 2.0) \left[ \frac{(200)(1.5)}{(300)(1.2) + (200)(1.5)} \right] =$	454.5

129

129

## First Iteration Matrix

Zone	1	2	3
1	–	96.0	384.0
2	103.8	–	346.2
3	545.5	454.5	–
Total	649	551	730

	Procedure	Value
$T_{1,2} = (400 \times 1.2)$	$\left[ \frac{(100)(1.5)}{(100)(1.5) + (300)(2.0)} \right] =$	96.0
$T_{2,1} = (300 \times 1.5)$	$\left[ \frac{(100)(1.2)}{(100)(1.2) + (200)(2.0)} \right] =$	103.8
$T_{1,3} = (400 \times 1.2)$	$\left[ \frac{(300)(2.0)}{(100)(1.5) + (300)(2.0)} \right] =$	384.0
$T_{3,1} = (500 \times 2.0)$	$\left[ \frac{(300)(1.2)}{(300)(1.2) + (200)(1.5)} \right] =$	545.5
$T_{2,3} = (300 \times 1.5)$	$\left[ \frac{(200)(2.0)}{(100)(1.2) + (200)(2.0)} \right] =$	346.2
$T_{3,2} = (500 \times 2.0)$	$\left[ \frac{(200)(1.5)}{(300)(1.2) + (200)(1.5)} \right] =$	454.5

130

## First Iteration Matrix

Zone	1	2	3
1			
2			
3			
Total			

	Procedure	Value
$T_{1,2} = (400 \times 1.2)$	$\left[ \frac{(100)(1.5)}{(100)(1.5) + (300)(2.0)} \right] =$	96.0
$T_{2,1} = (300 \times 1.5)$	$\left[ \frac{(100)(1.2)}{(100)(1.2) + (200)(2.0)} \right] =$	103.8
$T_{1,3} = (400 \times 1.2)$	$\left[ \frac{(300)(2.0)}{(100)(1.5) + (300)(2.0)} \right] =$	384.0
$T_{3,1} = (500 \times 2.0)$	$\left[ \frac{(300)(1.2)}{(300)(1.2) + (200)(1.5)} \right] =$	545.5
$T_{2,3} = (300 \times 1.5)$	$\left[ \frac{(200)(2.0)}{(100)(1.2) + (200)(2.0)} \right] =$	346.2
$T_{3,2} = (500 \times 2.0)$	$\left[ \frac{(200)(1.5)}{(300)(1.2) + (200)(1.5)} \right] =$	454.5

131

## The problem: Two different estimates for the same pair

### ↪ Trips between Zone 1 and Zone 3

- ❖ From zone 3 → zone 1 : **545.5 trips**
- ❖ From zone 1 → zone 3 : **384 trips**
- ❖ They are **not equal** (546 ≠ 384).

### ↪ Why is this a problem?

- A final trip matrix requires **one symmetric value** per zone pair (i.e.,  $T_{13} = T_{31}$ )
- Travel time and friction are usually **the same in both directions** → logically, trips should be balanced.
- Asymmetric estimates cannot be used directly in most traffic models (which assume symmetry for network assignment).

### ↪ Solution

- Trips should logically be balanced

Zone	1	2	3
1	–	96.0	384.0
2	103.8	–	346.2
3	545.5	454.5	–
Total	649	551	730

132

132

## The Standard Solution: Averaging

$$\bar{T}_{ij} = \frac{T_{ij} + T_{ji}}{2}$$

$$\bar{T}_{13} = \frac{T_{31} + T_{13}}{2} = \frac{545.5 + 384.0}{2} = 464.75 \approx 465$$

- Produces a **single, symmetric** trip estimate.
- Reduces origin-specific bias.

133

133

## First iteration

↪ Unbalanced

Zone	1	2	3
1	–	96.0	384.0
2	103.8	–	346.2
3	545.5	454.5	–
Total	649	551	730

$$\bar{T}_{12} = \frac{96.0 + 103.8}{2} = \frac{199.8}{2} = 99.9$$

$$\bar{T}_{13} = \frac{384.0 + 545.5}{2} = \frac{929.5}{2} = 464.75 \approx 465$$

Balanced

Zone	1	2	3
1			
2			
3			
Total			

$$\bar{T}_{23} = \frac{346.2 + 454.5}{2} = \frac{800.7}{2} = 400.35 \approx 400$$

134

134

## First iteration

↪ Unbalanced

Zone	1	2	3
1	–	96.0	384.0
2	103.8	–	346.2
3	545.5	454.5	–
Total	649	551	730

$$\bar{T}_{12} = \frac{96.0 + 103.8}{2} = \frac{199.8}{2} = 99.9$$

$$\bar{T}_{13} = \frac{384.0 + 545.5}{2} = \frac{929.5}{2} = 464.75 \approx 465$$

Balanced

Zone	1	2	3
1	–	99.9	464.7
2	99.9	–	400.3
3	464.7	400.3	–
Total	565	500	865

$$\bar{T}_{23} = \frac{346.2 + 454.5}{2} = \frac{800.7}{2} = 400.35 \approx 400$$

135

135

## First Iteration-Average Computed Trip Distribution

<b>Zone</b>	<b>1</b>	<b>2</b>	<b>3</b>
1	–	99.9	464.7
2	99.9	–	400.3
3	464.7	400.3	–
<b>Total</b>	<b>565</b>	<b>500</b>	<b>865</b>

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136

136

## First Iteration-Average Computed Trip Distribution

<b>Zone</b>	<b>1</b>	<b>2</b>	<b>3</b>	<u>Future Trip Generation</u>
				<b>Computed Total Trips</b>
1	–	99.9	464.7	
2	99.9	–	400.3	
3	464.7	400.3	–	
<b>Total</b>	<b>565</b>	<b>500</b>	<b>865</b>	

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137

137

## First Iteration-Average Computed Trip Distribution

Zone	Future Trip Generation			Computed Total Trips
	1	2	3	
1	–	99.9	464.7	565
2	99.9	–	400.3	500
3	464.7	400.3	–	865
Total	565	500	865	

138

138

## First Iteration-Average Computed Trip Distribution Calculate future trip generation



The present trip generation (productions) and future trips are computed for each zone based on the given data

➡ Add Actual future total trips

TABLE 2.70

Calculated Present and Future Trip Generation Results for Problem 2.33

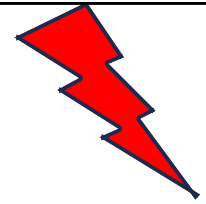
Zone	1	2	3	Present Trip Generation	Growth Factor	Future Trip Generation
1	–	100	300	400	1.2	480
2	100	–	200	300	1.5	450
3	300	200	–	500	2.0	1000
Total	400	300	500			

### Future Trip Generation

Zone	1	2	3	Computed Total Trips	Actual Total Trips
1	–	99.9	464.7	565	480
2	99.9	–	400.3	500	450
3	464.7	400.3	–	865	1000
Total	565	500	865		

139

## The need for second iteration



- ↪ The first iteration (averaged) gave us a symmetric trip matrix, but...
- ↪ **The computed totals do NOT match the actual targets.**
- ↪ This means the first iteration has **not yet balanced** productions (row sums) to the given future trip generation values.
- ↪ Therefore, we need to run a second iteration

Zone				Future Trip Generation	
	1	2	3	Computed Total Trips	Actual Total Trips
1	–	99.9	464.7	565	480
2	99.9	–	400.3	500	450
3	464.7	400.3	–	865	1000
Total	565	500	865		

140

140

## Data preparation for the second iteration

- ↪ You need to prepare
  - 1) New “Base Year” Trip Matrix
  - 2) New Growth Factors  $G_i^{(new)}$

141

141

## New “Base Year” Trip Matrix

Use the averaged symmetric matrix from the first iteration as the starting point.

### The need for second iteration

- The first iteration (averaged) gave us a symmetric trip matrix, but...
- The computed totals do NOT match the actual targets.
- This means the first iteration has **not yet balanced** productions (row sums) to the given future trip generation values.
- Therefore, we need to run a second iteration

Zone				Future Trip Generation	
	1	2	3	Computed Total Trips	Actual Total Trips
1	–	99.9	464.7	565	480
2	99.9	–	400.3	500	450
3	464.7	400.3	–	865	1000
Total	565	500	865		

138

Zone				Future Trip Generation
	1	2	3	Computed Total Trips
1	–	99.9	464.7	565
2	99.9	–	400.3	500
3	464.7	400.3	–	865
Total	565	500	865	

142

142

## 2) New Growth Factors $G_i^{(new)}$

Compute a **new growth factor for each zone**:

**Formula:**

$$G_i^{(new)} = \frac{\text{Actual future trip total for zone } i}{\text{Computed row total from 1st iteration}}$$

Zone	Computed Total (1st Iter)	Actual Target	New Growth Factor
1	565	480	$480/565 \approx 0.85$
2	500	450	$450/500 = 0.90$
3	865	1000	$1000/865 \approx 1.16$

### Calculate future trip generation

- The present trip generation (productions) and future trips are computed for each zone based on the given data

TABLE 2.70

Calculated Present and Future Trip Generation Results for Problem 2.33

Zone	1	2	3	Present Trip Generation	Growth Factor	Future Trip Generation
1	–	100	300	400	1.2	480
2	100	–	200	300	1.5	450
3	300	200	–	500	2.0	1000
Total	400	300	500			

### The need for second iteration

- The first iteration (averaged) gave us a symmetric trip matrix, but...
- The computed totals do NOT match the actual targets.
- This means the first iteration has **not yet balanced** productions (row sums) to the given future trip generation values.
- Therefore, we need to run a second iteration

Zone				Future Trip Generation	
	1	2	3	Computed Total Trips	Actual Total Trips
1	–	99.9	464.7	565	480
2	99.9	–	400.3	500	450
3	464.7	400.3	–	865	1000
Total	565	500	865		

143

143

## Second Iteration Growth Factors

Zone	1	2	3	Computed Total Trips	Actual Total Trips	Growth Factor
1	–	99.9	464.7	565	480	0.85
2	99.9	–	400.3	500	450	0.90
3	464.7	400.3	–	865	1000	1.16
Total	565	500	865			

144

144

- $T_{ij}$  = Number of trips estimated from zone *i* to zone *j*
- $t_i$  = Present trip generation in zone *i*
- $G_i$  = Growth factor of zone *i*
- $G_j$  = Growth factor of zone *j*
- $G_x$  = growth factor of zones *x*
- $T_i = t_i G_i$  = Future trip generation in zone *i*
- $t_{ix}$  = Number of trips between zone *i* and other zone *x*
- $t_{ij}$  = Present trips between zone *i* and zone *j*

Zone	1	2	3	Computed Total Trips	Actual Total Trips	Growth Factor
1	–	99.9	464.7	565	480	0.85
2	99.9	–	400.3	500	450	0.90
3	464.7	400.3	–	865	1000	1.16
Total	565	500	865			

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

$$T_{3-1} = (t_3 G_3) \left[ \frac{t_{31} G_1}{\sum_j t_{3j} G_j} \right] = (T_3) \left[ \frac{t_{31} G_1}{t_{31} G_1 + t_{32} G_2} \right]$$

$$T_{3-1} = (1000) \left[ \frac{(464.7)(0.85)}{(464.7)(0.85) + (400.3)(0.90)} \right] \cong 523.0 \text{ trips}$$

145

145

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

Zone	1	2	3	Computed Total Trips	Actual Total Trips	Growth Factor
1	–	99.9	464.7	565	480	0.85
2	99.9	–	400.3	500	450	0.90
3	464.7	400.3	–	865	1000	1.16
Total	565	500	865			

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

$$T_{1-3} = (t_1 G_1) \left[ \frac{t_{13} G_3}{\sum_j t_{1j} G_j} \right] = (T_1) \left[ \frac{t_{13} G_3}{t_{12} G_2 + t_{13} G_3} \right]$$

$$T_{1-3} = (480) \left[ \frac{(464.7)(1.16)}{(99.9)(0.90) + (464.7)(1.16)} \right] \cong 411 \text{ trips}$$

146

146

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

Zone	1	2	3	Computed Total Trips	Actual Total Trips	Growth Factor
1	–	99.9	464.7	565	480	0.85
2	99.9	–	400.3	500	450	0.90
3	464.7	400.3	–	865	1000	1.16
Total	565	500	865			

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

$$T_{3-1} = (1000) \left[ \frac{(464.7)(0.85)}{(464.7)(0.85) + (400.3)(0.90)} \right] \cong 523.0 \text{ trips}$$

$$T_{1-3} = (480) \left[ \frac{(464.7)(1.16)}{(99.9)(0.90) + (464.7)(1.16)} \right] \cong 411 \text{ trips}$$

$$T_{3-1} = \frac{523 + 411}{2} = 467 \text{ trips}$$

147

147

## Second Iteration-Computed Trip Distribution

↪ Unbalanced

Zone	1	2	3
1	–	68.8	411.2
2	69.8	–	380.2
3	523.1	476.9	–
Total	593	546	791

148

148

## Second Iteration-Average Computed

Zone	1	2	3
1	–	68.8	411.2
2	69.8	–	380.2
3	523.1	476.9	–
Total	593	546	791

Zone	1	2	3
1	–	69.3	467.2
2	69.3	–	428.5
3	467.2	428.5	–
Total	536	498	896

149

149

## Second Iteration-Average Computed

Zone	1	2	3	Future Trip Generation	
				Computed Total Trips	Actual Total Trips
1	–	69.3	467.2	536	480
2	69.3	–	428.5	498	450
3	467.2	428.5	–	896	1000
Total	536	498	896		

↪ It still need another iteration

↪ When do we stop?

- When the computed row totals are **close enough** to the actual targets (e.g., within 1–2% or a few trips). This usually takes 3–5 iterations.

150

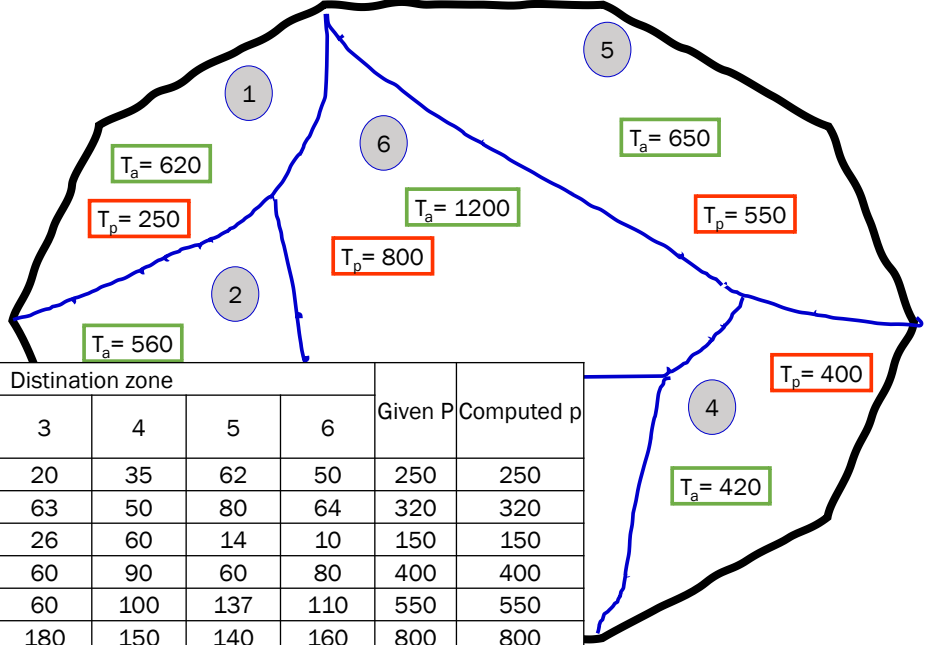
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## Trip Distribution

151

151

# Example



Origin zone	Distination zone						Given P	Computed p
	1	2	3	4	5	6		
1	63	20	20	35	62	50	250	250
2	41	22	63	50	80	64	320	320
3	18	22	26	60	14	10	150	150
4	40	70	60	90	60	80	400	400
5	63	80	60	100	137	110	550	550
6	90	80	180	150	140	160	800	800

# *Transportation Engineering and Planning*

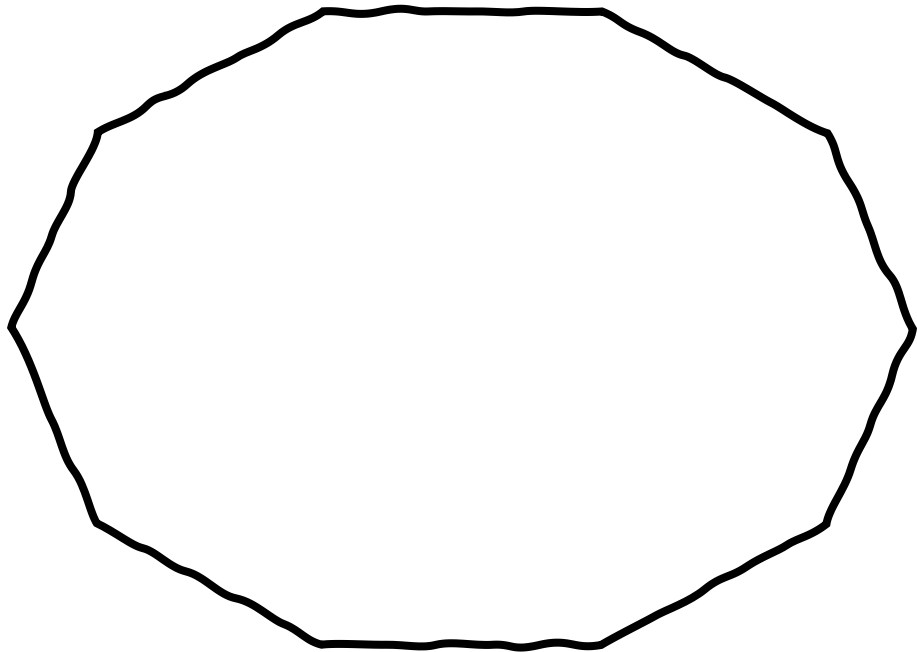
Module |3| Forecasting Travel in Urban Transportation Planning

## 3.7 | Mode Choice

*Dr. Hamza Mohammad Alkuime*

1

**Review**

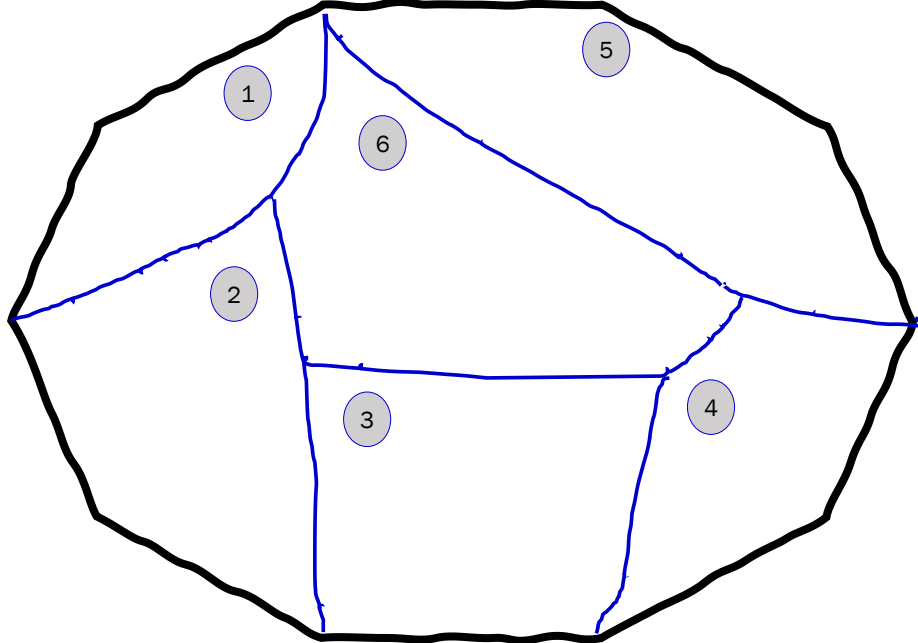


**Study area**

2

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## Review



Zoning

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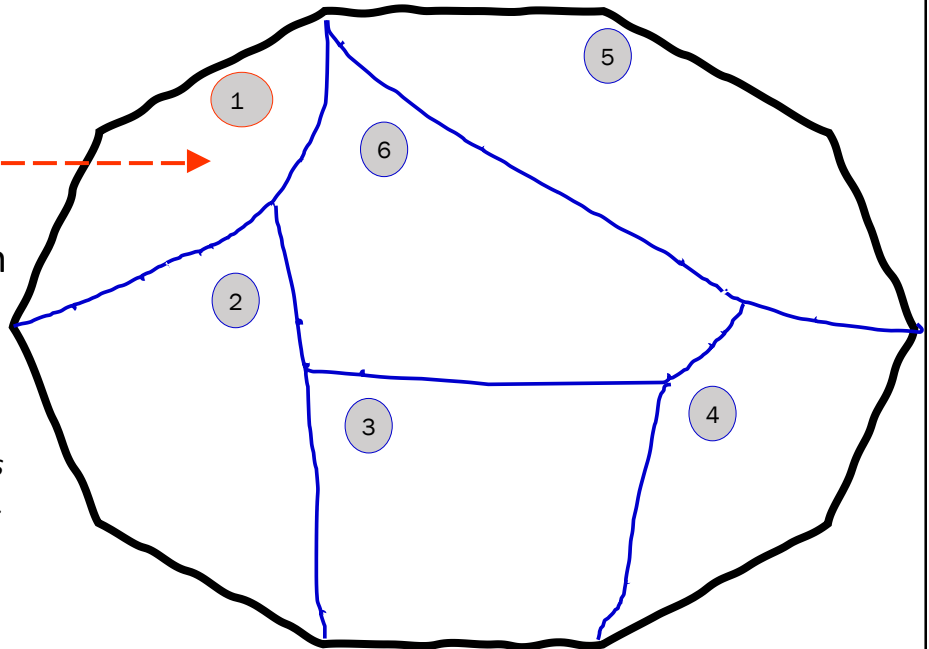
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## Review

### Attracted trips

The land use within  
**Zone 1** are

- 120 office space
- 500 factory
- 50 educational seats
- 100 shopping center



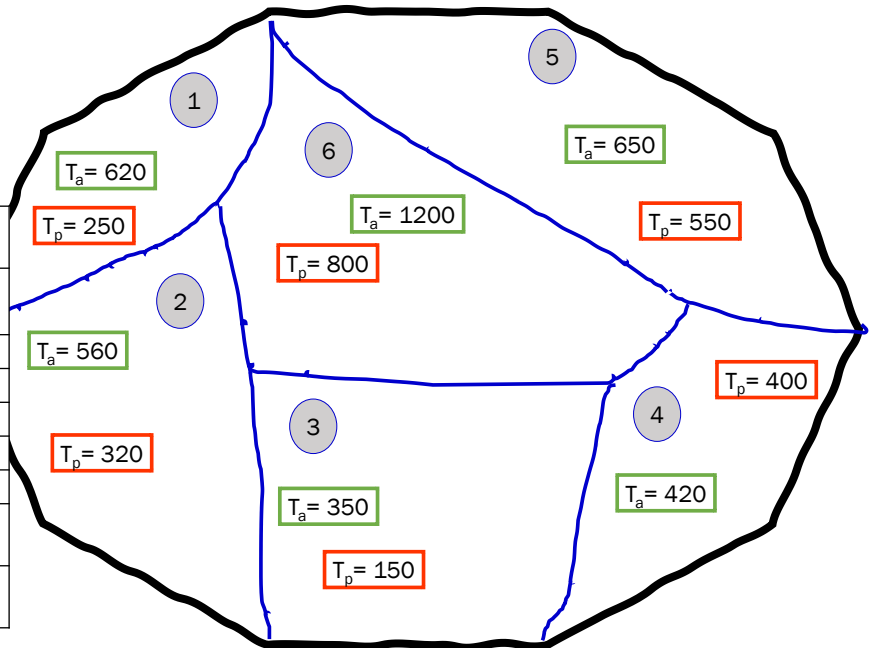
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# Review

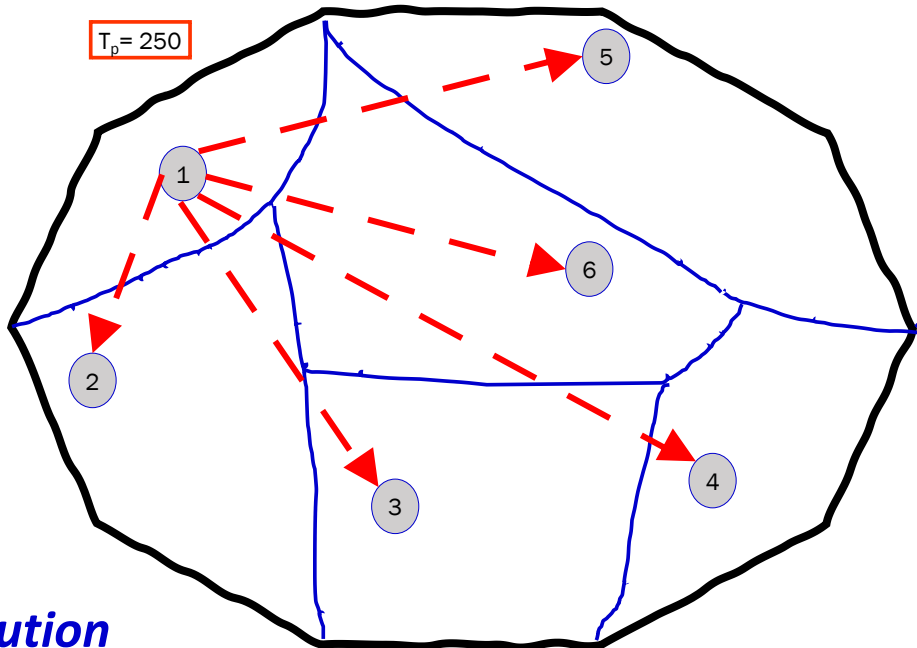
## Balanced Trip Productions and Attractions

Zone ID	Balanced trips	
	Production	Attraction
1	250	403
2	320	364
3	150	228
4	400	273
5	550	423
6	800	780
Total trips	2470	2470



5

# Review

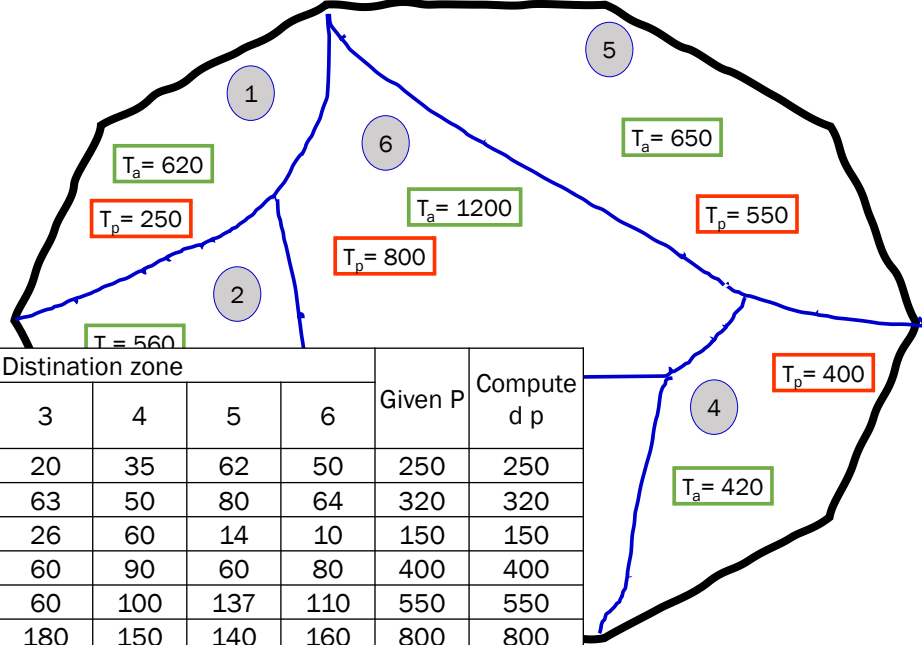


## Trip distribution

6

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## Example



Origin zone	Distination zone						Given P	Compute d p
	1	2	3	4	5	6		
1	63	20	20	35	62	50	250	250
2	41	22	63	50	80	64	320	320
3	18	22	26	60	14	10	150	150
4	40	70	60	90	60	80	400	400
5	63	80	60	100	137	110	550	550
6	90	80	180	150	140	160	800	800

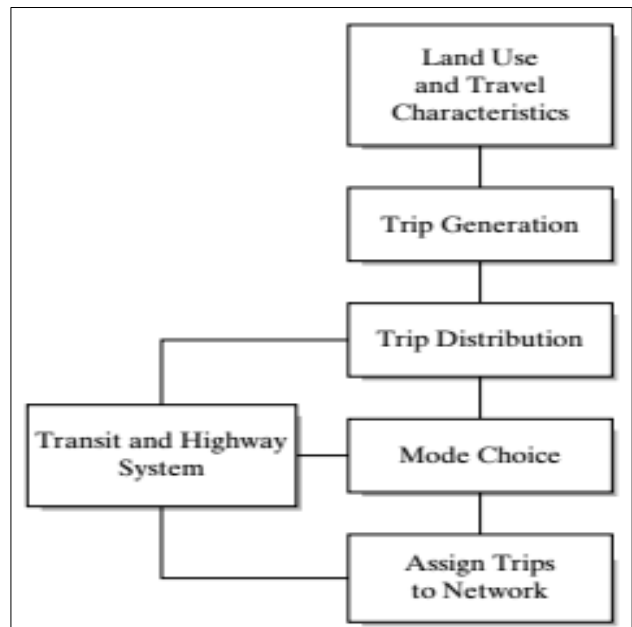
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## Review

### Travel Forecasting Process

Four-step process

- Trip generation
  - ❖ How many trips
- Trip distribution
  - ❖ From where to where
- Mode choice
  - ❖ On what mode
- Traffic assignment
  - ❖ On what route



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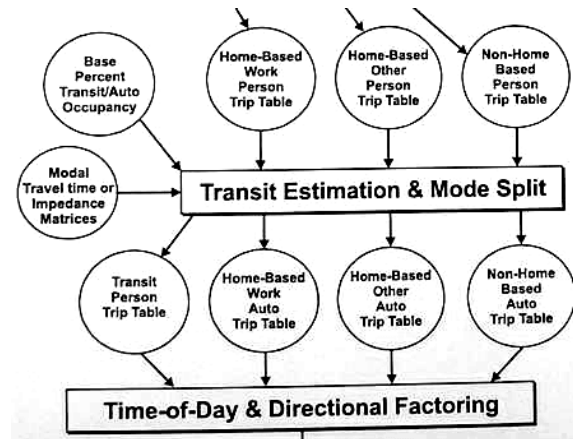
# Mode Split

## Definition

↪ To determine the **number (or %)** of trips made **between zones** using **each mode of travel**

↪ For the analysis, the following variables might be used:

1. *Trip characteristics*
  - ❖ length, time of day, purpose, ...etc.
2. *Trip maker characteristics*
  - ❖ Income, auto ownership, employment, ...etc.
3. *Transportation system characteristics*
  - ❖ Accessibility, parking, travel time, ...etc.



# Mode Choice

## Goal

➤ What modes these trips are taking ?

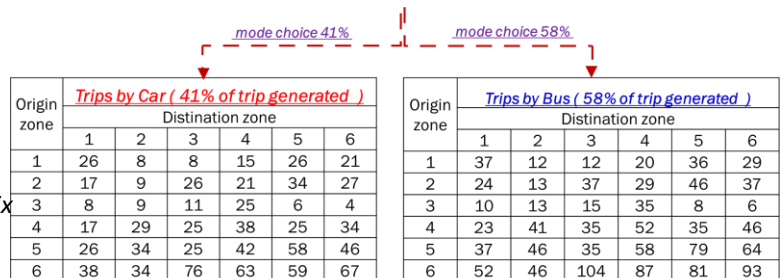
## Inputs

➤ Origin- destination matrix

## Output

➤ Mode wise Origin- destination matrix

Origin zone	<u>Generated trips</u>					
	Destination zone					
	1	2	3	4	5	6
1	63	20	20	35	62	50
2	41	22	63	50	80	64
3	18	22	26	60	14	10
4	40	70	60	90	60	80
5	63	80	60	100	137	110
6	90	80	180	150	140	160



## Mode Choice

### *Types of Mode Choice Models*

↳ Depending on the level of detail required, three types of transit estimating procedures

1. *Direct Generation of transit trips*
2. *Trip End models*
3. *Trip Interchange Models*

13

13

## Mode Choice Models

### *1. Direct Generation of transit trips*

14

14

# Mode Choice

## Direct Generation of transit trips

### Idea:

- Transit trips can be **estimated directly** (without a detailed mode choice model).

### Direct generation estimates the number of transit trips directly using simple relationships with:

- **Population density** (persons/acre)
- **Car ownership** (autos per household)

### What the method assumes

- Transit use is mainly explained by **land-use and population characteristics** (e.g., density, car ownership).
- **System attributes (Level of Service)** are treated as **not important** in this approach.

### What is NOT considered (important limitation)

- **Travel time, Travel cost, Comfort / convenience, Waiting time / frequency, Reliability**
- In other words, this approach **cannot capture changes in service quality**.

15

15

# Mode Choice

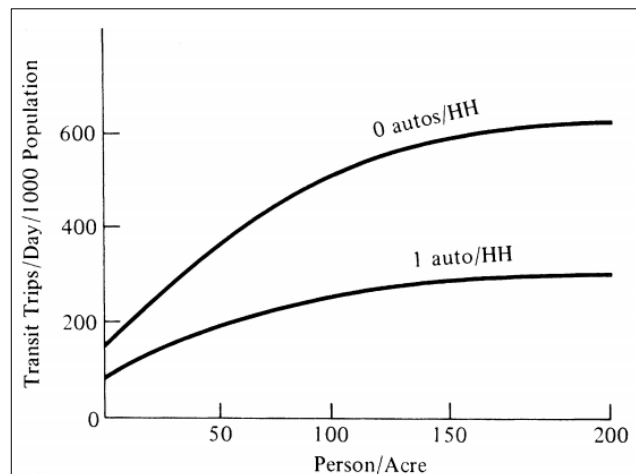
## Direct Generation of transit trips

### How to read the figure

- **X-axis:** Population density (persons/acre)
- **Y-axis:** Transit trips per day per 1000 population
- Two curves represent different **car ownership levels**:
  - ❖ **0 autos/HH:** higher transit trips
  - ❖ **1 auto/HH:** lower transit trips

### Interpretation

- As **density increases**, transit trips **increase** for both curves (more people nearby → transit can serve more trips).
- At the same density, **lower car ownership** produces **more transit trips** (fewer cars available → more reliance on transit).



16

16

# Mode Choice

## Example No. 1 (Example 12.7 ): Estimating Mode Choice by Direct Trip Generation

17

17

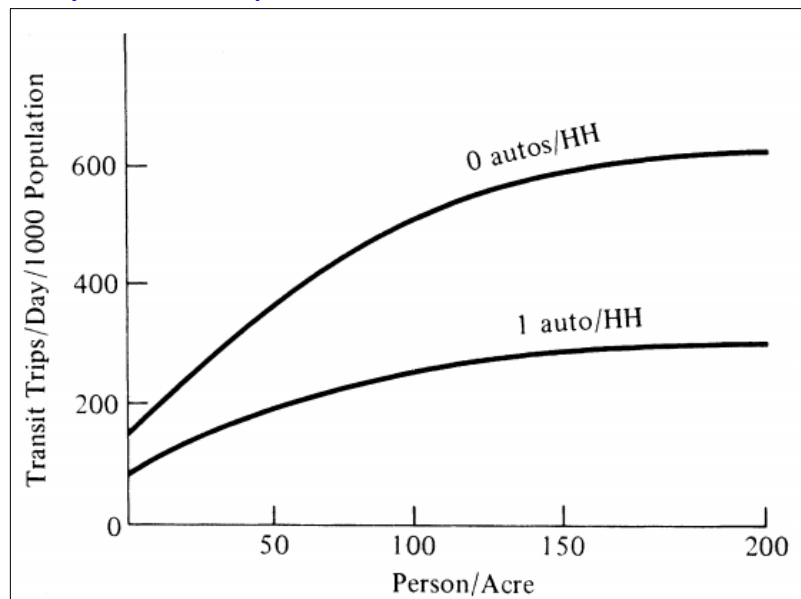
### Example No. 1 (Example 12.7 ): Estimating Mode Choice by Direct Trip Generation

↪ Determine the number of transit trips per day in a zone which has

➤ **5000 people** living on **50 acres**.

➤ Auto ownership is

- ❖ 40% of zero autos per household
- ❖ 60% of one auto per household



18

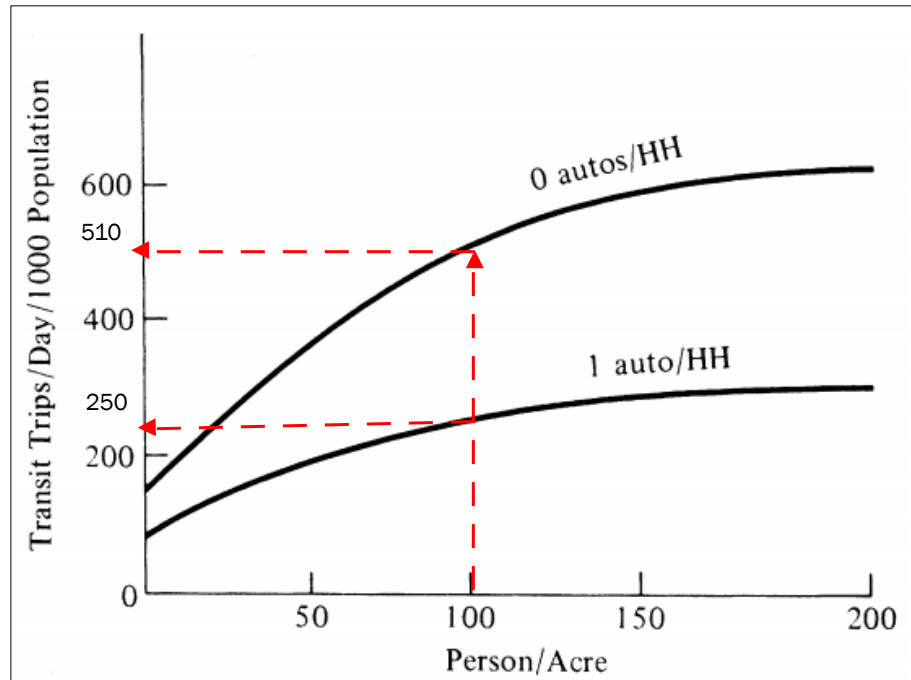
18

↪ Determine the number of transit trips per day in a zone which has

➤ **5000 people** living on **50 acres**.

➤ Auto ownership is

- ❖ 40% of zero autos per household
- ❖ 60% of one auto per household



19

19

## Solution of Example No. 1 (Example 12.7):

Convert population into groups of 1000:

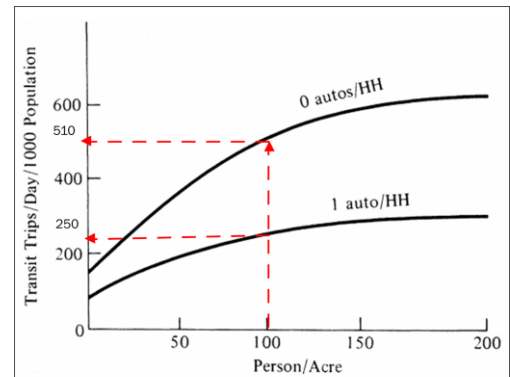
$$\frac{5000 \text{ people}}{1000} = 5 \text{ groups}$$

◆ Transit Trips from 0-auto HHs:

$$= 0.40 \times 510 \times 5 = 1020 \text{ trips/day}$$

◆ Transit Trips from 1-auto HHs:

$$= 0.60 \times 250 \times 5 = 750 \text{ trips/day}$$



19

✓ Final Answer:

$$\text{Total Transit Trips} = 1020 + 750 = 1770 \text{ transit trips/day}$$

20

20

# Mode Choice Models

## 2. Trip End Models

21

21

## Trip End Models

### Introduction

#### ↳ Purpose:

- Estimate the **percentage of total trips** (person trips or auto trips) that will use **each travel mode** (e.g., car, transit, walk).

#### ↳ When it is used:

- Mode shares are estimated **before** the **trip distribution** step (i.e., prior to connecting origins and destinations).

#### ↳ What it is based on (zone characteristics):

- **Land-use** (residential, commercial, industrial, mixed-use)
- **Socioeconomic factors** (income, car ownership, household size, employment, etc.)

#### ↳ Key limitation:

- Trip End Models **do NOT account for the quality of service (LOS)** (e.g., travel time, cost, frequency, comfort, reliability).

22

22

## Slide: Urban Travel Factor (UTF)

### Definition

- ↪ Urban Travel Factor (UTF) is a **zone-level index** used in **Trip End Models** to represent
  - *how “urban” an area is*
  - and *how limited car availability is.*
- ↪ UTF helps estimate **the transit mode split (%)** using a **mode choice curve.**
- ↪ **Formula**
  - $$UTF = \frac{1}{1000} \left( \frac{\text{Households}}{\text{Autos}} \right) \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$
- ↪ In general, **higher UTF** → **higher** expected transit use.

23

23

## Urban Travel Factor (UTF)

### Terms

$$\hookrightarrow UTF = \frac{1}{1000} \left( \frac{\text{Households}}{\text{Autos}} \right) \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$

- ↪ **1) Households**
  - Total number of **households in the zone**
  - Represents *how many “home units”* exist in that area.
- ↪ **2) Autos**
  - Total number of **private cars available** to those households in the zone
  - Used as a measure of **car availability.**
- ↪ **Interpretation of (Households / Autos):**
  - This ratio is basically the inverse of “cars per household.”
  - **Higher value** → **fewer cars available per household** → **more dependence on transit/walk.**
  - Example:
    - ❖ If 100 households / 50 autos = 2 → **low auto ownership**
    - ❖ If 100 households / 120 autos ≈ 0.83 → **high auto ownership**

24

24

## Trip End Models

### Urban Travel Factor (UTF) terms

$$UTF = \frac{1}{1000} \left( \frac{\text{Households}}{\text{Autos}} \right) \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$

#### 3) Persons

- Total number of **people living in the zone**
- Indicates population size.

#### 4) mi<sup>2</sup> (square miles)

- The **area size of the zone** in square miles.

#### Interpretation of (Persons / mi<sup>2</sup>):

- This is **population density** (how crowded/urban the area is).
- **Higher density** → transit becomes **more viable and attractive** (more destinations nearby, more riders per route, better service potential).

25

25

## Trip End Models

### Urban Travel Factor (UTF) terms

$$UTF = \frac{1}{1000} \left( \frac{\text{Households}}{\text{Autos}} \right) \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$

#### Why multiply the two ratios?

$$\left( \frac{\text{Households}}{\text{Autos}} \right) \times \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$

#### Combines two **key drivers of transit use**:

- **Car availability** (how easy it is to use a private car)
- **Urban intensity** (how dense the zone is)

#### Overall meaning of UTF

- **Higher UTF** → **more urban** + **fewer cars** → **higher transit mode share**
- **Lower UTF** → **more cars** + **lower density** → **higher auto mode share**

26

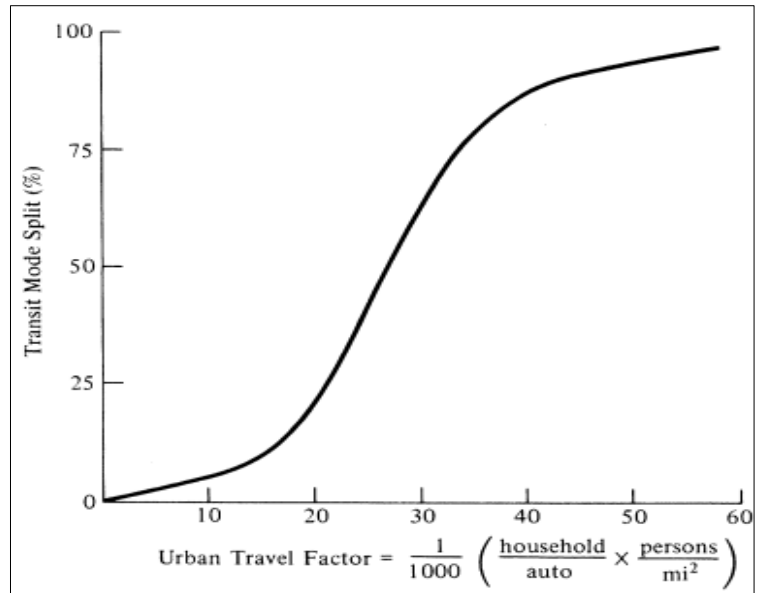
26

## Trip End Models

### Procedures (How the Method Works)

#### Overall meaning of UTF

- Higher UTF → more urban + fewer cars → higher transit mode share
- Lower UTF → more cars + lower density → higher auto mode share



27

27

## Trip End Models

### Procedures (How the Method Works)

#### Compute total trips by purpose

- Estimate trip productions (P) and trip attractions (A) for each zone and each trip purpose (from the Trip Generation step).

#### Calculate the Urban Travel Factor (UTF)

$$UTF = \frac{1}{1000} \left( \frac{\text{Households}}{\text{Autos}} \right) \left( \frac{\text{Persons}}{\text{mi}^2} \right)$$

- Higher UTF → typically higher transit use

28

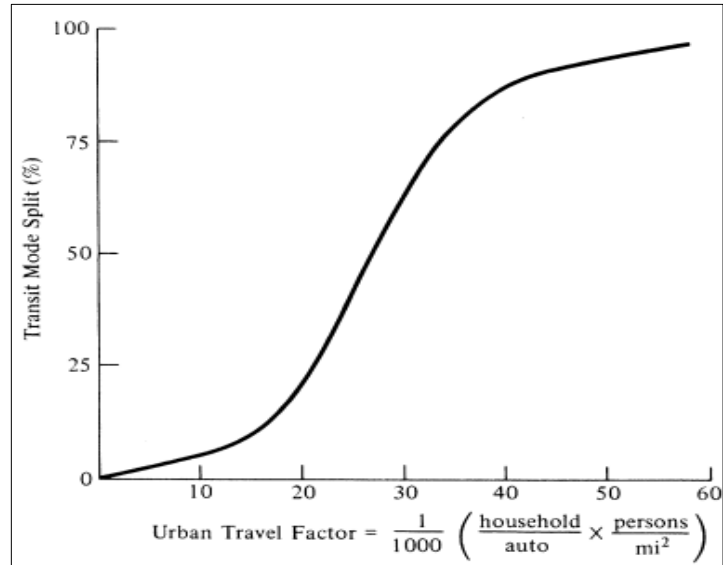
28

## Trip End Models

### Procedures (How the Method Works)

↪ Estimate transit share using a Mode Choice Curve

- Use the **UTF value** to read the **% of trips made by transit** from the curve.



29

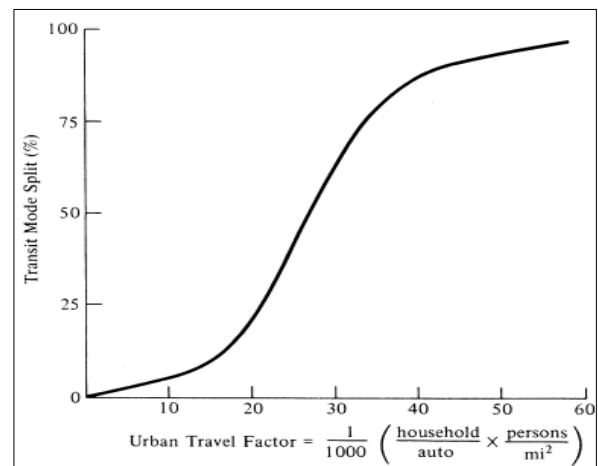
29

## Trip End Models

### Procedures (How the Method Works)

↪ Compute:

- **Transit Trips = (Transit %) × Total Trips**
- **Auto Trips = Total Trips – Transit Trips**



30

30

## Trip End Models

*Procedures (How the Method Works)*

↪ **Distribute trips separately by mode**

➤ *Perform **Trip Distribution** twice:*

- ❖ Transit trips distributed independently
- ❖ Auto trips distributed independently

↪ **Output: two OD matrices** (Transit OD + Auto OD)

33

33

## Trip End Models

*Example No.1 (Example 12.8 ): Estimating  
Trip Productions by Transit*

34

34

## Trip End Models

### Example No. 1 (Example 12.8): Estimating Trip Productions by Transit

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

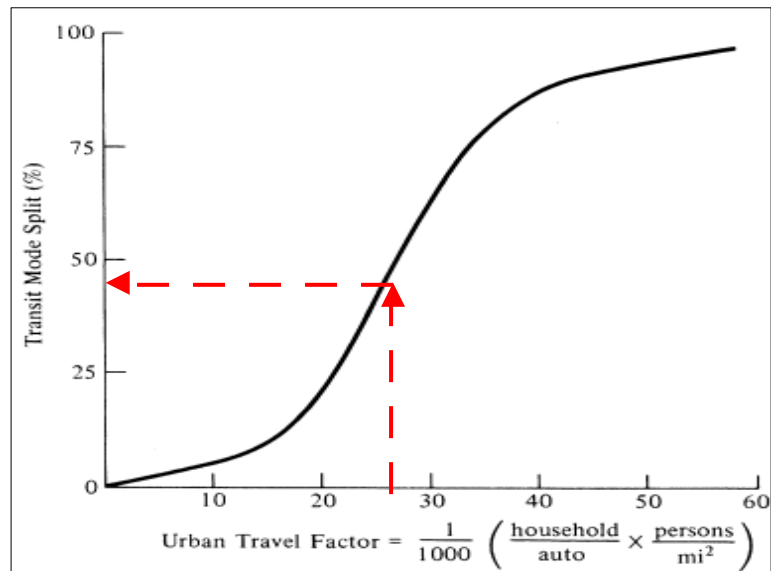
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35

## Trip End Models

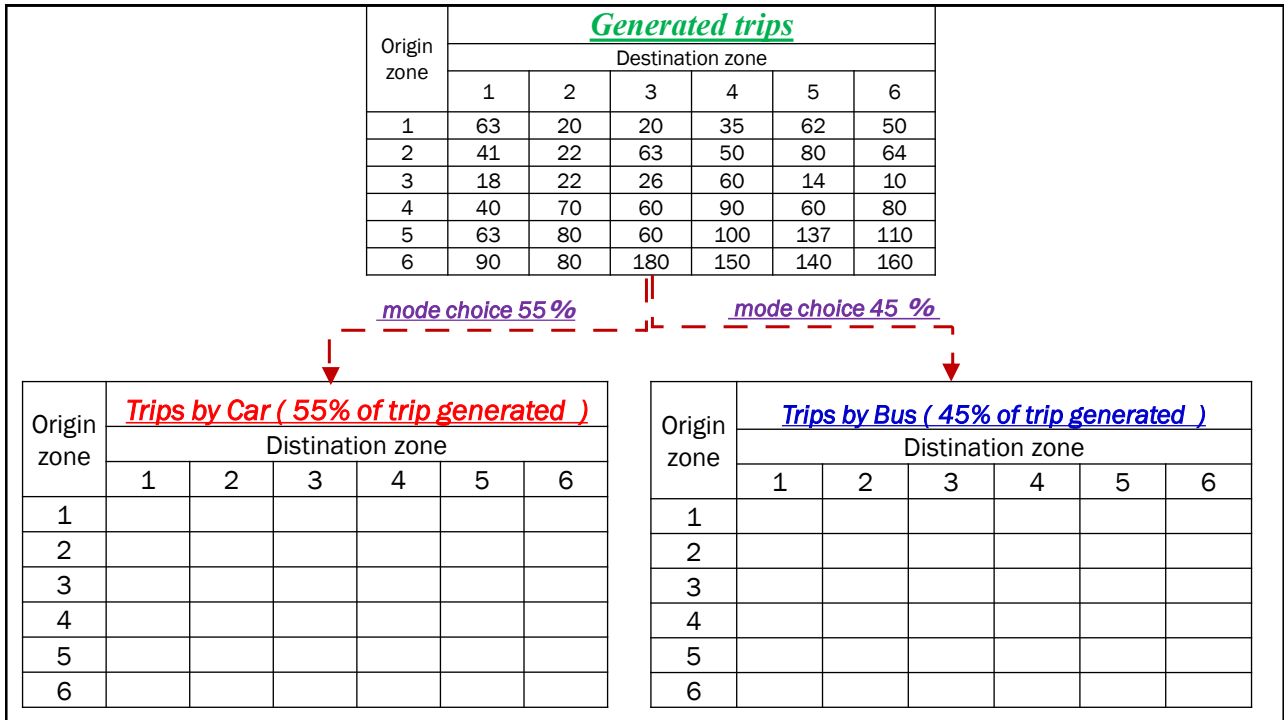
### Solution of Example No.1 (Example 12.8)

- ↪ Compute the urban travel factor (UTF)
  - $UTF = \frac{1}{1000} \times \left( \frac{\text{Houdhold}}{\text{auto}} \right) \times \left( \frac{\text{Person}}{\text{mi}^2} \right)$
  - $UTF = \frac{1}{1000} \times (1.8) \times (15000) = 27.0$
- ↪ Transit mode split = 45%.



36

36



37

## Mode Choice Models

### 3. Trip Interchange Models

38

# Mode Choice

## Trip Interchange Models (Mode Choice Approach)

### ↩ When it is applied:

- Mode choice is estimated **after Trip Distribution**
- (i.e., after we know the **OD pairs**: which zones travel to which zones).

### ↩ Main idea:

- This method uses **system Level-of-Service (LOS)** variables to explain **why travelers choose one mode over another**.

### ↩ Typical LOS variables considered

- **Relative travel time** (e.g., transit time compared to auto time)
- **Relative travel cost** (fare, fuel, parking, tolls)
- **Traveler socioeconomic characteristics** (income, car ownership, value of time)
- **Relative service quality** (frequency, reliability, comfort, access/egress, waiting time)

### ↩ Why it's stronger than Trip End Models:

- It can reflect changes in the transport system (e.g., faster bus, cheaper fare, better frequency)

39

39

# Trip Interchange Models

## Quick Response System (QRS) Method — Introduction

↩ **Quick Response System (QRS)** is a **planning-level** method used to estimate **mode choice** (how trips split among auto, transit, walk, etc.).

↩ It is commonly used as an example of **Trip Interchange (post-distribution) mode choice**, where mode shares are estimated **after Trip Distribution** (after OD pairs are known).

↩ **Key feature:** QRS explicitly considers **service (Level-of-Service) parameters**, such as:

- **Travel time** (in-vehicle time, walking time, waiting time)
- **Travel cost** (fare, fuel, parking, tolls)
- **Service quality** (frequency/headway, reliability, transfers, comfort)

↩ **Main output:** Estimated **mode split (%)** for each OD pair or corridor, **based on the relative attractiveness of each mode**.

40

40

## QRS method

### Impedance (I) in the QRS Model

↪ Impedance (I) is a single “generalized cost” measure that combines time, inconvenience, and money into one value to represent how difficult (or unattractive) a trip is by a specific mode.

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪ Key interpretation

➤ Lower I → more attractive mode → higher probability of being chosen

➤ Travelers generally choose the mode with the smallest impedance

41

41

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪  $I_{ijm}$  is the impedance (generalized travel “resistance”) for a trip

↪ It combines time + inconvenience + money into a single value

↪ Indices:

➤  $i$ : origin zone

➤  $j$ : destination zone

➤  $m$ : mode (e.g., auto, transit)

i is origin zone number  
j is destination zone number  
t for transit mode  
a for auto mode

↪ Interpretation:

➤ Lower  $I_{ijm}$  → more attractive mode → more likely to be chosen

➤ Higher  $I_{ijm}$  → less attractive mode

42

42

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪  $t_{ijm}^{iv}$  = **in-vehicle travel time** in minutes

↪ It is the time spent **inside** the main vehicle while traveling

↪ Examples:

- Auto: **driving time** from zone  $i$  to zone  $j$
- Transit: **time on the bus/train** between boarding and alighting

↪ Note:

- This term represents the “main movement time” of the trip

43

43

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪  $t_{ijm}^{ex}$  = **excess time** in minutes

↪ It includes time spent **outside the vehicle** or in activities that feel more inconvenient than riding

↪ Typical components:

- walking to/from stop or parking (access/egress)
- waiting time
- transfer time
- time spent searching for parking (auto)

44

44

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪ Why it is weighted:

- Excess time is multiplied by 2.5 because *travelers usually perceive walking/waiting/transfer time* as **more stressful** than in-vehicle time

↪ **The 2.5 Weight on Excess Time**

- The coefficient 2.5 reflects *perceived inconvenience*

↪ Meaning:

- **1 minute of excess time** is treated like **2.5 minutes of in-vehicle time**

↪ Example:

- If  $t^{ex} = 4 \text{ min}$ , then  $2.5t^{ex} = 10$  "equivalent minutes"

↪ Interpretation:

- Reducing waiting or walking time can strongly improve a mode's attractiveness

45

45

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪  $C_{ijm}$  = **monetary cost** of traveling from  $i$  to  $j$  by mode  $m$  in **dollars**

↪ Examples of what may be included:

- *Transit: fare, passes (converted per trip), transfer fees*
- *Auto: fuel cost, parking fees, tolls*

↪ Important:

- *Cost affects mode choice, especially when differences between modes are large*

46

46

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↻  $IR$  = income rate expressed in \$/minute

↻ Purpose:

➤ converts **money cost** into an **equivalent time cost**

↻ Typical calculation:

$$\text{IR} = \frac{\text{Annual income (\$/year)}}{\text{Minutes worked per year (min/year)}}$$

↻ Common assumption:

➤ minutes worked per year  $\approx$  **120,000 min/year** (e.g., 2000 hr/year  $\times$  60)

↻

47

47

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↻  $\frac{C_{ijm}}{IR}$  converts dollars into **equivalent minutes**

↻ Interpretation:

➤ "How many minutes of work-time does this cost represent?"

↻ Example:

➤ If  $C = 2\$$  and  $IR = 0.20\$/min$

$$\text{↻ } \frac{C}{IR} = \frac{2}{0.20} = 10 \text{ min}$$

↻ Meaning:

➤ Paying \$2 is treated like spending **10 minutes** (time-equivalent)

48

48

## Impedance (I) in the QRS Model

$$\text{Impedance } (I_{ijm}) = t_{ijm}^{iv} + 2.5 t_{ijm}^{ex} + 3 \left( \frac{C_{ijm}}{IR} \right)$$

↪ The coefficient **3** increases the influence of money cost in QRS

↪ Meaning:

➤ the cost-based “time-equivalent minutes” are multiplied by 3

↪ Example:

➤ if  $\frac{C}{IR} = 10 \text{ min}$ , then  $3 \left( \frac{C}{IR} \right) = 30$  “equivalent minutes”

↪ Interpretation:

➤ *cost differences* can strongly shift mode choice in the QRS approach

49

49

## QRS method

### Mode Share Equations (Auto vs Transit)

i is origin zone number  
j is destination zone number  
t for transit mode  
a for auto mode

↪  $MS_a$ : **Auto mode share** (%) of trips between zone  $i$  and zone  $j$

↪  $MS_t$ : **Transit mode share** (%) of trips between zone  $i$  and zone  $j$

↪  $I_{ija}$ : **auto impedance** for travel from  $i$  to  $j$

↪  $I_{ijt}$ : **transit impedance** for travel from  $i$  to  $j$

↪  $b$ : **calibration exponent** (depends on trip purpose)

↪ **Key interpretation**

↪  $\frac{1}{I^b}$  represents **mode attractiveness**

↪ If a mode has **lower impedance**, it has **higher attractiveness** and therefore **higher share**

$$MS_a = \frac{1/I_{ija}^b}{1/I_{ija}^b + 1/I_{ijt}^b} \times 100$$

$$MS_t = 100 - MS_a$$

50

50

## ***b*— Calibration Exponent**

### ↩ What is *b*?

- *b* is a **calibration exponent** that controls **how sensitive mode share is to differences in impedance between modes**.
- It is sometimes called a **sensitivity** or **steepness** parameter.

### ↩ What does *b* do in the equation?

- QRS uses mode attractiveness: **Attractiveness**  $\propto \frac{1}{I^b}$
- **If *b* is large** → **small impedance differences cause a large shift** in mode share
- **If *b* is small** → mode shares change **slowly** with impedance differences

51

51

## ***b*— Calibration Exponent**

### ***Example 1 — How *b* affects mode share***

- ↩ Assume impedances between the same OD pair are: Auto impedance:  $I_a = 40$ , Transit impedance:  $I_t = 50$
- ↩ QRS auto share:  $MS_a = \frac{1/I_a^b}{1/I_a^b + 1/I_t^b} \times 100$
- ↩ **Case A:  $b = 1$** 
  - $MS_a = \frac{1/40}{1/40 + 1/50} \times 100 \approx 55.6\%$      $MS_t \approx 44.4\%$
- ↩ **Case B:  $b = 2$** 
  - $MS_a = \frac{1/40^2}{1/40^2 + 1/50^2} \times 100 \approx 61.0\%$ ,     $MS_t \approx 39.0\%$
- ↩ **Conclusion:** Increasing *b* makes the **model more sensitive**, so the lower-impedance mode (auto here) gains **more share**.

52

52

## ***b*— Calibration Exponent**

### **Where Do We Get *b* From? (Calibration Using Observed Data)**

- ↪ *b* is not guessed — it is **calibrated** using **real observed mode shares**.
- ↪ We estimate *b* by fitting the QRS mode share model to **measured data** for a specific **trip purpose** (work, school, shopping, leisure, etc.).
- ↪ **Observed data sources (examples)**
  - Household travel surveys (reported mode choices)
  - OD surveys / stated preference surveys
  - Transit ridership counts and passenger surveys
  - Traffic counts
- ↪ **Calibration idea**
  - Choose a trip purpose (e.g., work trips).
  - For many OD pairs (*i*, *j*), we have:
    - ❖ Observed shares:  $MS_a$  and  $MS_t$
    - ❖ Computed impedances:  $I_{ija}$  and  $I_{ijt}$
- ↪ **Helpful calibration form (used in practice)**  $\frac{MS_a}{MS_t} = \left(\frac{I_a}{I_t}\right)^b$  ..... Taking logs:  $\ln\left(\frac{MS_a}{MS_t}\right) = b \ln\left(\frac{I_a}{I_t}\right)$
- ↪ Using many OD observations, estimate *b* as the **best-fit slope** (regression).
- ↪ Result: a calibrated *b* value for each **trip purpose** (and sometimes time period)

53

53

## **How to Use the QRS Mode Share Formula**

- ↪ **Steps**
  - Compute  $I_{ija}$  and  $I_{ijt}$  using the QRS impedance equation
  - Get value for *Bb*
  - Compute attractiveness terms:  $\frac{1}{(I_{ija})^b}$  and  $\frac{1}{(I_{ijt})^b}$
  - Substitute into the mode share equation to get  $MS_a$
  - Compute  $MS_t = 100 - MS_a$

54

54

## QRS method

### Example No. 1 (Example 12.9) : Computing Mode Choice Using the QRS Model

58

58

## QRS method

### Example No. 1 (Example 12.9) : Computing Mode Choice Using the QRS Model

- ↪ The data in table 12.21 have been developed for travel between a suburban zone *S* and a downtown zone *D*
- ↪ Determine the percent of work trips by auto and transit
- ↪ An exponent value of 2.0 is used for work travel.
- ↪ Median income is \$24,000 per year

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

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

59

59

	<i>Auto</i>	<i>Transit</i>
Distance	10 mi	8 mi
Cost per mile	\$0.15	\$0.10
Excess time	5 min	8 min
Parking cost	[ ] or 0.75/trip	—
Speed	30 mi/h	20 mi/h

$$\text{Travel Time (min)} = \frac{\text{Distance (mi)}}{\text{Speed (mi/h)}} \times 60 \text{ (min/h)}$$
  

$$\text{Auto Time} = \frac{10 \text{ mi}}{30 \text{ mi/h}} \times 60 \text{ min/h} = \frac{10}{30} \times 60 = \frac{1}{3} \times 60 = \boxed{20 \text{ minutes}}$$
  

$$\text{Transit Time} = \frac{8 \text{ mi}}{20 \text{ mi/h}} \times 60 \text{ min/h} = \frac{8}{20} \times 60 = 0.4 \times 60 = \boxed{24 \text{ minutes}}$$

60

60

Excess time

	<i>Auto</i>	<i>Transit</i>
Distance	10 mi	8 mi
Cost per mile	\$0.15	\$0.10
Excess time	5 min	8 min
Parking cost	[ ] or 0.75/trip	—
Speed	30 mi/h	20 mi/h

**Given in the Example:**

Mode	Excess Time
Auto	5 min
Transit	8 min

61

61

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

Trip Cost = (Distance × Cost per mile) + Additional Charges (e.g., parking)

---

**Given Data:**

Mode	Distance	Cost/mi	Parking	Total Cost (\$)
Auto	10 mi	\$0.15	\$0.75	$10 \times 0.15 + 0.75 = 2.25$
Transit	8 mi	\$0.10	—	$8 \times 0.10 = 0.80$

63

63

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

**Given:**

- Annual income = \$24,000
- Working time per year = 120,000 minutes

---

◆ **Formula:**

$$\text{Income Rate} = \frac{\text{Annual Income (\$)}}{\text{Annual Work Minutes}} = \frac{24,000}{120,000} = \boxed{\$0.20/\text{minute}}$$

64

64

### Impedance Formula:

$$I = \text{In-Vehicle Time} + 2.5 \times \text{Excess Time} + \frac{3 \times \text{Trip Cost}}{\text{Income Rate}}$$

### Calculation Table:

Mode	In-Vehicle Time	2.5 × Excess Time	$\frac{3 \times \text{Cost}}{0.20}$	Total Impedance
Auto	20.0 min	12.5 min	$\frac{6.75}{0.20} = 33.75 \text{ min}$	66.25 min
Transit	24.0 min	20.0 min	$\frac{2.40}{0.20} = 12.00 \text{ min}$	56.00 min

65

65

- Impedance (Auto) = 66.25
- Impedance (Transit) = 56.00
- Exponent  $b = 2$  (typical for work trips)

Correct Formula (Using Inverse Impedance):


$$MS_a = \frac{1/I_{auto}^b}{1/I_{auto}^b + 1/I_{transit}^b} \times 100$$


Step-by-Step:

$$\frac{1}{66.25^2} = 0.000228, \quad \frac{1}{56^2} = 0.000318$$

$$MS_a = \frac{0.000228}{0.000228 + 0.000318} \times 100 = 41.73\%$$

$$MS_t = 100 - MS_a = 58.27\%$$

 Auto Share: 41.73%

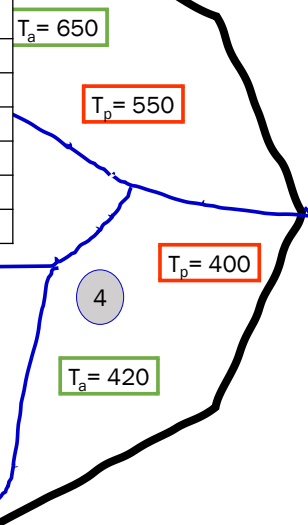
 Transit Share: 58.27%

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66

# Example

Origin zone	Trip distribution						Given P	Compute d p
	Destination zone							
	1	2	3	4	5	6		
1	63	20	20	35	62	50	250	250
2	41	22	63	50	80	64	320	320
3	18	22	26	60	14	10	150	150
4	40	70	60	90	60	80	400	400
5	63	80	60	100	137	110	550	550
6	90	80	180	150	140	160	800	800



## Mode Choice

- 42 % by car
- 58% by bus

76

Origin zone	Generated trips					
	Destination zone					
	1	2	3	4	5	6
1	63	20	20	35	62	50
2	41	22	63	50	80	64
3	18	22	26	60	14	10
4	40	70	60	90	60	80
5	63	80	60	100	137	110
6	90	80	180	150	140	160

mode choice 41.7%

mode choice 78.1%

Origin zone	Trips by Car ( 58 % of trip generated )					
	Distination zone					
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

Origin zone	Trips by Bus ( 41 % of trip generated )					
	Distination zone					
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

77

# *Transportation Engineering and Planning*

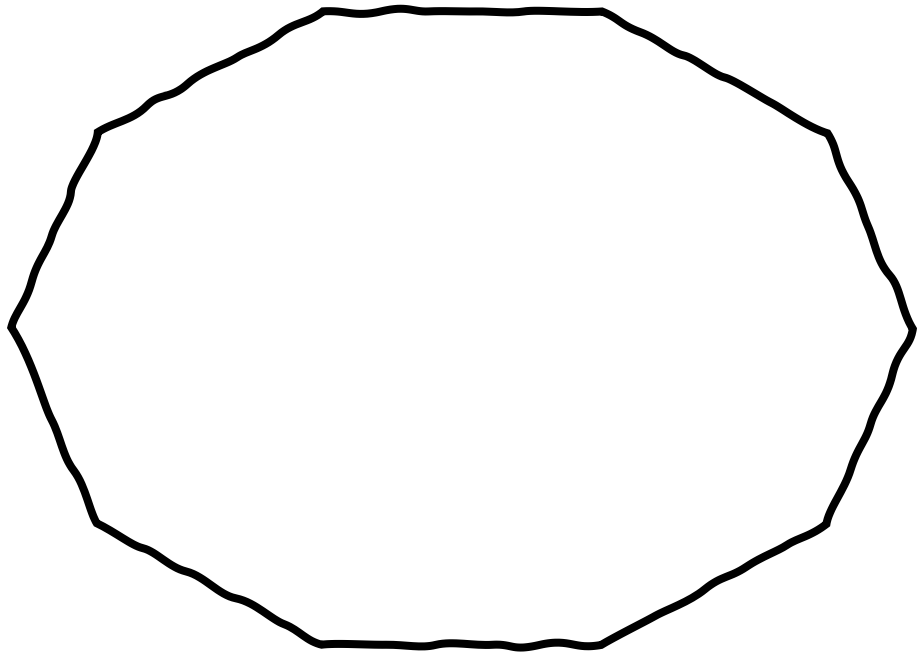
Module |5| Forecasting Travel in Urban Transportation Planning

## 3.8 | Traffic Assignment

*Dr. Hamza Mohammad Alkuime*

1

**Review**

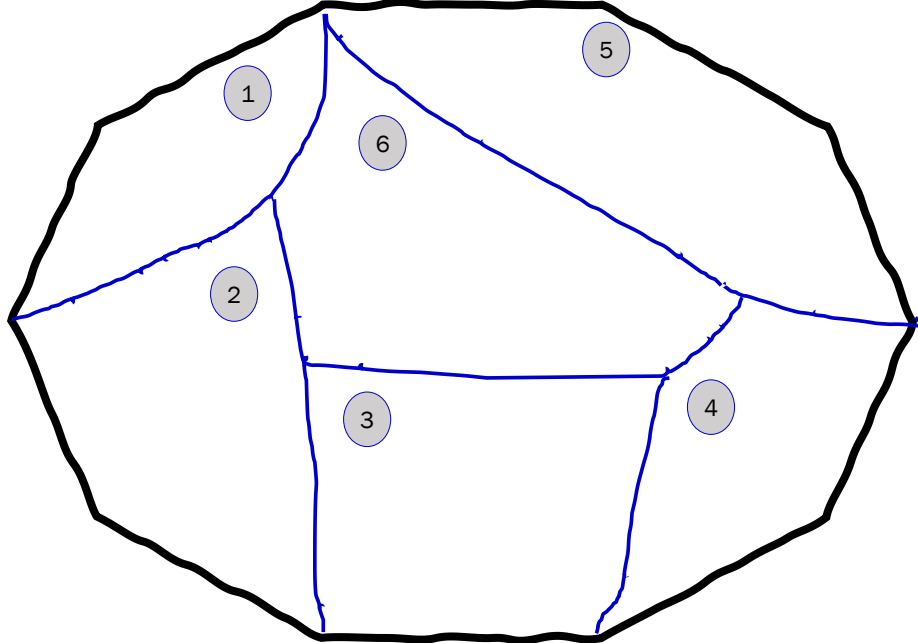


**Study area**

2

2

## Review



Zoning

3

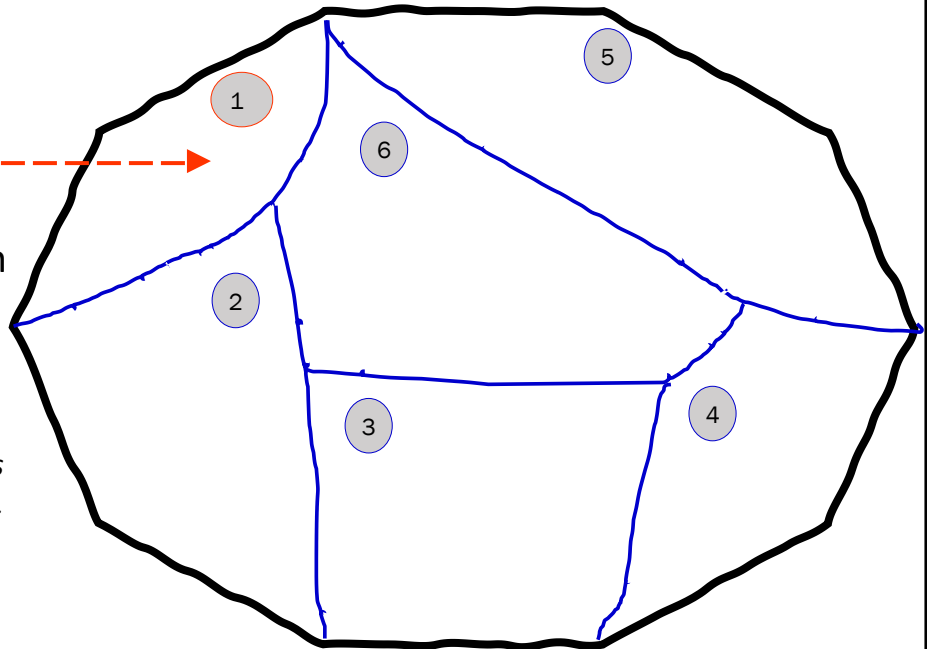
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## Review

### Attracted trips

The land use within  
**Zone 1** are

- 120 office space
- 500 factory
- 50 educational seats
- 100 shopping center



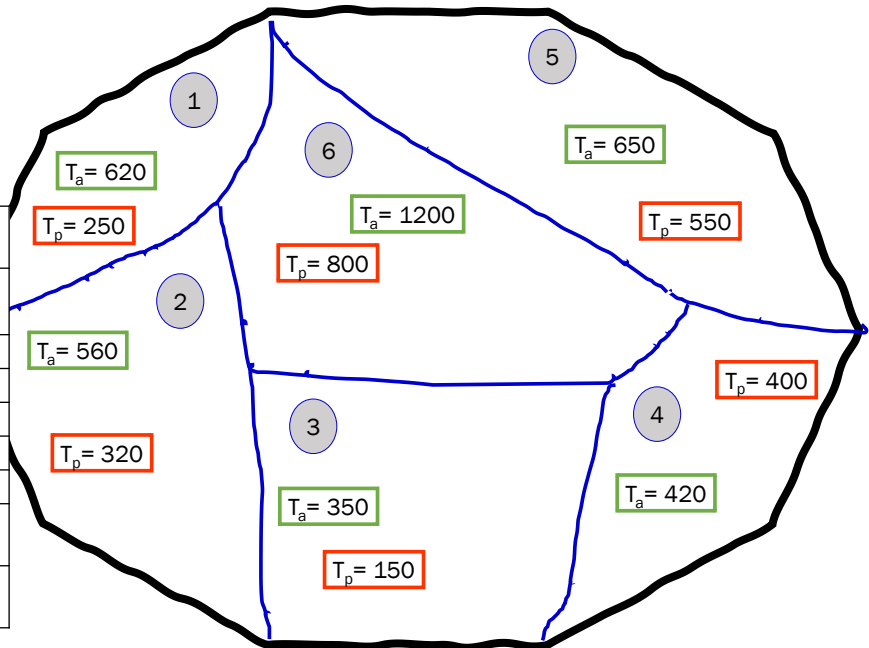
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4

# Review

## Balanced Trip Productions and Attractions

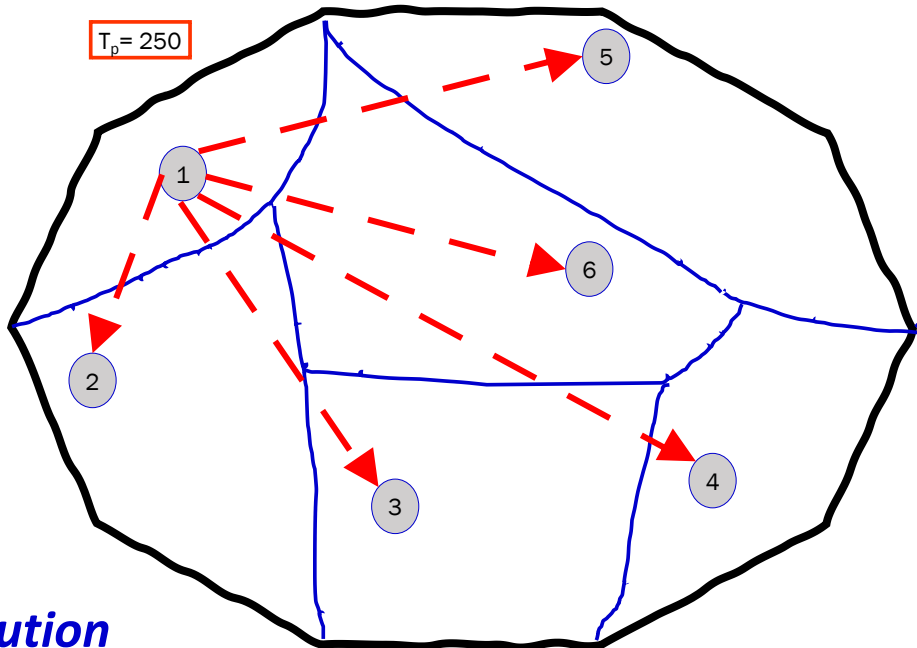
Zone ID	Balanced trips	
	Production	Attraction
1	250	403
2	320	364
3	150	228
4	400	273
5	550	423
6	800	780
Total trips	2470	2470



5

# Review

## Trip distribution



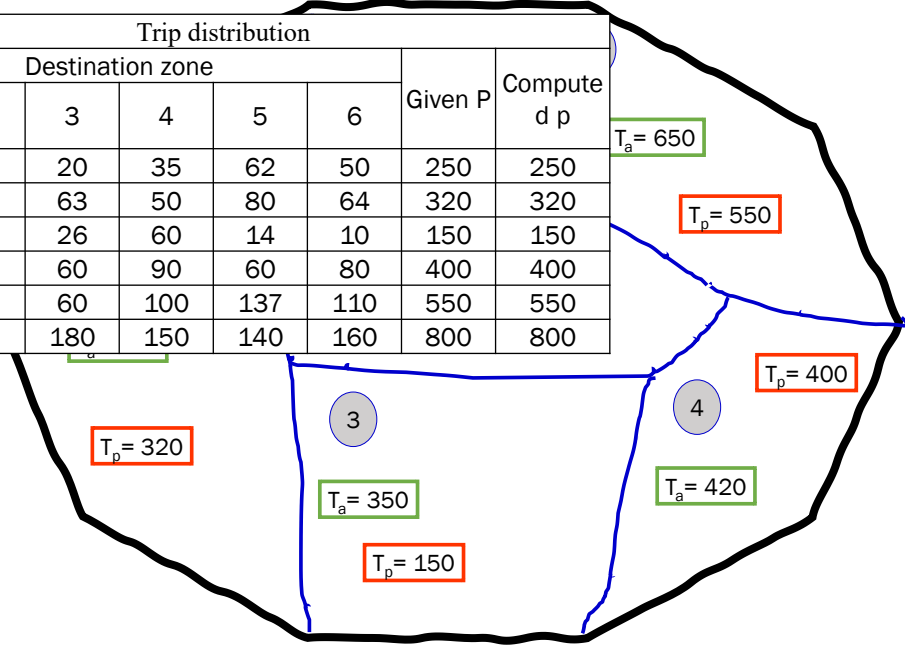
6

# Example

Origin zone	Trip distribution						Given P	Compute d p
	Destination zone							
	1	2	3	4	5	6		
1	63	20	20	35	62	50	250	250
2	41	22	63	50	80	64	320	320
3	18	22	26	60	14	10	150	150
4	40	70	60	90	60	80	400	400
5	63	80	60	100	137	110	550	550
6	90	80	180	150	140	160	800	800

## Model split

- 42 % by car
- 58% by bus



7

Origin zone	Generated trips					
	Destination zone					
	1	2	3	4	5	6
1	63	20	20	35	62	50
2	41	22	63	50	80	64
3	18	22	26	60	14	10
4	40	70	60	90	60	80
5	63	80	60	100	137	110
6	90	80	180	150	140	160

mode choice 41%

mode choice 58%

Origin zone	Trips by Car ( 41% of trip generated )					
	Distination zone					
	1	2	3	4	5	6
1	26	8	8	15	26	21
2	17	9	26	21	34	27
3	8	9	11	25	6	4
4	17	29	25	38	25	34
5	26	34	25	42	58	46
6	38	34	76	63	59	67

Origin zone	Trips by Bus ( 58% of trip generated )					
	Distination zone					
	1	2	3	4	5	6
1	37	12	12	20	36	29
2	24	13	37	29	46	37
3	10	13	15	35	8	6
4	23	41	35	52	35	46
5	37	46	35	58	79	64
6	52	46	104	87	81	93

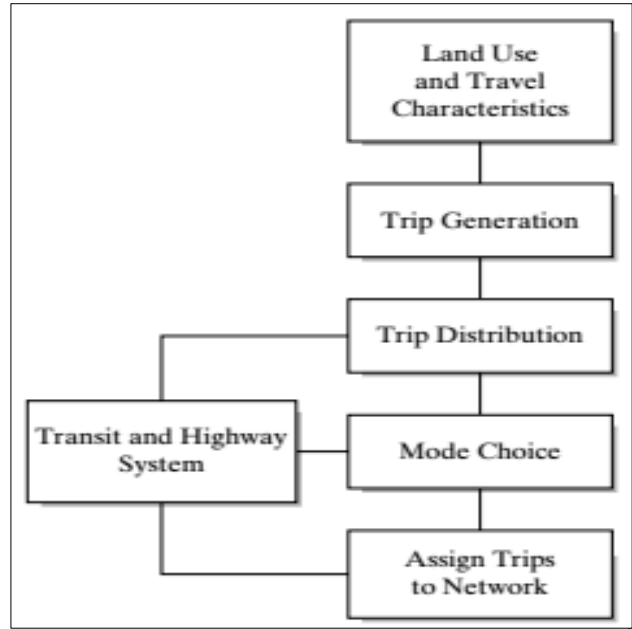
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# Review

## Travel Forecasting Process

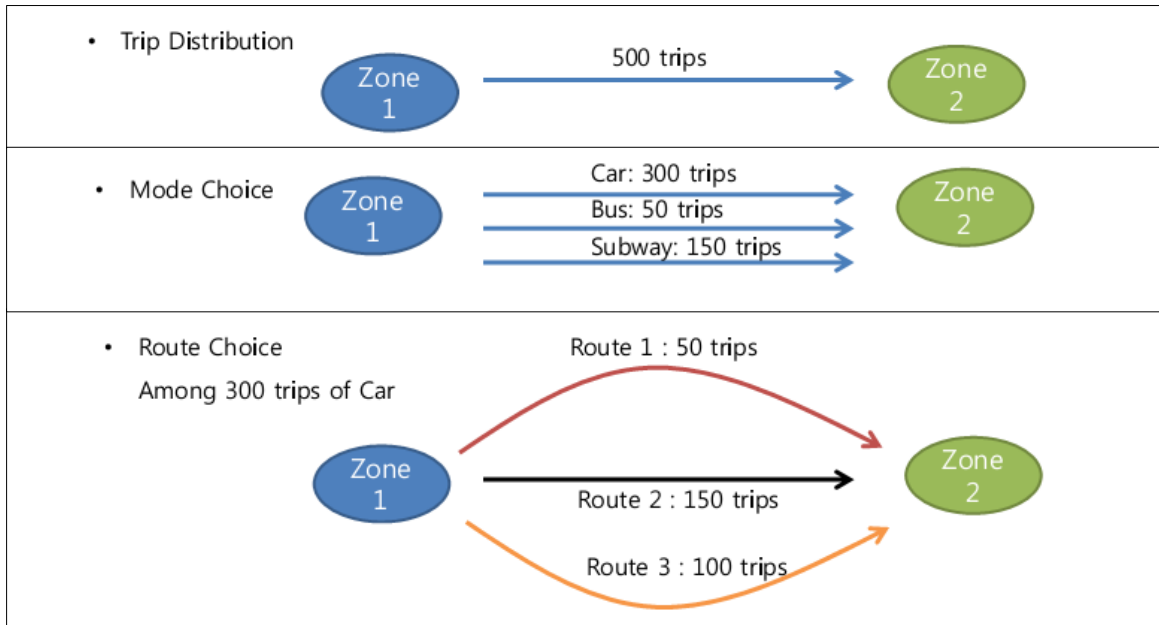
Four-step process

- Trip generation
  - ❖ [How many trips](#)
- Trip distribution
  - ❖ [From where to where](#)
- Modal choice
  - ❖ [On what mode](#)
- Traffic assignment
  - ❖ [On what route](#)



9

# Traffic Assignment (Route choice)



10

10

## Traffic assignment

### ↪ Goal

- Determines the route a traveler chooses based on **travel time, cost, distance, and speed**
- Identifies which **roads and highways** will carry traffic
- Predicts **traffic volumes** of automobiles and buses on each network link

### ↪ Input

- **Origin–Destination (O–D) Matrix (Trip Table)**

### ↪ Output

- **Path table** showing assigned routes and corresponding **traffic volumes**

11

11

## Traffic Assignment

*Required Data*

12

12

## Required Data for Traffic Assignment

- ↪ To perform traffic assignment, we need:
- ↪ **O–D Trip Matrix**
- ↪ **Network Representation**
- ↪ **Link Attributes**
- ↪ **Route Choice Logic**

13

13

## Required Data for Traffic Assignment

*O–D Trip Matrix*

14

14

## Required Data for Traffic Assignment

### *O-D Trip Matrix*

Origin zone	<u><i>Trips by Car ( 41% of trip generated )</i></u>					
	Distination zone					
	1	2	3	4	5	6
1	26	8	8	15	26	21
2	17	9	26	21	34	27
3	8	9	11	25	6	4
4	17	29	25	38	25	34
5	26	34	25	42	58	46
6	38	34	76	63	59	67

Origin zone	<u><i>Trips by Bus ( 58% of trip generated )</i></u>					
	Distination zone					
	1	2	3	4	5	6
1	37	12	12	20	36	29
2	24	13	37	29	46	37
3	10	13	15	35	8	6
4	23	41	35	52	35	46
5	37	46	35	58	79	64
6	52	46	104	87	81	93

15

15

## Required Data for Traffic Assignment

### *Network Representation*

16

16

# Required Data for Traffic Assignment

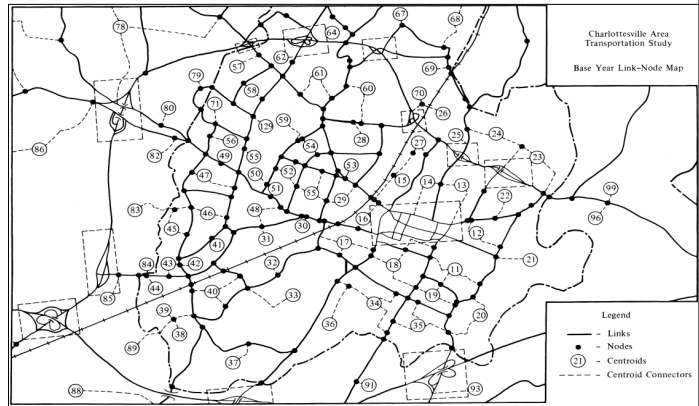
## Network Representation

### ↳ Transportation Network

➤ A simplified representation of the transportation system used for **traffic assignment and route choice analysis**

### ↳ Main Components of a Road Network

1. Nodes
2. Links
3. Terminals
4. Centroids
5. External Stations.



17

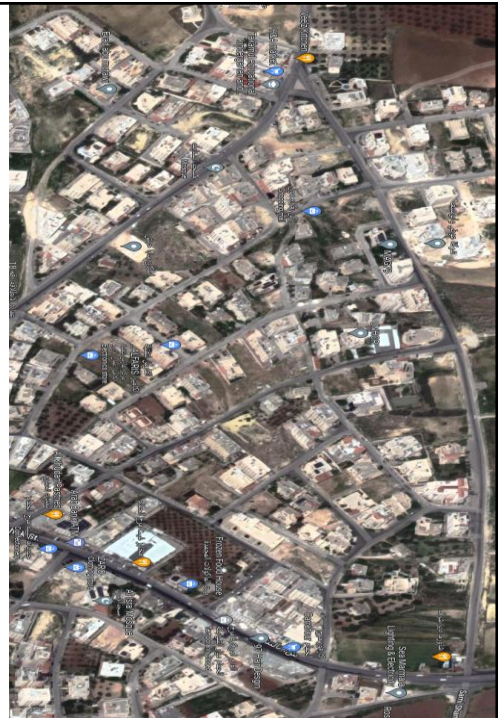
17

## Nodes in a Road Network

- Nodes are **points where movement begins, ends, or changes direction in the road network.**
- **The end point of a link**
- **location** where a link changes direction, capacity, width, or speed

### ☐ Types of Nodes:

1. **Intersections** – Points where multiple roads meet.
2. **Roundabouts** – Circular junctions for continuous traffic flow.
3. **Traffic Signals** – Control vehicle movement at junctions.
4. **Interchanges** – Multi-level connections between highways.



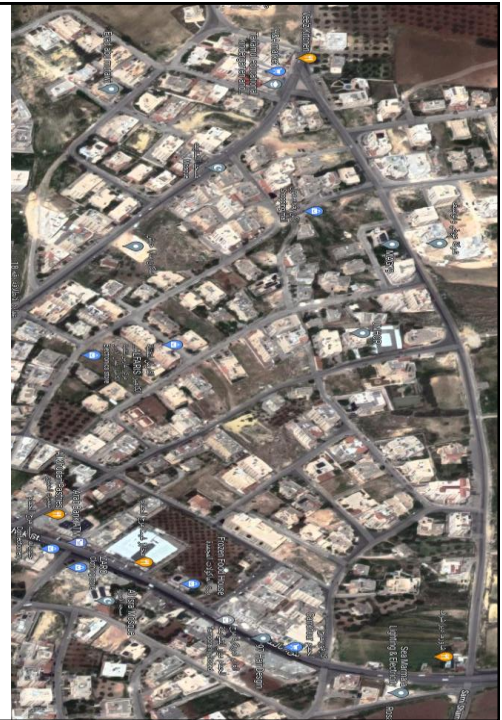
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# Links in a Road Network

- Links are the road segments that connect nodes and allow movement within the network.
- A portion of the highway system that can be described by its capacity, lane width, and speed

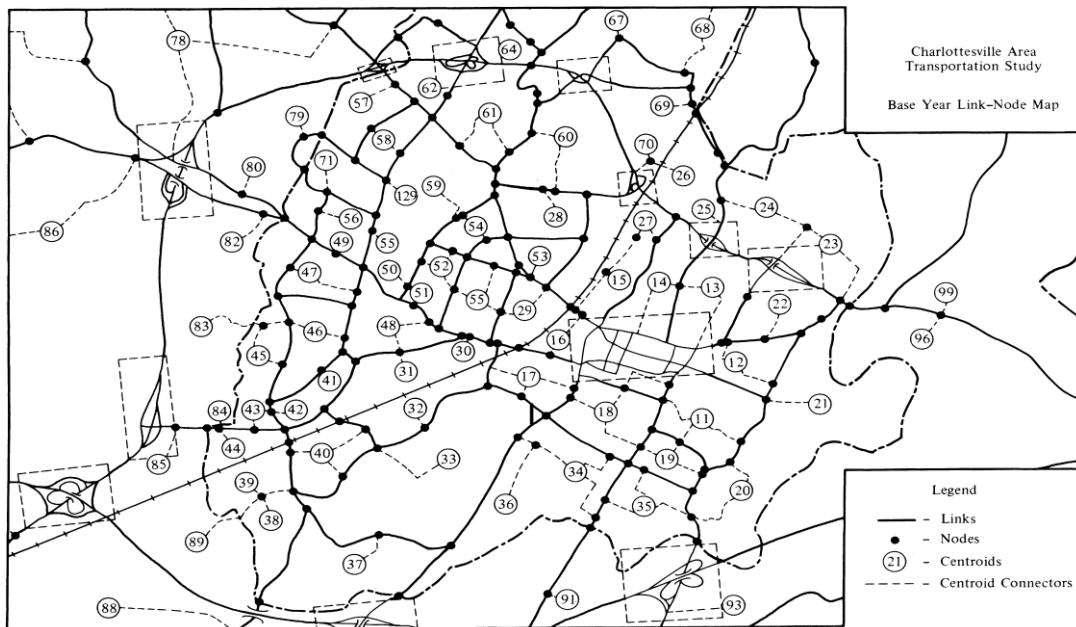
☐ **Types of Links:**

1. **Expressways and Highways** – High-speed roads for long-distance travel.
2. **Arterial Roads** – Connect major urban centers.
3. **Collector Roads** – Distribute traffic between local and arterial roads.
4. **Local Streets** – Provide access to homes, businesses, and small roads.

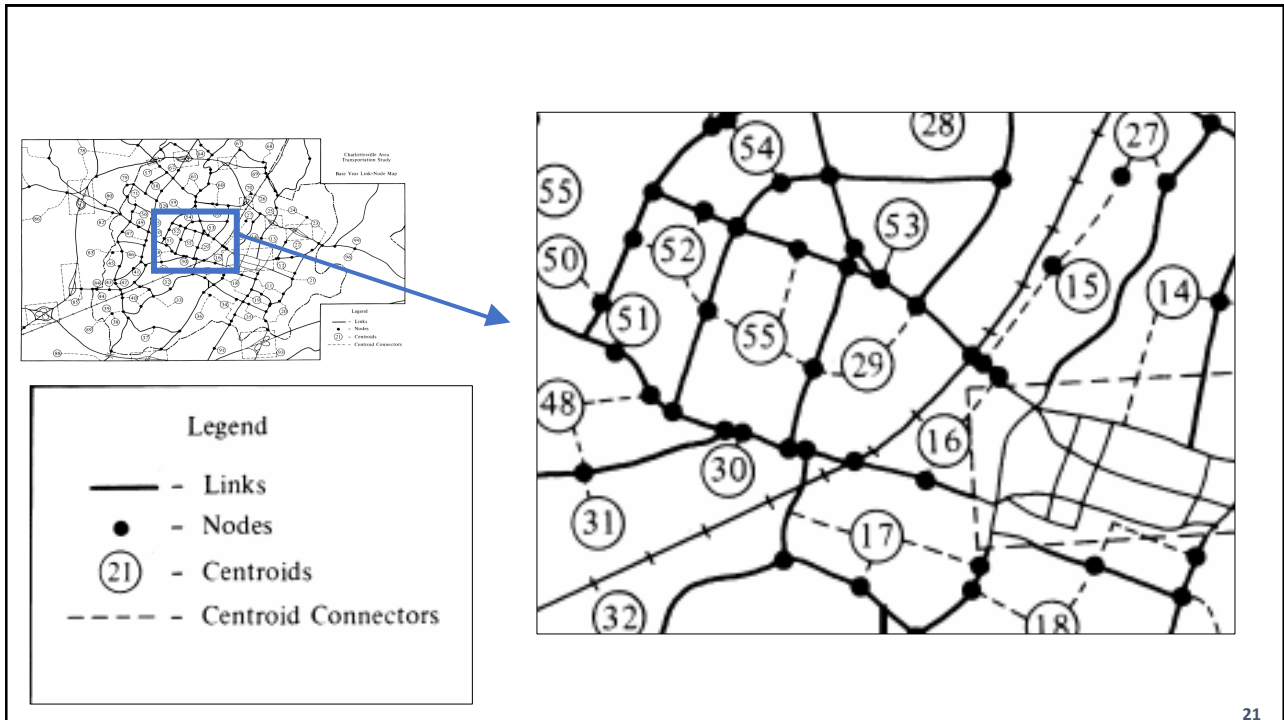


19

# A computerized network of the existing street and highway system



20



21

## Terminals in a Road Network

- **Terminals** are locations where **traffic begins, ends, or changes between routes.**

☐ **Types of Terminals:**

1. **Bus Stations and Depots** – Serve public transportation users.
2. **Parking Lots and Park-and-Ride Areas** – Provide vehicle storage.
3. **Freight Terminals** – Handle goods transportation.

22

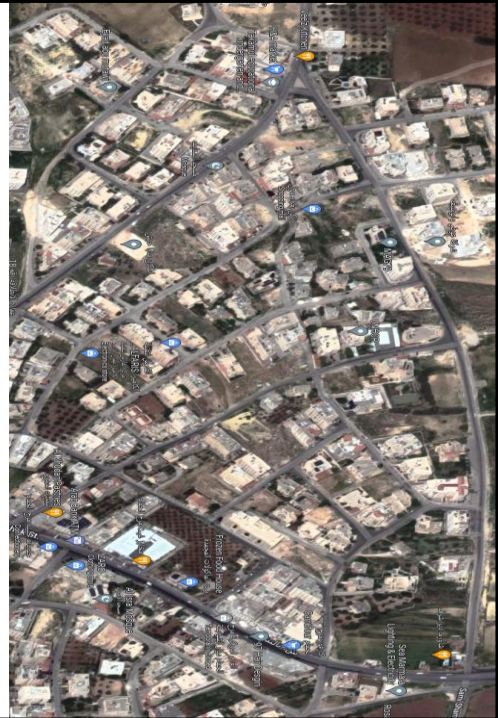
22

## Centroids in a Road Network

- Centroids represent **the central location of a traffic analysis zone (TAZ)**, summarizing all trips generated in that zone.
- The location within a zone where trips are considered to **begin and to end**

### ☐ Functions:

1. *Simplifies traffic modeling* by aggregating travel demand.
2. *Represents trip origins and destinations* within a zone.
3. *Connected to the road network through centroid connectors.*



23

## Required Data for Traffic Assignment

### *Link Attributes*

24

24

## 4. Required Data for Traffic Assignment

### Link Attributes

#### ↪ What are Link Attributes?

- Link attributes are *measurable properties* of a roadway or transit segment that *determine travel cost, performance, and capacity, and directly influence route selection in traffic assignment models.*

#### ↪ Common Link Attributes

- Travel time
- Speed
- Length
- Capacity

25

25

## 4. Required Data for Traffic Assignment

### Link Attributes

#### ↪ Travel Time

- Time required to traverse a link under specific traffic conditions
- May represent **free-flow travel time** or **congested travel time**
- Primary criterion used in **route choice and shortest-path algorithms**

#### ↪ Speed

- Average or posted speed on the link
- Used to calculate travel time
- $\text{Travel Time} = \frac{\text{Length}}{\text{Speed}}$
- Decreases as traffic volume approaches capacity

#### ↪ Length

- Physical distance of the link (km or m)
- Influences both **travel time** and **vehicle operating cost**
- Important for fuel consumption and emissions analysis

#### ↪ Capacity

- Maximum number of vehicles a link can carry per unit time (veh/hr)
- Determines congestion effects and level of service
- Used in **capacity-restraint and equilibrium assignment models**

26

26

# Network Representation

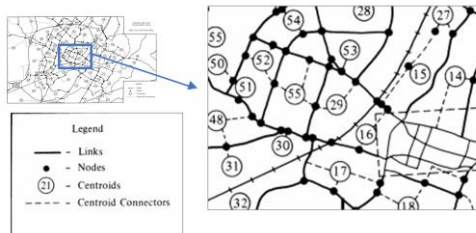
## Skim tree

27

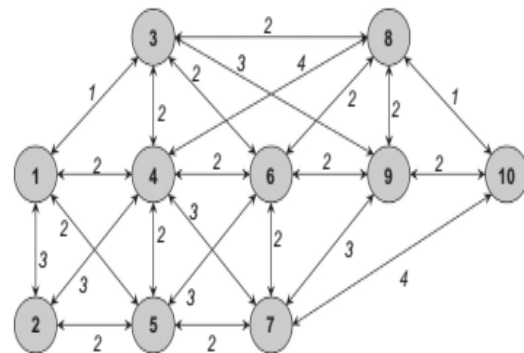
27

## Skim Tree: Concept

- ↪ A **skim tree** represents the **minimum-travel-time paths** from **one origin zone** to **all other zones** in the network.
- ↪ It is created using **fixed link travel times**, consistent with the **all-or-nothing assignment** assumption.



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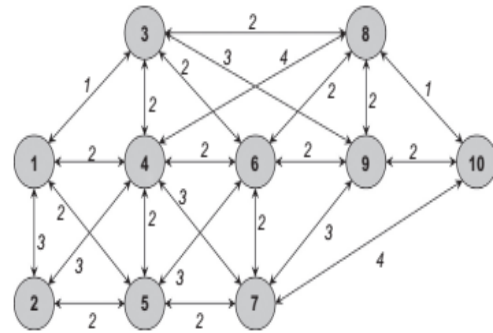
# Network Elements in a Skim Tree

## Nodes

- Each zone is represented by a **node** in the network.
- A node represents the **entire zone area**, not a single intersection.
- Example:
  - ❖ Zone 1 → Residential area
  - ❖ Zone 10 → Central Business District (CBD)

## Links

- Links connect nodes and represent **road or transit segments**.
- Each link has physical and operational characteristics



11 10 10 10 10 10 10 10 10 10

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# Network Elements in a Skim Tree

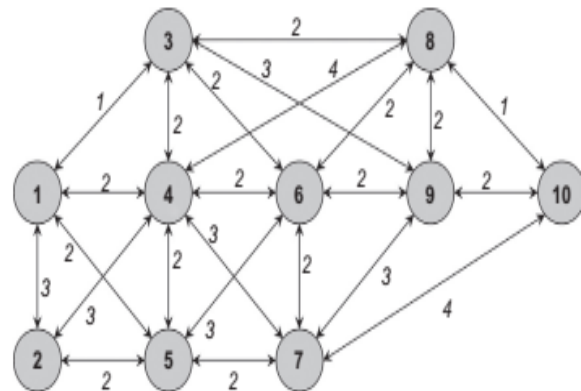
## Link Attributes

- Link attributes describe the **performance of each network segment** and may include:

- Travel time
- Speed
- Length
- Capacity
- Functional classification

## Example:

- Link (6–9)
  - ❖ Travel time = 2 minutes
  - ❖ Capacity = 800 vehicles/hour



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## Network Elements in a Skim Tree

### Path Definition

↪ A **path** is a **sequence of connected links** forming a complete route from origin to destination.

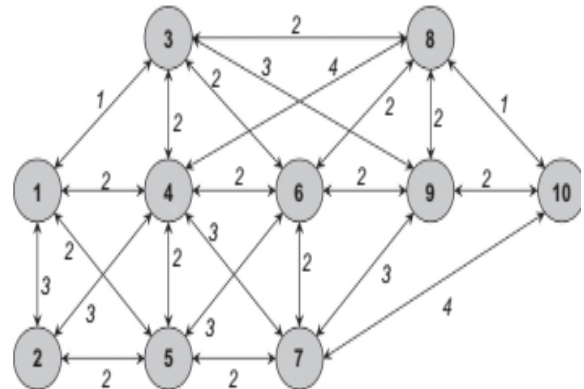
↪ Path travel time is calculated as:

➤  $Path\ Travel\ Time = \sum(Link\ Travel\ Times)$

↪ Example:

➤ Path:  $1 \rightarrow 4 \rightarrow 6 \rightarrow 9 \rightarrow 10$

➤ This represents the **shortest-time path**, not necessarily the shortest distance.



11 01 13 01 10 10 10 10 10 10

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## Network Elements in a Skim Tree

### Skimming Process

↪ **Skimming** is the process of:

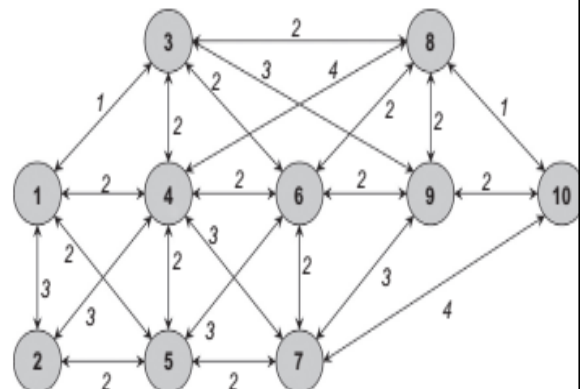
➤ Translating **link-level attributes** into **path-level attributes**

↪ For each destination:

➤ Link travel times are **aggregated**

➤ The **minimum cumulative value** is stored

↪ The result is a **table or tree** of minimum travel times and paths from the origin.



11 01 13 01 10 10 10 10 10 10

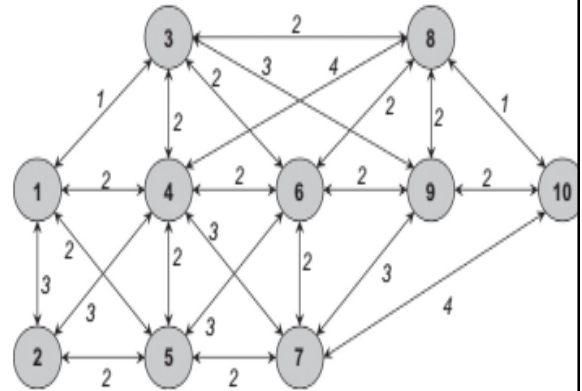
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32

## Traffic assignment

### Skim Tree – Example Path Evaluation

- ↪ **Problem Definition**
- ↪ **Origin:** Zone 1
- ↪ **Destination:** Zone 4
- ↪ The network contains **multiple possible paths** between Zones 1 and 4
- ↪ Each link has a **given travel time (in minutes)**
- ↪ **Objective: Identify the minimum travel-time path**



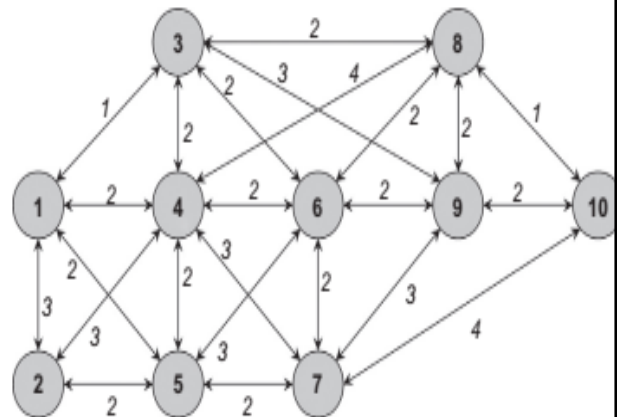
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34

## Traffic assignment

### Skim Tree – Example Path Evaluation

- ↪ **Possible Path Options and Travel Time Calculation**
- ↪ Each path travel time is computed as the **sum of its link travel times**:
- ↪ Path Travel Time =  $\sum(\text{Link Travel Times})$
- ↪



35

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## Traffic assignment

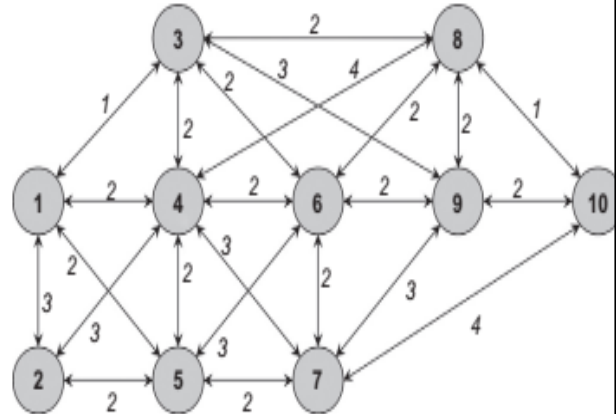
### Skim Tree – Example Path Evaluation

#### Path Options:

- A. 1 → 4 → 2 minutes
- B. 1 → 3 → 3 → 4 → 1 + 3 + 2 = 6 minutes
- C. 1 → 5 → 5 → 4 → 3 + 3 + 2 = 8 minutes
- D. 1 → 2 → 2 → 4 → 2 + 2 + 3 = 7 minutes
- E. 1 → 2 → 5 → 5 → 4 → 2 + 2 + 3 + 2 = 9 minutes

#### ✓ Minimum Time Path Chosen:

- Path A: 1 → 4 with the shortest travel time of 2 minutes



36

36

## Required Data for Traffic Assignment

### Route Choice Logic

37

37

## 4. Required Data for Traffic Assignment

### Route Choice Logic

- ↪ Defines **how travelers select routes** between origin and destination zones
- ↪ Provides the **rules or algorithms** used to **assign trips to network paths**
- ↪ Determines how trips are distributed among **available alternative routes**

38

38

## Common Route Choice Assumptions Include

### 1. Travelers choose the minimum travel time path

↪ (Route choice rule: what travelers try to minimize)

#### ↪ Explanation

- Assumes travelers select routes based on **travel time only**
- The chosen route is the one with the **minimum total travel time** between origin and destination
- Other factors (distance, cost, comfort) **are ignored or included within travel time**
- Forms the basis of **shortest-path algorithms**

#### ↪ Simple Example

- Origin A → Destination B
- Route 1 = 10 min
- Route 2 = 12 min
- **Route 1 is preferred** because it has the shorter travel time  
(This statement does NOT say how many travelers choose it)

39

39

## Common Route Choice Assumptions Include

### 2. All travelers behave identically (Deterministic Models)

↪ (Behavioral assumption: how travelers differ from each other)

#### ↪ Explanation

- Assumes all travelers facing the same conditions:
  - ❖ perceive travel times identically
  - ❖ have the same preferences
- No randomness or individual variation in route choice
- Leads to **all trips between an O-D pair using one single route**
- Produces **all-or-nothing assignment**

#### ↪ Simple Example

- Same situation as above
  - ❖ Route 1 = 10 min
  - ❖ Route 2 = 12 min
- **100% of travelers choose Route 1**  
Route 2 receives **0 trips**

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## 4. Required Data for Traffic Assignment

### 3. Travel time is fixed

↪ (Simplifying assumption used in basic models)

#### ↪ Explanation

- Travel times on links are **constant**
- Travel time is **independent of traffic volume**
- Adding more vehicles does **not** change travel time
- Used in **simple models**, such as: All-or-nothing assignment, Shortest-path analysis

#### ↪ Simple Example

- A road has a travel time of **10 minutes**
- Whether:
  - ❖ 100 vehicles/hour or
  - ❖ 1,000 vehicles/hour  
Travel time remains **10 minutes**
- Easy to compute
- Does **not** represent congestion effect

41

41

## 4. Required Data for Traffic Assignment

### 4. Travel time varies with congestion

↪ (Realistic assumption used in advanced models)

#### ↪ Explanation

- Travel time **increases as traffic volume approaches link capacity**
- Reflects real-world congestion and delay
- Travel time becomes a **function of volume and capacity**
- Used in:
  - ❖ Capacity-restraint assignment
  - ❖ User equilibrium models

#### ↪ Simple Example

- A road has a free-flow travel time of **10 minutes**
- Traffic conditions:
  - ❖ Light traffic → **10 minutes**
  - ❖ Heavy traffic → **15–20 minutes**
- *Realistic representation of congestion*  
*Allows traffic to redistribute across route*

42

42

## Traffic assignment

### *Approaches*

43

43

## Traffic assignment

### *Approaches*

- **Three basic approaches** are commonly used in traffic assignment:
  - *Diversion curves*
  - *Minimum time path (all-or-nothing) assignment*
  - *Minimum time path with **capacity restraint***

44

44

## Traffic assignment Approaches

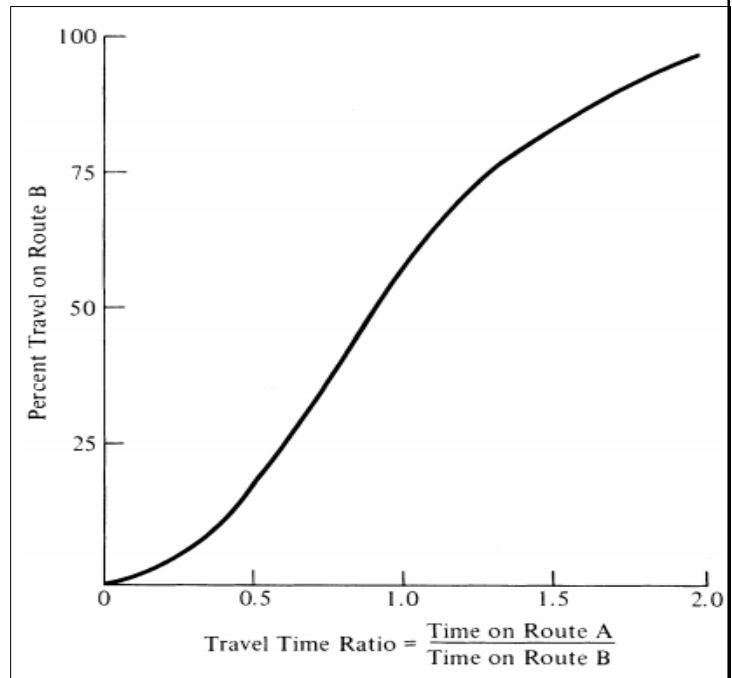
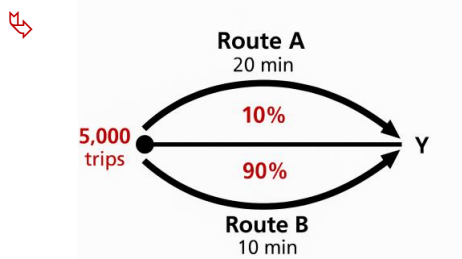
### *1. Diversion curves*

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# 1. Diversion curves

↪ **Diversion curves are empirical relationships** used in traffic assignment that describe how trips are divided between **alternative routes** connecting the same origin–destination pair, based on **observed driver behavior**.



46

# 1. Diversion curves

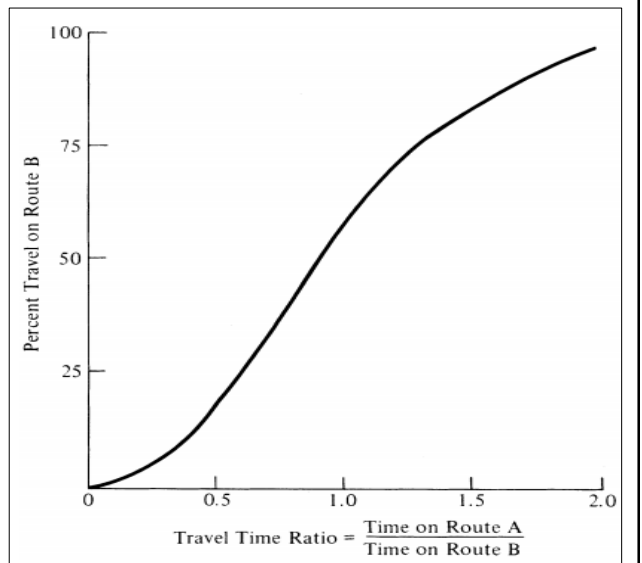
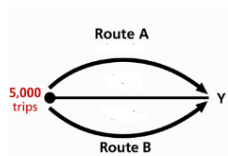
## curve explanation

↪ The horizontal axis represents the Travel Time Ratio

➤  $\text{Travel Time Ratio} = \frac{\text{Time on Route A}}{\text{Time on Route B}}$

↪ The vertical axis represents the percentage of travelers using Route B.

- Ratio = 1.0 → equal split
- Ratio > 1.0 → traffic diverts to Route B
- Ratio < 1.0 → traffic diverts to Route A



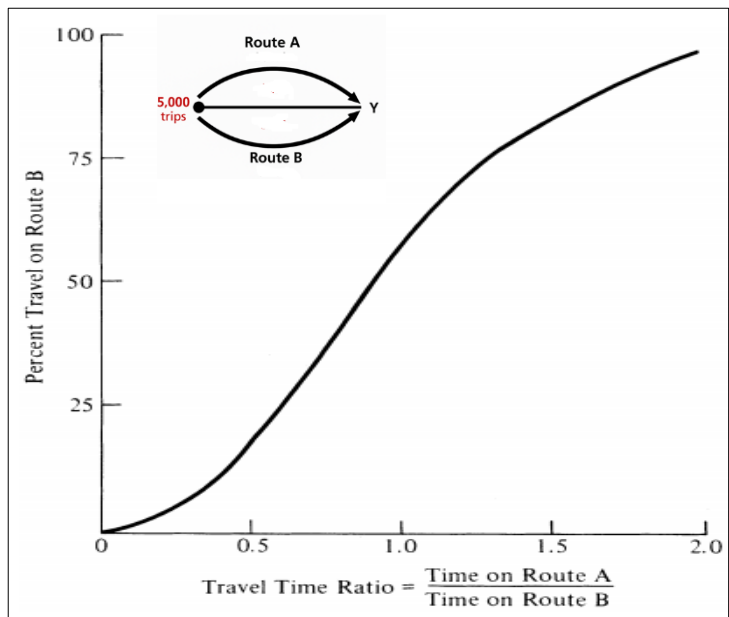
Time on Route A = (Travel Time Ratio) × Time on Route B

47

# 1. Diversion curves

## Case 1: Travel Time Ratio = 1.0

- ↪ Both routes have equal travel time
- ↪ Example:
  - Time on Route B = 15 min
  - Travel Time Ratio = 1.0
  - Time on Route A =  $1.0 \times 15 = 15\text{min}$
- ↪ Interpretation:
  - Routes A and B are equally attractive
  - Traffic is **approximately evenly split** between routes

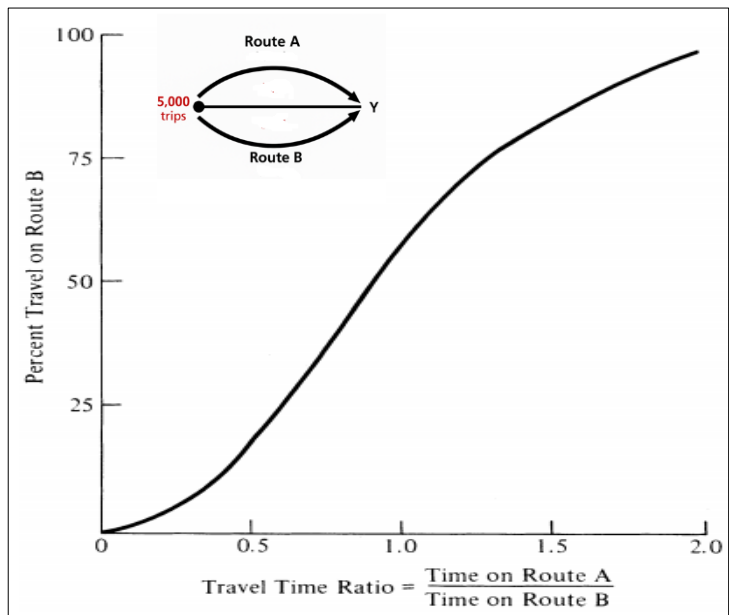


$$\text{Time on Route A} = (\text{Travel Time Ratio}) \times \text{Time on Route B}$$

# 1. Diversion curves

## Case 2: Travel Time Ratio > 1.0

- ↪ Route A is slower than Route B
- ↪ Example:
  - Time on Route B = 10 min
  - Time on Route A = 20 min
  - Travel Time Ratio = 2.0
- ↪ Interpretation:
  - Route A takes longer
  - A larger percentage of travelers divert to Route B
  - From the diversion curve, most traffic uses Route B



$$\text{Time on Route A} = (\text{Travel Time Ratio}) \times \text{Time on Route B}$$

# 1. Diversion curves

## Case 3: Travel Time Ratio < 1.0

↪ Route A is faster than Route B

↪ Example:

➤ Time on Route B = 20 min

➤ Travel Time Ratio = 0.75

➤ Time on Route A =  $0.75 \times 20 = 15\text{min}$

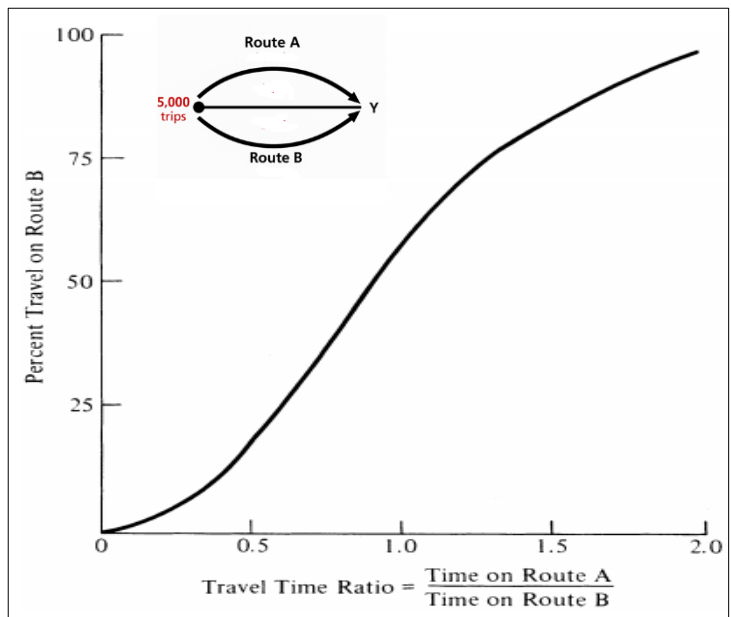
↪ Interpretation:

➤ Route A is faster

➤ More travelers choose Route A

➤ Percentage using Route B is low

↪



$$\text{Time on Route A} = (\text{Travel Time Ratio}) \times \text{Time on Route B}$$

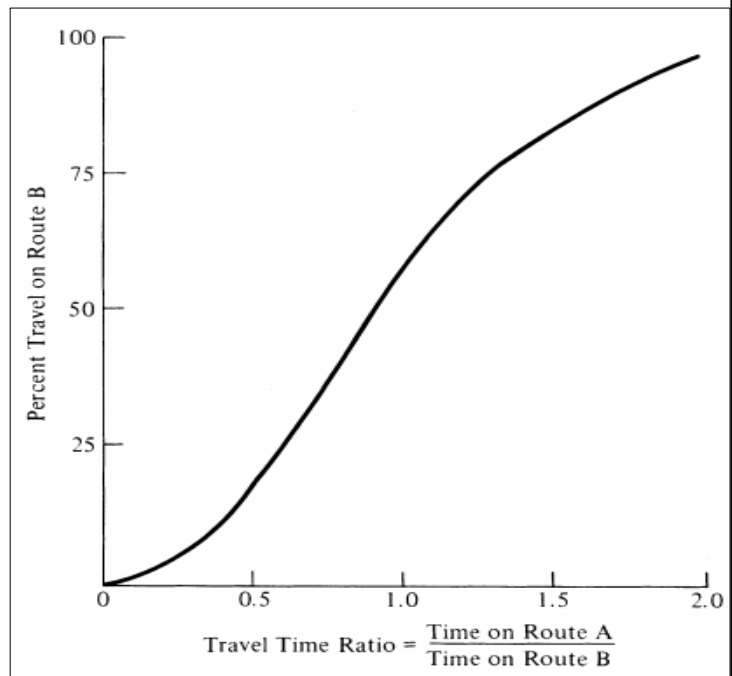
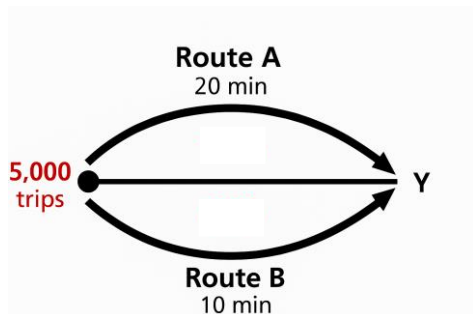
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# 1. Diversion curves

## Example

- Two parallel routes: **Route A** and **Route B**
- Travel time on **Route A** = 20 minutes, on **Route B** = 10 minutes



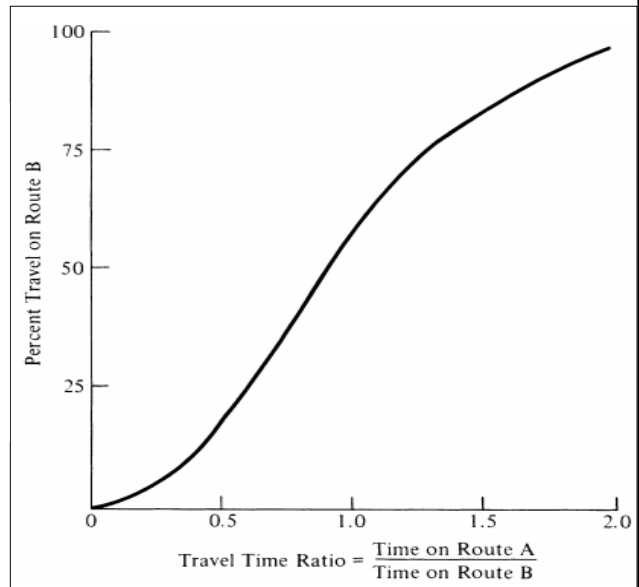
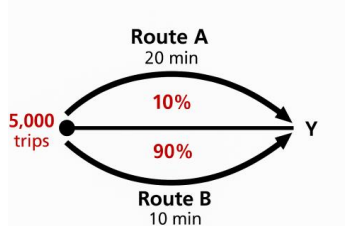
51

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# 1. Diversion curves

## Example

- Two parallel routes: Route A and Route B
- Travel time on Route A = 20 minutes, on Route B = 10 minutes
- **Travel Time Ratio** =  $20 \div 10 = 2.0$
- From the diversion curve:
  - At a ratio of 2.0, approximately 90% of trips will divert to Route B
- If there are 5,000 total trips, then:
  - Route A receives 10%  $\rightarrow 0.10 \times 5000 = 500$  trips
  - Route B receives 90%  $\rightarrow 0.90 \times 5000 = 4500$  trips

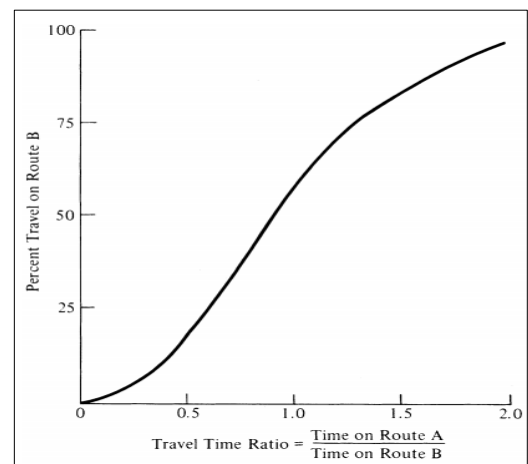


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52

# How Diversion Curves Are Generated

- ↪ **Identify alternative routes**
  - ☐ Select two or more competing routes connecting the same O-D pair
- ↪ **Collect observed field data**
  - ☐ Measure traffic volumes and travel times on each route
  - ☐ Use traffic counts, surveys, GPS data, or past studies
- ↪ **Calculate relative performance**
  - ☐ Compute the **Travel Time Ratio**  $\text{Travel Time Ratio} = \frac{\text{Time on Route A}}{\text{Time on Route B}}$
- ↪ Determine the percentage of travelers using each route
- ↪ **Plot observed behavior**
  - ☐ X-axis: Travel Time Ratio
  - ☐ Y-axis: Percentage of traffic using one route
- ↪ **Fit a smooth curve**
  - ☐ Draw an empirical (typically S-shaped) curve through the data points
- ↪ **Apply for prediction**
  - ☐ Use the curve with new travel times to estimate future traffic splits



53

53

# Traffic assignment

## 2. Minimum time path (all-or-nothing) Algorithm

54

54

## 2. Minimum time path (all-or-nothing) Algorithm

### ↳ Definition

- The **all-or-nothing (AON) assignment** method assigns **all trips** between each origin–destination (O–D) pair to **the single route with minimum travel time**.

55

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## 2. Minimum Time Path (All-or-Nothing) Algorithm

### Basic Assumptions

- ↪ **Travelers have perfect knowledge of the network**
  - All routes and travel times are known and accurately perceived
- ↪ **Travelers always choose the minimum travel time path**
  - Route choice is based solely on travel time
  - Other factors (cost, comfort, reliability) are ignored
- ↪ **All travelers behave identically**
  - No variation in individual preferences or decision-making
  - All users facing the same conditions make the same choice
- ↪ **Travel time is fixed**
  - Link travel times do **not change with traffic volume**
  - Congestion effects are not reflected
- ↪ **Congestion effects are ignored**
  - Links can carry unlimited traffic without delay increase

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## 2. Minimum time path (all-or-nothing) Algorithm

### How the Algorithm Works

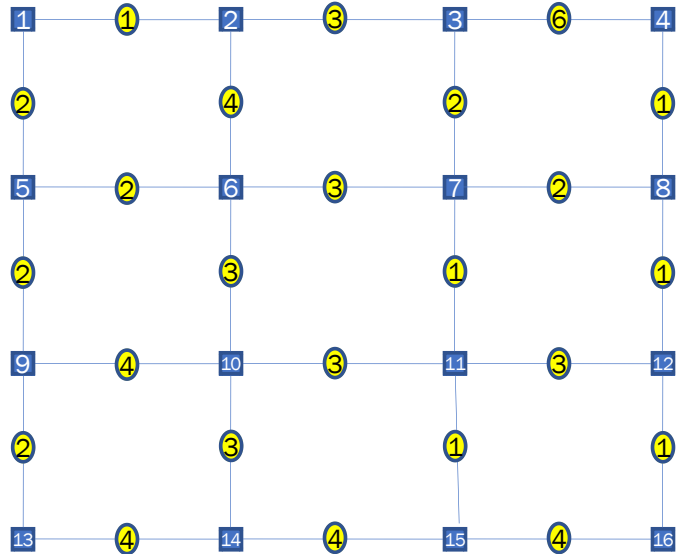
- ↪ Represent the transportation system as a **network**:
  - Nodes → zones or intersections
  - Links → roads or transit segments
- ↪ Assign a **travel time** to each link.
- ↪ For each origin zone:
  - Find the **shortest travel time path** to all destination zones
  - Use a shortest-path algorithm (e.g., Dijkstra's algorithm)
- ↪ Assign **100% of trips** between each O–D pair to the identified shortest path.

57

57

Find the shortest path from node 1 to all other nodes (from Garber and Hoel)

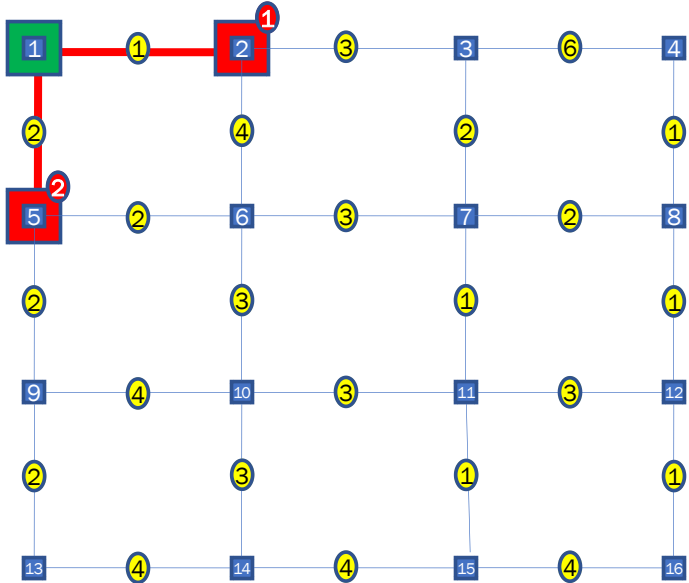
Here's how ...



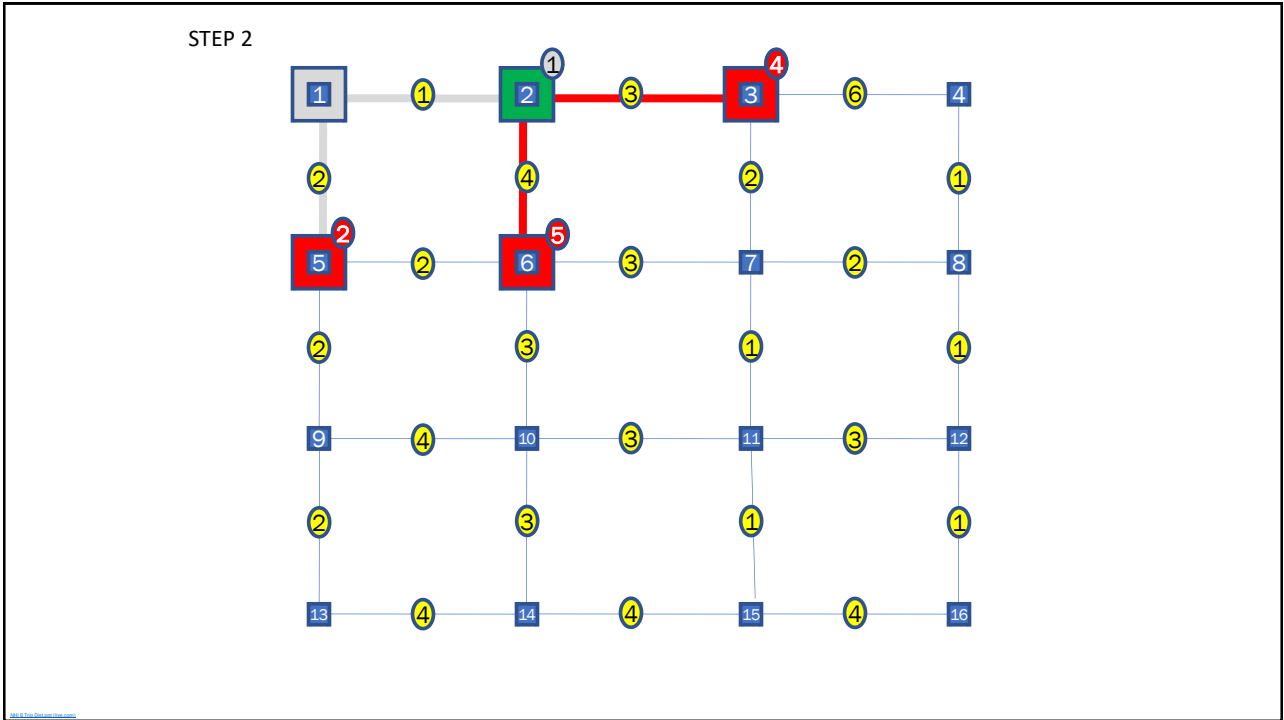
Yellow numbers ③ represent link travel times in minutes

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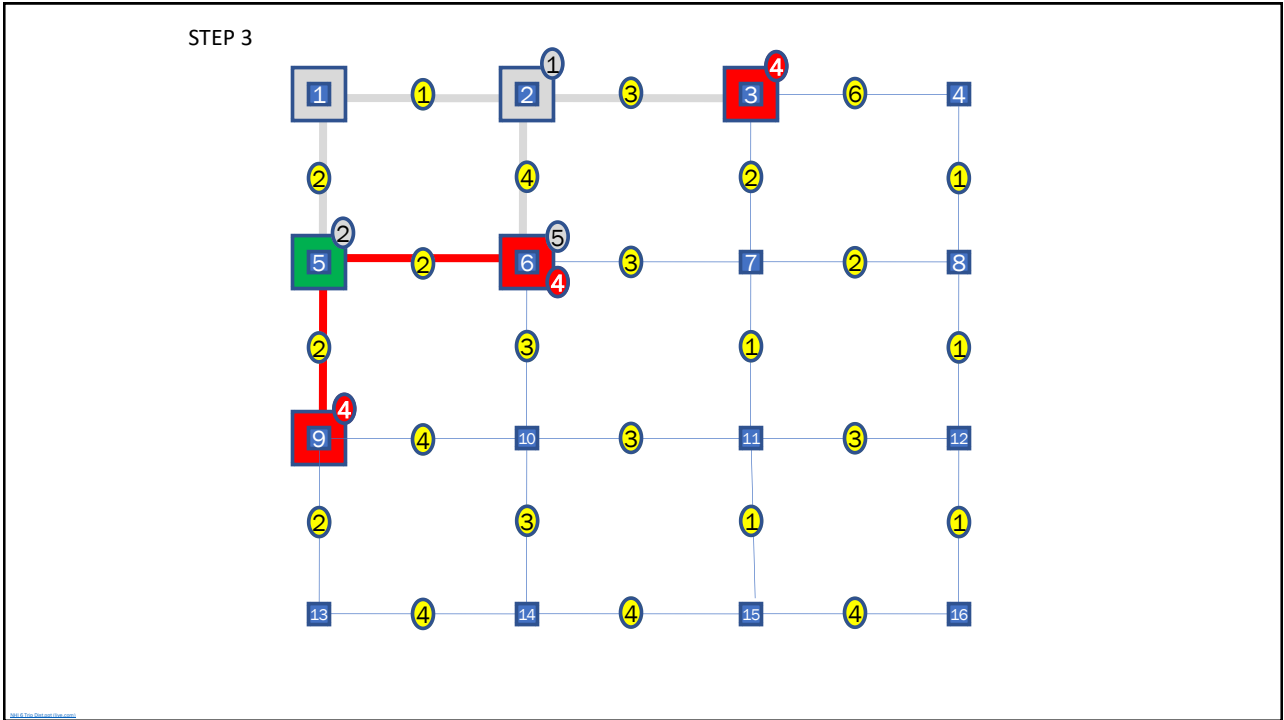
STEP 1



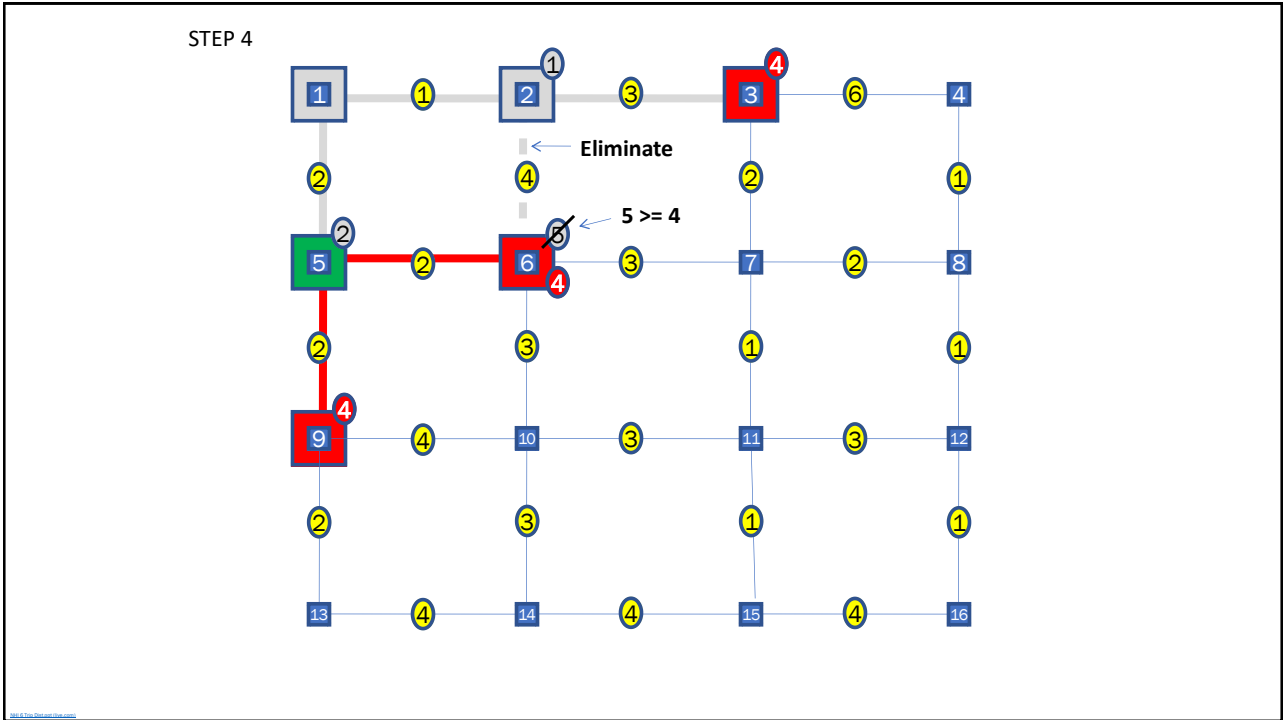
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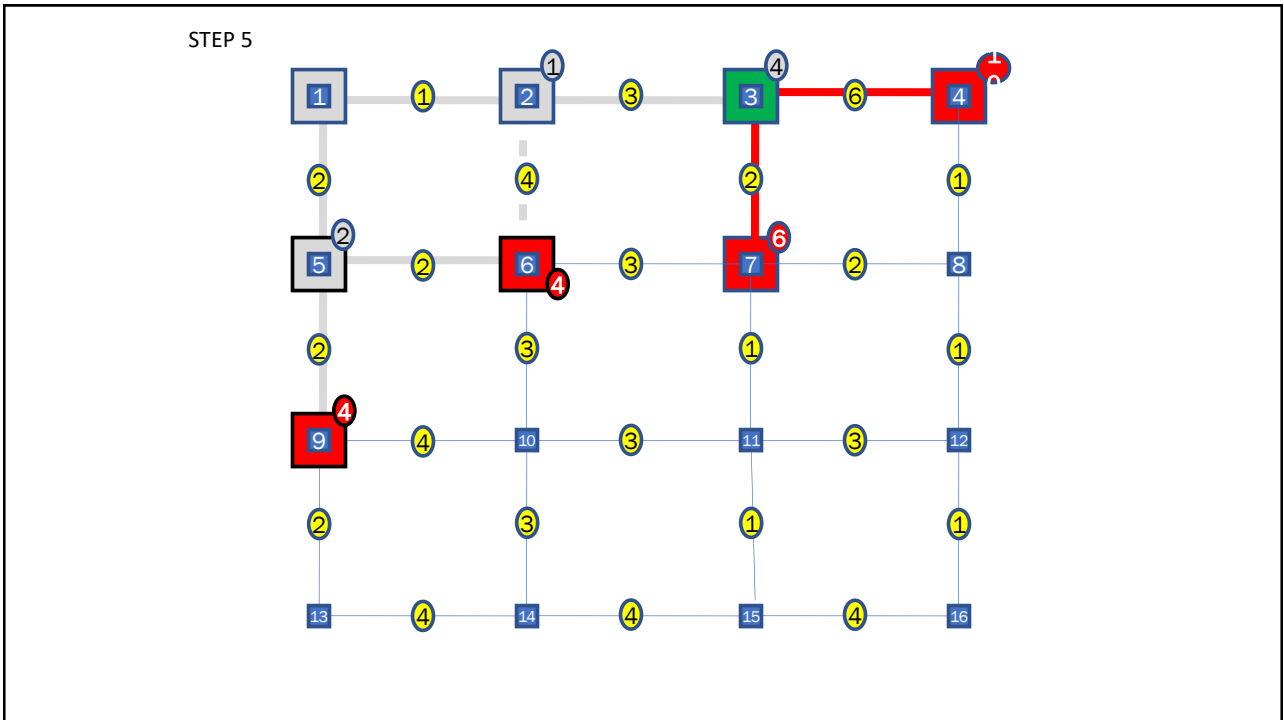
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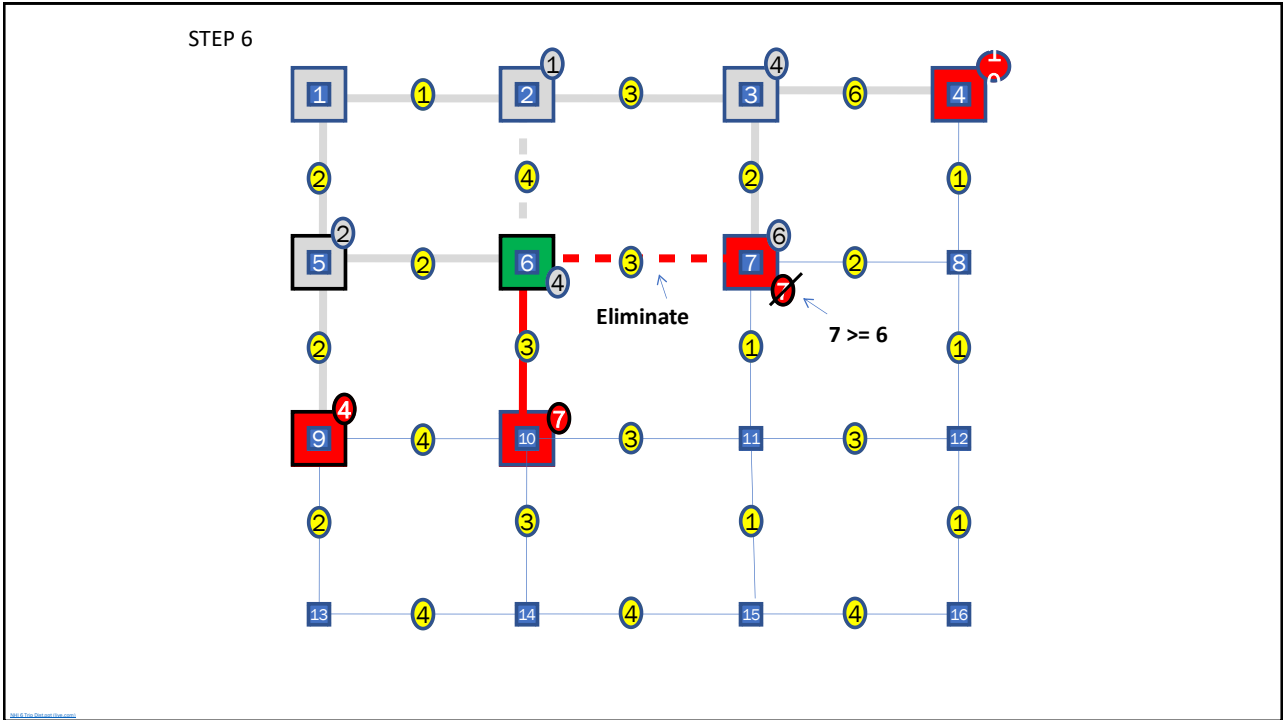
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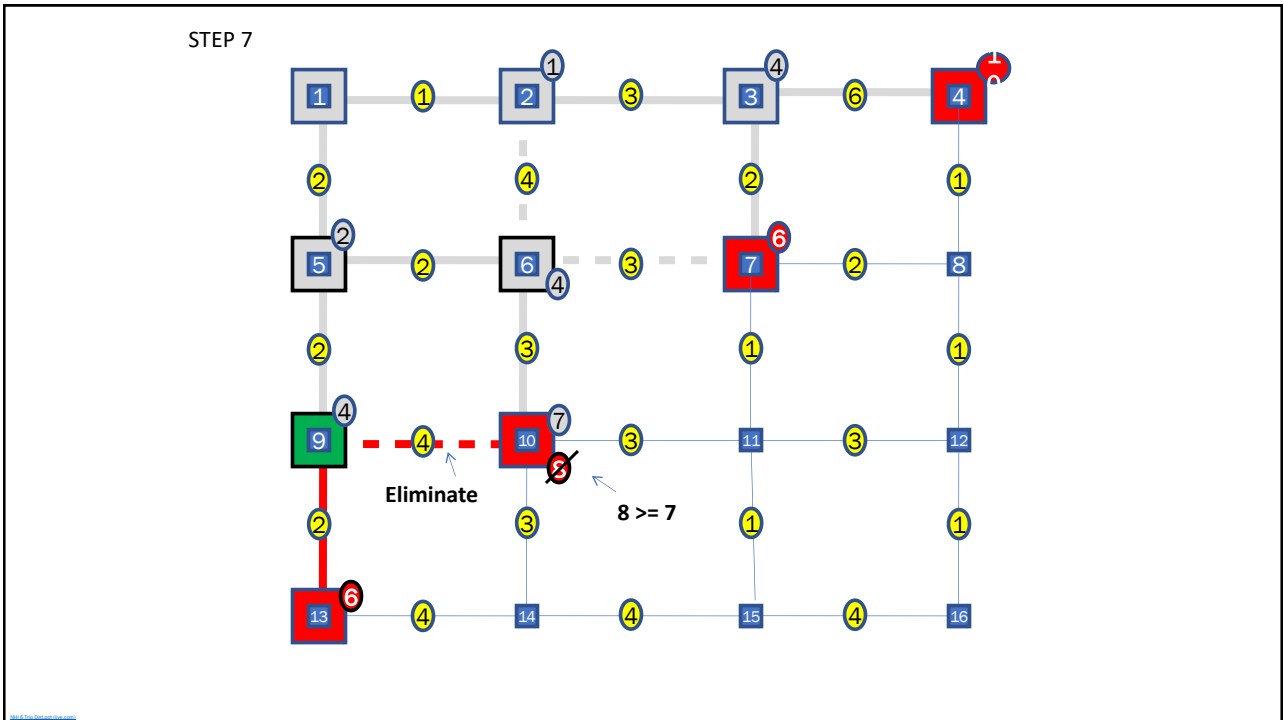
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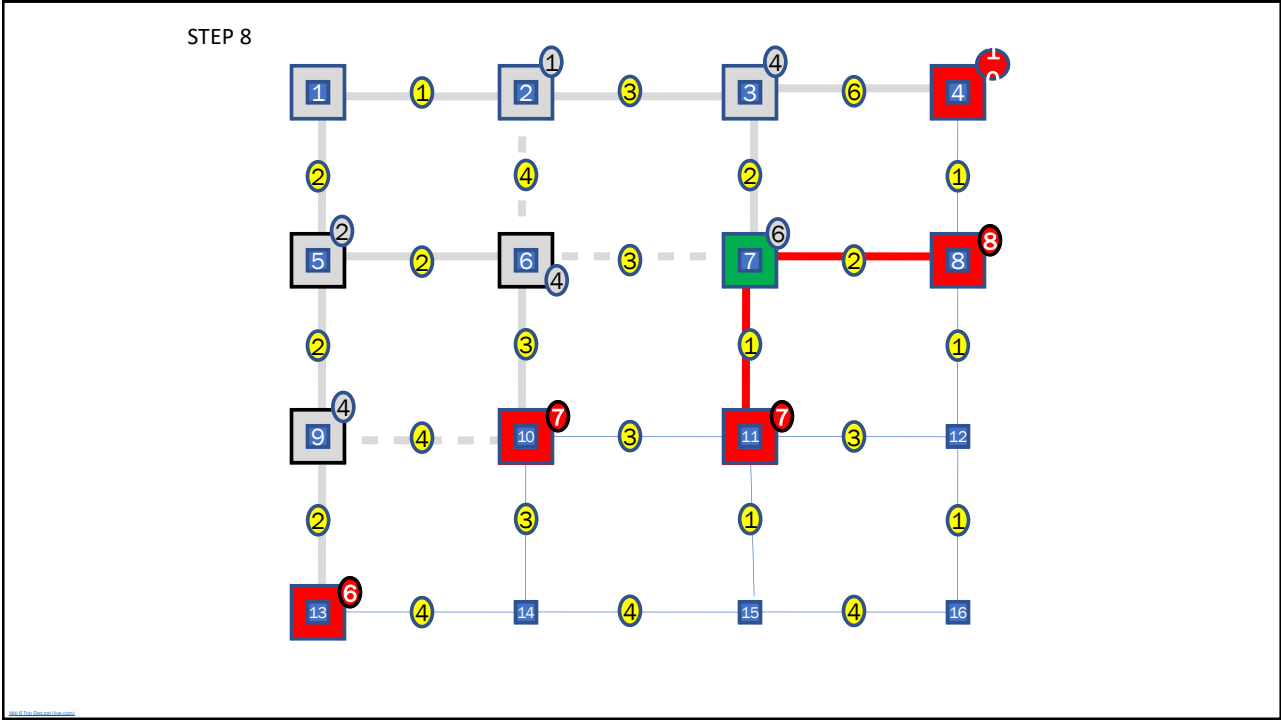
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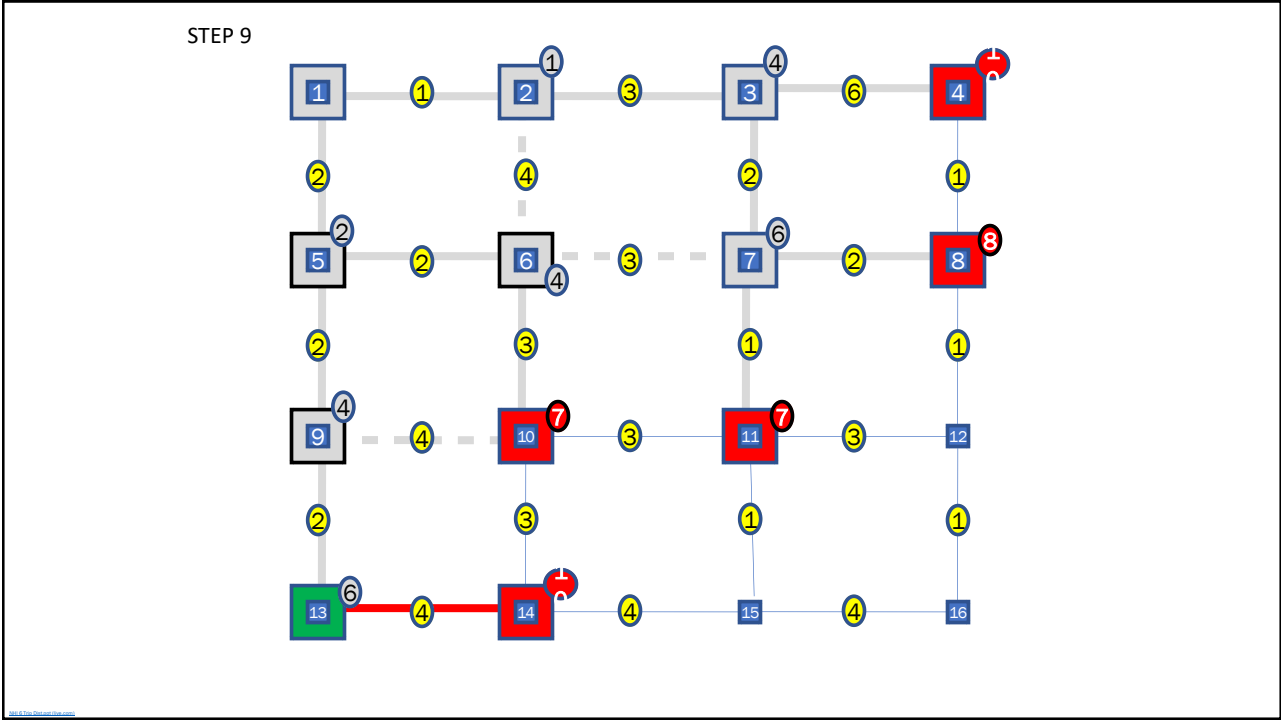
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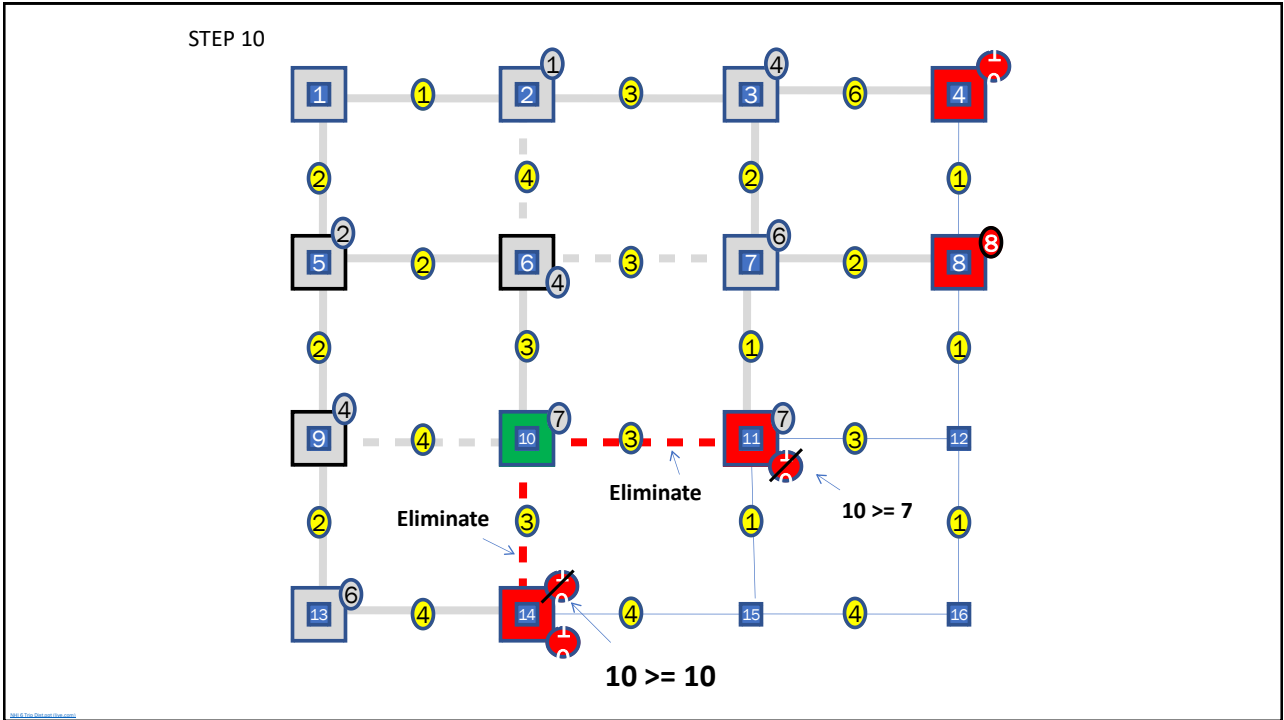
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## Skim tree

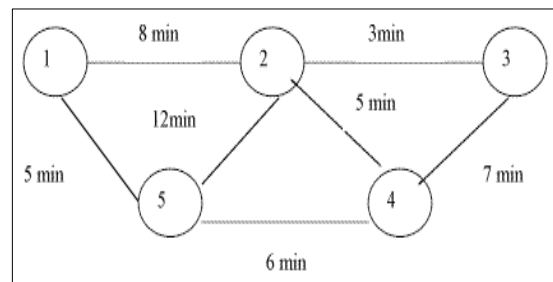
*Example No. 2 (Example 12.10) : Using of Skim tree*

76

### Example No. 1 (Example 12.10) : Using of Skim tree

1. Assign the vehicle trips shown in the O-D trip table to the network shown in Figure below using the all-or-nothing assignment technique.
2. Make a list of the links in the network and indicate the volume assigned to each.
3. Calculate the total vehicle minutes of travel.
4. Show the minimum path and assign traffic for each of the five nodes.

		Trips between Zones				
From/to	1	2	3	4	5	
1	-	100	100	200	150	
2	400	-	200	100	500	
3	200	100	-	100	150	
4	250	150	300	-	400	
5	200	100	50	350	-	

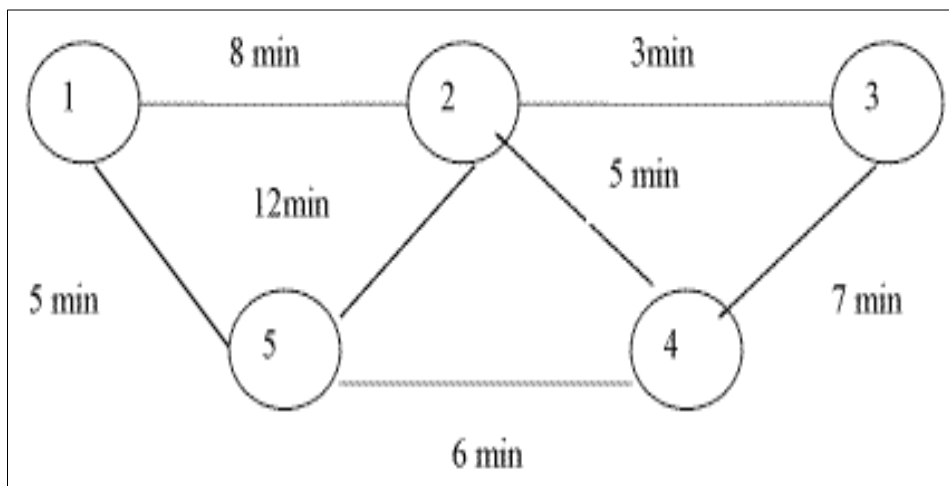


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### Example No.1 (Example 12.10) : Using of Skim tree

*Travel time between zones*



78

78

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

### Steps:

- Step 1: Find the shortest paths between zones
- Step 2: Find total cumulative travel time for shortest paths between zones
- Step 3: Find traffic volumes (or estimated trips) for shortest paths **between zones**
  - ❖ **from O-D matrix**
- Step 4: Find total trips (volume) on each link
- Step 5: Find total vehicle minutes of travel on each link
- Step 6: Assign traffic for each of the five nodes
- Step 7: Draw the minimum path (skim trees) at each node

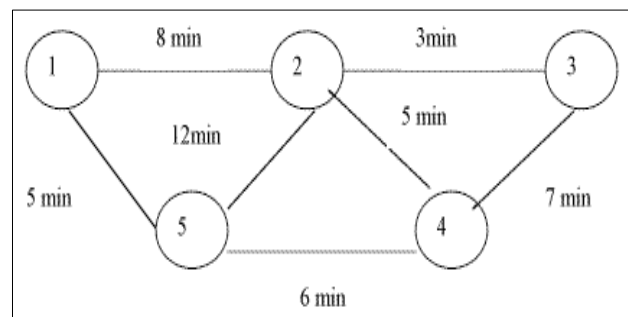
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## Solution of Example No.1 (Example 12.10) : Using of Skim tree

### Step 1: Find the shortest paths between zones

Nodes		Shortest Path	Path ID
From	To		
1	2		
	3		
	4		
	5		
2	1		
	3		
	4		
	5		
3	1		
	2		
	4		
	5		
4	1		
	2		
	3		
	5		
5	1		
	2		
	3		
	4		



shortest path = The path with minimum cumulative travel time

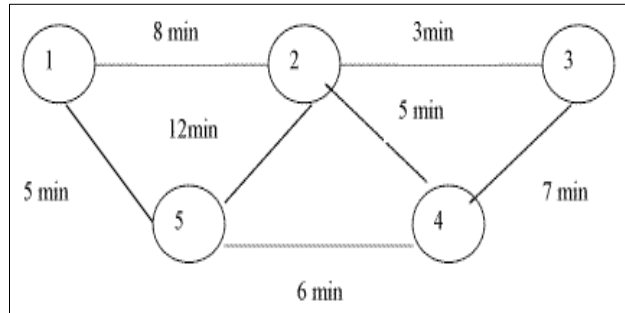
80

80

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 1: Find the shortest paths between zones

Nodes		Shortest Path	Path ID
From	To		
1	2	1-2	1
	3	1-2,2-3	2
	4	1-5,5-4	3
	5	1-5	4
2	1	2-1	5
	3	2-3	6
	4	2-4	7
	5	2-4,4-5	8
3	1	3-2,2-1	9
	2	3-2	10
	4	3-4	11
	5	3-4,4-5	12
4	1	4-5,5-1	13
	2	4-2	14
	3	4-	15
	5	4-5	16
5	1	5-1	17
	2	5-4,4-2	18
	3	5-4,4-3	19
	4	5-4	20



shortest path = The path with minimum cumulative travel time

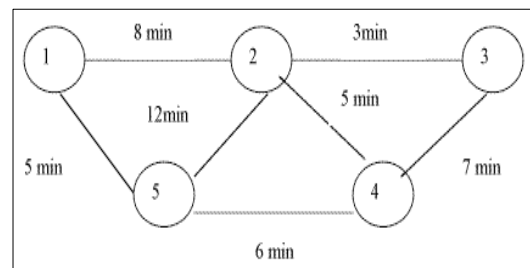
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## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 2: Find total cumulative travel time for shortest paths between zones

Nodes		Shortest Path	Path ID	Cumulative Travel Time (min)
From	To			
1	2	1-2	1	
	3	1-2,2-3	2	
	4	1-5,5-4	3	
	5	1-5	4	
2	1	2-1	5	
	3	2-3	6	
	4	2-4	7	
	5	2-4,4-5	8	
3	1	3-2,2-1	9	
	2	3-2	10	
	4	3-4	11	
	5	3-4,4-5	12	
4	1	4-5,5-1	13	
	2	4-2	14	
	3	4-	15	
	5	4-5	16	
5	1	5-1	17	
	2	5-4,4-2	18	
	3	5-4,4-3	19	
	4	5-4	20	



shortest path = The path with minimum cumulative travel time

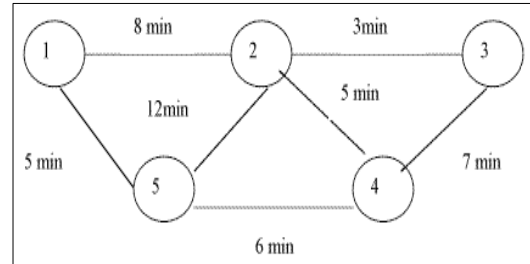
82

82

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 2: Find total cumulative travel time for shortest paths between zones

Nodes		Shortest Path	Path ID	Cumulative Travel Time (min)
From	To			
1	2	1-2	1	8
	3	1-2,2-3	2	11
	4	1-5,5-4	3	11
	5	1-5	4	5
2	1	2-1	5	8
	3	2-3	6	3
	4	2-4	7	5
	5	2-4,4-5	8	11
3	1	3-2,2-1	9	11
	2	3-2	10	3
	4	3-4	11	7
	5	3-4,4-5	12	13
4	1	4-5,5-1	13	11
	2	4-2	14	5
	3	4-	15	7
	5	4-5	16	6
5	1	5-1	17	5
	2	5-4,4-2	18	11
	3	5-4,4-3	19	13
	4	5-4	20	6

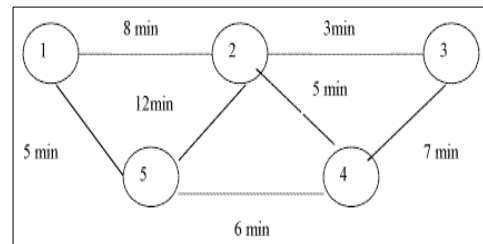


shortest path = The path with minimum cumulative travel time

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 3: Find traffic volumes (or estimated trips) for shortest paths between zones (from O-D matrix)

Nodes		Shortest Path	Path ID	Cumulative Travel Time (min)	Traffic volume on shortest paths
From	To				
1	2	1-2	1	8	
	3	1-2,2-3	2	11	
	4	1-5,5-4	3	11	
	5	1-5	4	5	
2	1	2-1	5	8	
	3	2-3	6	3	
	4	2-4	7	5	
	5	2-4,4-5	8	11	
3	1	3-2,2-1	9	11	
	2	3-2	10	3	
	4	3-4	11	7	
	5	3-4,4-5	12	13	
4	1	4-5,5-1	13	11	
	2	4-2	14	5	
	3	4-	15	7	
	5	4-5	16	6	
5	1	5-1	17	5	
	2	5-4,4-2	18	11	
	3	5-4,4-3	19	13	
	4	5-4	20	6	

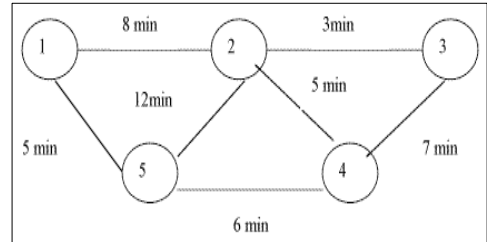


Trips between Zones					
From/to	1	2	3	4	5
1	-	100	100	200	150
2	400	-	200	100	500
3	200	100	-	100	150
4	250	150	300	-	400
5	200	100	50	350	-

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 3: Find traffic volumes (or estimated trips) for shortest paths **between zones** (from O-D matrix)

Nodes		Shortest Path	Path ID	Cumulative Travel Time (min)	Traffic volume on shortest paths
From	To				
1	2	1-2	1	8	100
	3	1-2,2-3	2	11	100
	4	1-5,5-4	3	11	200
	5	1-5	4	5	150
2	1	2-1	5	8	400
	3	2-3	6	3	200
	4	2-4	7	5	100
	5	2-4,4-5	8	11	500
3	1	3-2,2-1	9	11	200
	2	3-2	10	3	100
	4	3-4	11	7	100
	5	3-4,4-5	12	13	150
4	1	4-5,5-1	13	11	250
	2	4-2	14	5	150
	3	4-3	15	7	300
	5	4-5	16	6	400
5	1	5-1	17	5	200
	2	5-4,4-2	18	11	100
	3	5-4,4-3	19	13	50
	4	5-4	20	6	350



From/to	Trips between Zones				
	1	2	3	4	5
1	-	100	100	200	150
2	400	-	200	100	500
3	200	100	-	100	150
4	250	150	300	-	400
5	200	100	50	350	-

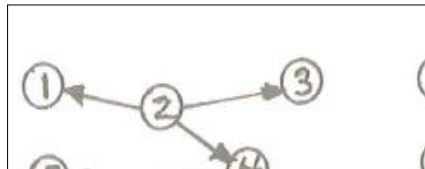
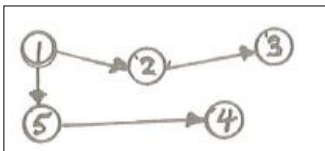
85

85

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 4: Find total trips (volume) on **each link**

Link	Used in Paths with ID	Cumulative trips on link
1-2		
2-1		



Nodes		Shortest Path	Path ID	Estimated trips between zones
From	To			
1	2	1-2	1	100
	3	1-2,2-3	2	100
	4	1-5,5-4	3	200
	5	1-5	4	150
2	1	2-1	5	400
	3	2-3	6	200
	4	2-4	7	100
	5	2-4,4-5	8	500
3	1	3-2,2-1	9	200
	2	3-2	10	100
	4	3-4	11	100
	5	3-4,4-5	12	150
4	5-4	20	350	

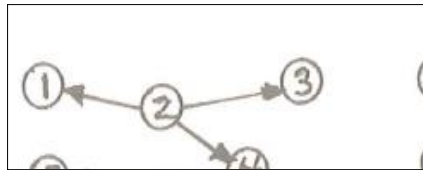
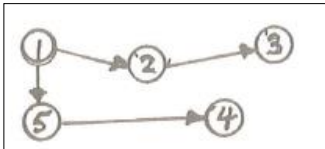
86

86

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 4: Find total trips (volume) on each link

Link	Used in Paths with ID	Cumulative trips on link
1-2	1 and 2	=100+100=200
2-1	5 and 9	=400+200=600



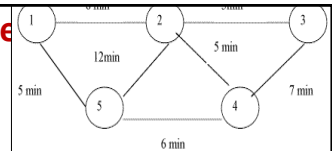
Nodes		Shortest Path	Path ID	Estimated trips between zones
From	To			
1	2	1-2	1	100
	3	1-2,2-3	2	100
	4	1-5,5-4	3	200
	5	1-5	4	150
2	1	2-1	5	400
	3	2-3	6	200
	4	2-4	7	100
	5	2-4,4-5	8	500
3	1	3-2,2-1	9	200
	2	3-2	10	100
	4	3-4	11	100
	5	3-4,4-5	12	150
4	5-4	20	350	

87

87

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 4: Find total trips (volume) on each link (Cont.)



Selected Link	Used in Paths with ID	Cumulative trips on link	Link travel time (min) from
1-2			
2-1			
1-5			
5-1			
2-5			
5-2			
2-3			
3-2			
2-4			
4-2			
3-4			
4-3			
4-5			
5-4			

Nodes		Shortest Path	Path ID	Cumulative Travel Time (min)	Traffic volume on shortest paths
From	To				
1	2	1-2	1	8	100
	3	1-2,2-3	2	11	100
	4	1-5,5-4	3	11	200
	5	1-5	4	5	150
2	1	2-1	5	8	400
	3	2-3	6	3	200
	4	2-4	7	5	100
	5	2-4,4-5	8	11	500
3	1	3-2,2-1	9	11	200
	2	3-2	10	3	100
	4	3-4	11	7	100
	5	3-4,4-5	12	13	150
4	1	4-5,5-1	13	11	250
	2	4-2	14	5	150
	3	4-	15	7	300
	5	4-5	16	6	400
5	1	5-1	17	5	200
	2	5-4,4-2	18	11	100
	3	5-4,4-3	19	13	50
	4	5-4	20	6	350

88

88

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 5: Find total vehicle minutes of travel on each link

### ↩ Total Vehicle Minutes:

➤ The **total cumulative time** all vehicles spend traveling through a roadway segment or network during a given time period.

### ↩ Formula:

➤ Total Vehicle Minutes = Travel Time per Vehicle (min) × Number of Vehicles

### ↩ Interpretation

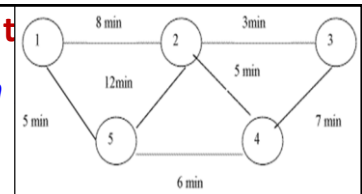
Total Vehicle Minutes	Total Vehicle Minutes	Traffic Condition	Implication
Low	0 – 5,000	Free-flow traffic	Efficient flow, short delays
Moderate	5,001 – 20,000	Steady or peak-hour traffic	Manageable demand, moderate congestion
High	20,001 – 50,000	Heavy congestion	Long delays, poor Level of Service (LOS)
Very High	50,001 and above	Severe congestion or incidents	Major delays, inefficiency, high user cost impact

90

90

## Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 5: Find total vehicle minutes of travel on each



Selected Link	Used in Paths with ID	Colmiative trips on link	Link travel time (min [from figure])	Total vehicle minutes of travel
1-2	1, 2	200	8.00	
2-1	5, 9	600	8.00	
1-5	3, 4	350	5.00	
5-1	3	450	5.00	
2-5	0	0	5.00	
5-2	0	0	12.00	
2-3	3,6	400.00	3.00	
3-2	9,10	300	3.00	
2-4	7,8	600	5.00	
4-2	14,18,	250	5.00	
3-4	12,	250	7.00	
4-3	19	350	7.00	
4-5	8,12,13,16	1300	6.00	
5-4	18,19,20	700	6.00	
				0

91

91

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 5: Find total vehicle minutes of travel on each link

Selected Link	Used in Paths with ID	Colmlative trips on link	Link travel time (min [from figure])	Total vehicle minutes of travel
1-2	1, 2	200	8.00	1600.00
2-1	5, 9	600	8.00	4800.00
1-5	3, 4	350	5.00	1750.00
5-1	3	450	5.00	2250.00
2-5	0	0	5.00	0.00
5-2	0	0	12.00	0.00
2-3	3,6	400.00	3.00	1200.00
3-2	9,10	300	3.00	900.00
2-4	7,8	600	5.00	3000.00
4-2	14,18,	250	5.00	1250.00
3-4	12,	250	7.00	1750.00
4-3	19	350	7.00	2450.00
4-5	8,12,13,16	1300	6.00	7800.00
5-4	18,19,20	700	6.00	4200.00
				32950

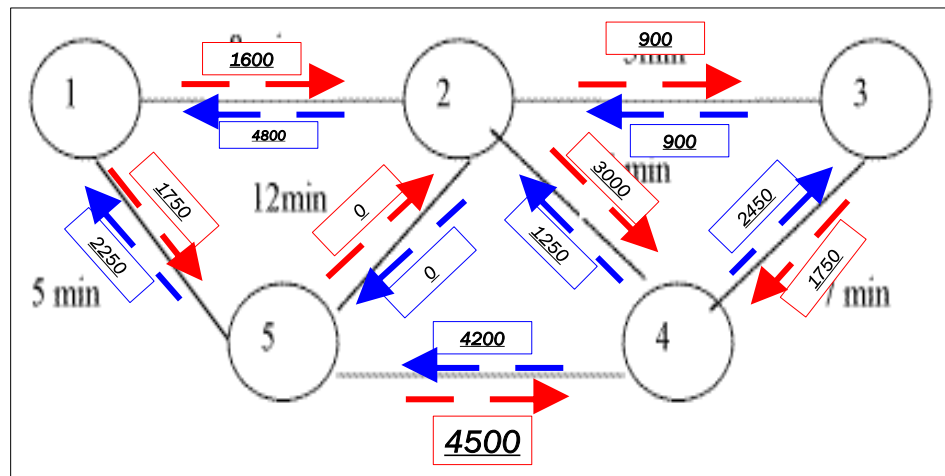
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92

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 6: Assign traffic for each of the five nodes

Link	Total vehicle minutes of travel ( column 2 X column 3)
1-2	1600
2-1	4800
1-5	1750
5-1	2250
2-5	0
5-2	0
2-3	900
3-2	900
2-4	3000
4-2	1250
3-4	1750
4-3	2450
4-5	7800
5-4	4200
Total	32650



93

93

### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 6: Assign traffic for each of the five nodes

Link	Cumulative trips on link
1-2	200
2-1	600
1-5	350
5-1	450
2-5	0
5-2	0
2-3	300
3-2	300
2-4	600
4-2	250
3-4	250
4-3	350
4-5	1300
5-4	700
Total	

From/to	Trips between Zones					Total
	1	2	3	4	5	
1	-	100	100	200	150	
2	400	-	200	100	500	
3	200	100	-	100	150	
4	250	150	300	-	400	
5	200	100	50	350	-	
Total	1050	450	650	750	1200	

Node	Attracted trips	Volume Assigned
1	600+450	1050
2	200+300+250	750
3	300+350	650
4	600+250+700	1550
5	350+1300	1650

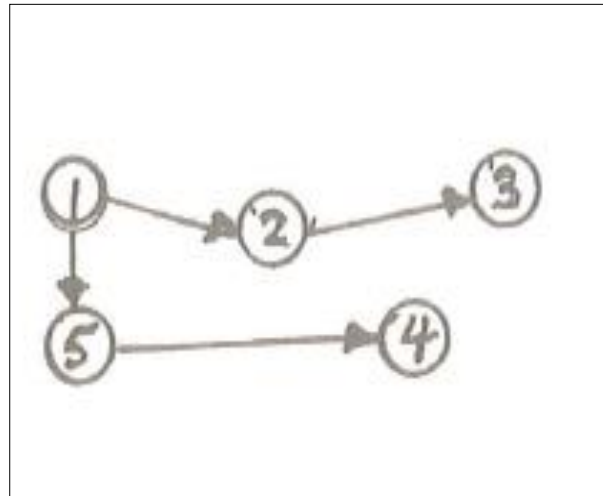
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### Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 7: Draw the minimum path (skim trees) at each node

Nodes		Shortest Path	Path ID
From	To		
<u>1</u>	2	1-2	1
	3	1-2,2-3	2
	4	1-5,5-4	3
	5	1-5	4



95

95

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>2</u>	1	2-1	5
	3	2-3	6
	4	2-4	7
	5	2-4,4-5	8

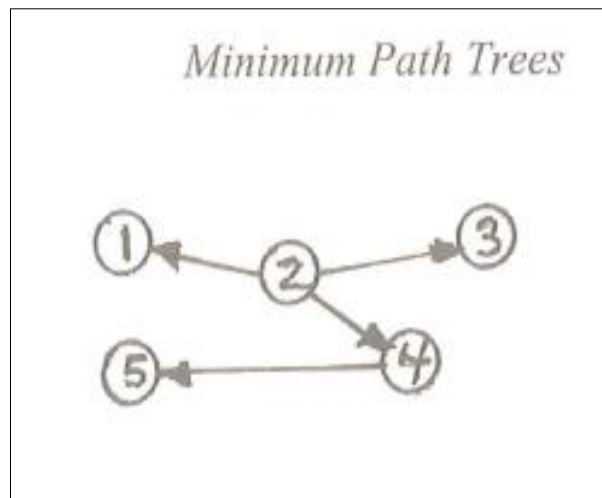
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96

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>2</u>	1	2-1	5
	3	2-3	6
	4	2-4	7
	5	2-4,4-5	8



97

97

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>3</u>	1	3-2,2-1	9
	2	3-2	10
	4	3-4	11
	5	3-4,4-5	12

98

98

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>3</u>	1	3-2,2-1	9
	2	3-2	10
	4	3-4	11
	5	3-4,4-5	12



99

99

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>4</u>	1	4-5,5-1	13
	2	4-2	14
	3	4-3	15
	5	4-5	16

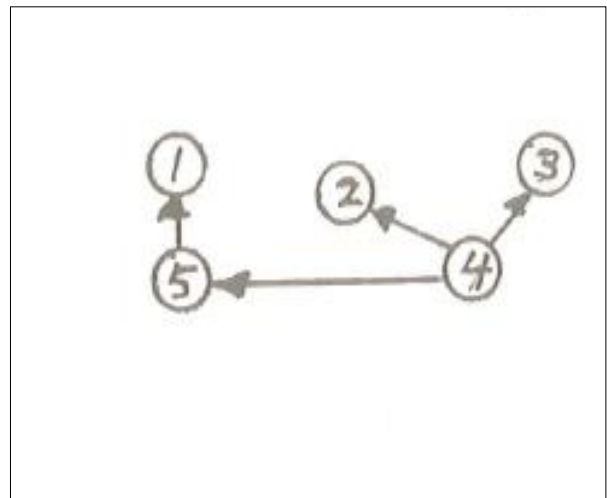
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**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>4</u>	1	4-5,5-1	13
	2	4-2	14
	3	4-	15
	5	4-5	16



101

101

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>5</u>	1	5-1	17
	2	5-4,4-2	18
	3	5-4,4-3	19
	4	5-4	20

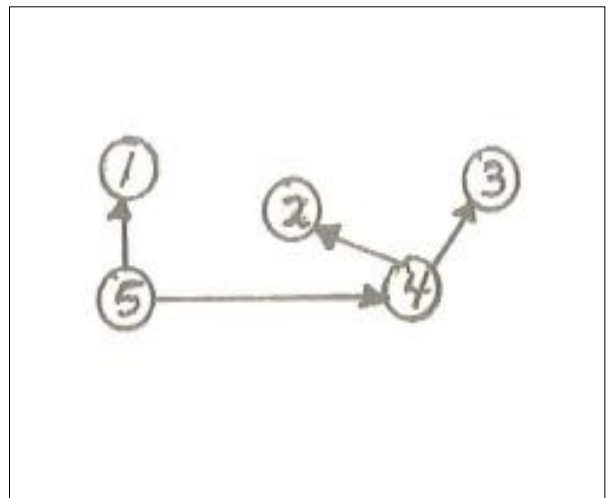
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102

**Solution of Example No.1 (Example 12.10) : Using of Skim tree**

*Step 7: Draw the minimum path (skim trees) at each node (cont.)*

Nodes		Shortest Path	Path ID
From	To		
<u>5</u>	1	5-1	17
	2	5-4,4-2	18
	3	5-4,4-3	19
	4	5-4	20



103

103

## What Next

✓ The **travel demand calculation** for the urban transportation system has been successfully completed

↪ 📌 The results of this work will be used to:

- 🔍 **Identify where improvements** are needed in the transportation system
- 💰 **Evaluate project priorities** through economic analysis
- 📁 **Support the design process**, including geometric layout and pavement planning

# *Transportation Engineering and Planning*

Module | 4 | Engineering Economics with  
Transportation Applications

## 4.1 | Introduction to Engineering Economics

*Dr. Hamza Mohammad Alkuime*

1

Introduction

2

## Engineering Economy

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- ❑ Engineering Economy is the **application of economic principles and analysis techniques** to evaluate the costs, benefits, and financial feasibility of engineering projects.

3

## Importance

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**It helps answer critical questions in transportation project planning:**

- **Which projects are worth investing in?**
  - Does building a new highway or expanding public transport bring economic benefits?
- **Which projects should be prioritized?**
  - Should funds go to road maintenance or new infrastructure based on cost-effectiveness?
- **How should transportation projects be designed?**
  - What is the best road alignment or material choice to reduce costs and improve durability?
- **What are the financial impacts?**
  - Have future costs, inflation, and funding sources been considered?

4

## Engineering Economy in Transportation

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- **Definition:**
  - Application of **economic principles** in **transportation decision-making**.
- **Role**
  - **Determining Economic Viability:** Select projects with **highest economic return**.
  - **Cost-Benefit Trade-offs:** Balances **cost and benefits**.
  - **Optimizing Resource Allocation:** Ensures **efficient use of budgets**.
  - **Improving Decision-Making:** Provides **quantitative basis** for comparing options

5

## Basic Concepts of Engineering Economy

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- **Cash Flow:**
  - Represents **inflows (revenues)** and **outflows (expenses)** over time.
- **Time Value of Money (TVM):**
  - Future costs & benefits are **discounted to present value** for accurate comparison.
- **Cost-Benefit Analysis (CBA):**
  - Compares **project benefits against costs** to determine feasibility.
- **Life Cycle Cost Analysis (LCCA):**
  - Evaluates the **total cost of ownership** over a project's **entire lifespan**.

6

# Performing an Engineering Economy Study

7

## Engineering Economy Study

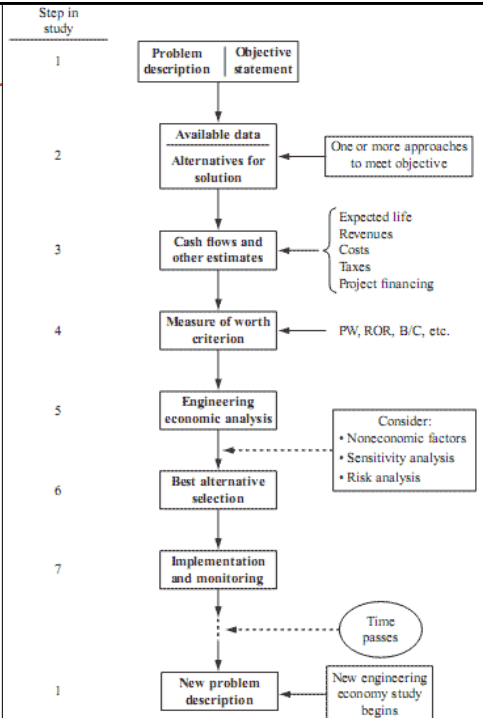
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- **Definition:**
  - A structured approach to **evaluating economic feasibility and decision-making** in engineering projects.
- **Objective:**
  - Identify, analyze, and select the best financial alternative for transportation infrastructure and systems.

8

## Steps

1. Identify and understand the **problem and the objective** of the project.
2. Collect **relevant, available data** and define viable solution alternatives.
3. Make realistic cash flow estimates.
4. Identify an economic measure of **worth criterion** for **decision making**
5. Evaluate each alternative
6. Select the best alternative
7. Implement the solution and monitor the results.



9

# Engineering Economy

## Terminology and Symbols

10

## Terminology and Symbols

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- **t = Time**
  - Stated in **years, months, days**.
- **P = Present Value**
  - **Value of money at the present time (t = 0).**
  - Also called **Present Worth (PW), Present Value (PV), Net Present Value (NPV), Discounted Cash Flow (DCF), Capitalized Cost (CC)**.
  - Expressed in **monetary units** (e.g., dollars, JOD).
- **F = Future Value**
  - **Value of money at a future time.**
  - Also called **Future Worth (FW), Future Value (FV)**.
  - Expressed in **monetary units** (e.g., dollars, JOD).

11

## Terminology and Symbols

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- **A = Annuity (Equal Series of Payments)**
  - **A sequence of equal, end-of-period cash flows = Paid at the end of the period**
  - Also known as **Annual Worth (AW), Equivalent Uniform Annual Worth (EUAW)**.
  - Expressed in **dollars per year, euros per month**.
- **i = Interest Rate per Time Period**
  - **The percentage applied to a principal amount over a specific time interval.**
  - Determines the **growth or discounting of money over time**.
  - Expressed as **percent per year (% per year), percent per month (% per month)**.
- **n = Number of Interest Periods**
  - **Total number of time intervals over which interest is applied.**
  - Defined in **years, months, or days**.

12

## General Notes

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- **P and F represent one-time occurrences**
  - **P (Present Value):** A single amount at **time = 0**.
  - **F (Future Value):** A single amount at a **future time**.
- **A represents a uniform series**
  - **Equal amounts** occurring at **the end of each period**.
  - Remains **constant** over a **specified number of periods**
- **Fundamental Rule for Solving Problems**
  - Every problem involves **at least four** of the symbols **P, F, A, n, and i**.
  - **At least three** of them must be **known or estimated** to solve for the unknown.

13

## Terminology and Symbols

Examples

14

## Example

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A transportation engineer **borrows \$5,000** to purchase **surveying equipment** for road design.

The loan can be repaid using one of two options:

- **Option A:** Five equal annual installments with an interest rate of 5% per year.
- **Option B:** A single lump-sum payment after 3 years with an interest rate of 7% per year.
- Determine the engineering economy symbols and their value for each option.

15

## Terminology and Symbols

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### *Solution of Example 1.6*

#### **SOLUTION**

(a) The repayment schedule requires an equivalent annual amount  $A$ , which is unknown.

$$P = \$5000 \quad i = 5\% \text{ per year} \quad n = 5 \text{ years} \quad A = ?$$

(b) Repayment requires a single future amount  $F$ , which is unknown.

$$P = \$5000 \quad i = 7\% \text{ per year} \quad n = 3 \text{ years} \quad F = ?$$

16

# Engineering Economy

## Cash Flow

19

## Cash Flow – Definition

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- **Cash flows represent the movement of money** (inflows and outflows) in a project.
- **Types of cash flows:**
  - **Estimated** for future projects.
  - **Observed** for completed transactions.
- **Timing of Cash Flows:**
  - Can occur **monthly, semi-annually, or annually**.
  - **Annual cash flows** are the **most common** in engineering economy.
- **Example:**
  - A payment of **\$10,000 once every year for 5 years** is a **series of 5 outgoing cash flows**.

20

## Cash Inflows in Transportation Projects

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- ❑ **Cash inflows** are revenues, savings, and funding sources generated by a transportation project.
- ❑ Represented by a **positive sign (+)** in engineering economic analysis.
- ❑ **Common Transportation Cash Inflows:**
  - **Toll Revenue:** JD **150,000/year** from a newly constructed expressway
  - **Cost Savings:** JD **24,500** in tax savings from road construction equipment
  - **Government Grants:** JD **750,000** received for public transportation development
  - **Efficiency Savings:** JD **150,000/year** from energy-efficient LED streetlights
  - **Revenue Growth:** JD **50,000–75,000/month** after upgrading bus and metro services

21

## Cash Outflows in Transportation Projects

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- ❑ **Cash outflows** are costs, expenses, and taxes incurred during a transportation project.
- ❑ Represented by a **negative sign (-)** in engineering economic analysis.
- ❑ **Common Transportation Cash Outflows:**
  - **Operating Costs:** JD **230,000/year** for road maintenance and highway operations
  - **First Cost (Capital Cost):** JD **800,000** next year to purchase replacement vehicles for a public transport fleet
  - **Financing Expense:** JD **20,000/year** for loan interest payments on transportation infrastructure projects

22

## Net Cash Flow in Transportation Projects

- **Net Cash Flow (NCF)** represents **the difference** between total cash inflows and outflows.
- **Formula:**

$$\text{Net Cash Flow} = \text{Cash Inflows} - \text{Cash Outflows}$$

$$NCF = R - D$$

### Where:

- **NCF = Net Cash Flow** (overall financial position of the project)
- **R = Receipts** (total income, funding, and revenue sources)
- **D = Disbursements** (total expenses, investments, and operational costs)

### Application in Transportation Projects:

- **Positive NCF:** Indicates a **profitable or sustainable project**, ensuring financial stability.
- **Negative NCF:** Suggests a **funding gap**, requiring additional investment or cost reductions.

23

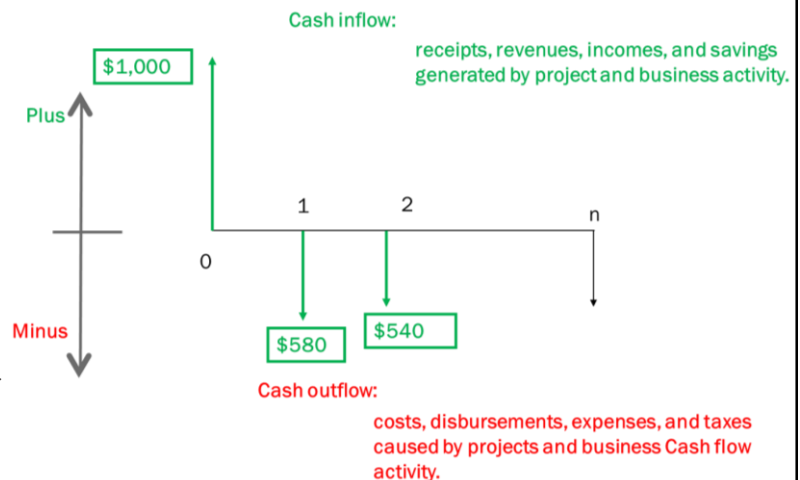
## Cash Flow Diagrams in Transportation Projects

- **Cash Flow Diagrams (CFD)** visually represent cash movements over time.

- **Time is shown on the x-axis, while cash inflows and outflows are on the y-axis.**

### Arrow Direction:

- **Upward Arrows** represent **positive cash flows** (income, grants, or savings).
- **Downward Arrows** indicate **negative cash flows** (construction costs, maintenance expenses, or loan payments).



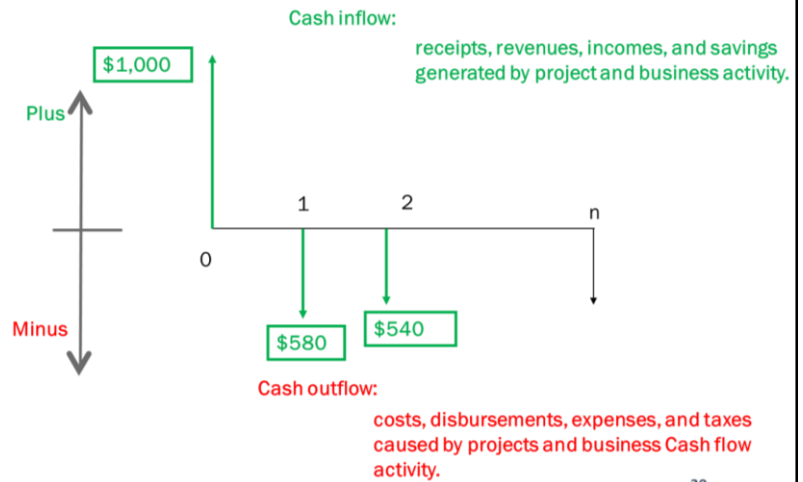
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## Cash Flow Diagrams in Transportation Projects

### Diagram Components:

- **What is known:** Confirmed costs, toll revenues, or government grants.
- **What is estimated:** Future maintenance costs, operational expenses, or projected fare revenues.



20

25

## Cash Flow Diagram

### Example 1.8

26

## Cash Flow Diagram

Assume you borrow \$8500 from a bank today to purchase an \$ 8000 used car for cash next week, and you plan to spend the remaining \$500 on a new paint job for the car two weeks from now.

There are several perspectives possible when developing the cash flow diagram

- ❖ Those of the borrower (that's you)
- ❖ The banker
- ❖ The car dealer
- ❖ The paint shop owner

Perspective	Activity	Cash flow with Sign, \$	Time, week
You	Borrow	+8500	0
	Buy car	-8000	1
	Paint job	-500	2
Banker	Lender	-8500	0
Car dealer	Car sale	+8000	1
Painter	Paint job	+500	2

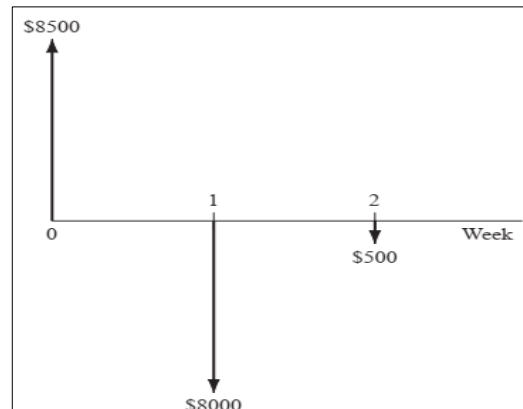
Cash flows from perspective of borrower for loan and purchases

27

## Cash Flow Diagram

Cash flows from perspective of borrower for loan and purchases

Perspective	Activity	Cash flow with Sign, \$	Time, week
You	Borrow	+8500	0
	Buy car	-8000	1
	Paint job	-500	2
Banker	Lender	-8500	0
Car dealer	Car sale	+8000	1
Painter	Paint job	+500	2



*One, and only one, of the perspectives is selected to develop the diagram.*

28

# Cash Flow Diagram

## Example 1.9

29

## Cash Flow Diagram

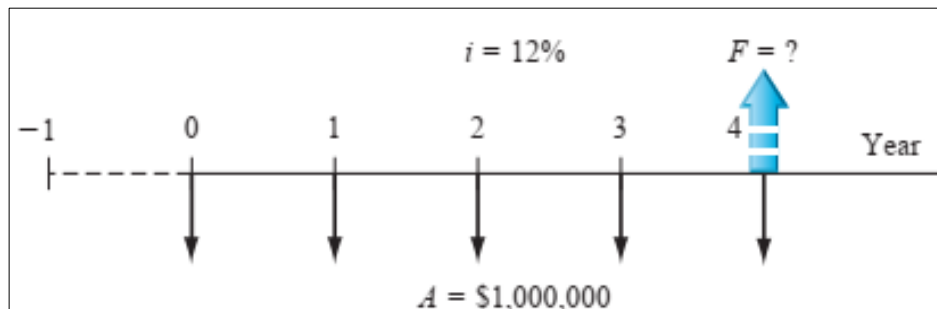
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- A national transportation agency allocates **\$1 million now** and **\$1 million annually for the next 4 years** to upgrade **traffic signal systems** on highways.
- The objective is to improve **road safety and traffic efficiency** by deploying **smart traffic control technologies**.
- Construct the cash flow diagram ,assuming a **12% annual cost of capital**.

30

## Cash Flow Diagram

- A national transportation agency allocates **\$1 million now** and **\$1 million annually for the next 4 years** to upgrade **traffic signal systems** on highways.
- The objective is to improve **road safety and traffic efficiency** by deploying **smart traffic control technologies**.
- Construct the cash flow diagram, then calculate the **equivalent value of these expenditures at the end of year 4**, assuming a **12% annual cost of capital**.



34

## Cash Flow Diagram

Example 1.10

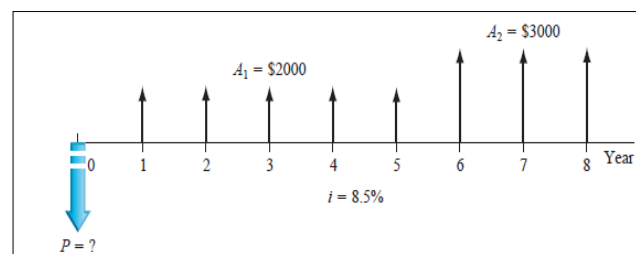
35

- ❑ A transportation agency plans to **deposit an amount  $P$  now** to fund periodic road maintenance and infrastructure improvements.
- ❑ The agency will **withdraw an equal annual amount of \$2000 per year for the first 5 years** to cover routine road maintenance costs.
- ❑ After the first phase, the agency will withdraw a different annual amount of **\$3000 per year for the following 3 years** to fund larger-scale rehabilitation projects.
- ❑ The interest rate is **8.5% per year**.

36

A transportation agency plans to **deposit an amount  $P$  now** to fund periodic road maintenance and infrastructure improvements. The agency will **withdraw an equal annual amount of \$2000 per year for the first 5 years** to cover routine road maintenance costs. After the first phase, the agency will withdraw a different annual amount of **\$3000 per year for the following 3 years** to fund larger-scale rehabilitation projects.

- ❑ The interest rate is **8.5% per year**.



38

# Cash Flow Diagram

## Example 1.11

39

39

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A **highway agency** spent **\$2500** on a **new traffic signal system** **7 years ago**.

- The **annual revenue** generated from improved traffic management and toll savings has been **\$750**.
- The **maintenance cost** for the traffic signal system was **\$100 in the first year** and has **increased by \$25 each year**.
- The agency plans to **decommission and sell** the traffic signal system **at the end of next year for \$150**.

### Task:

- Construct the cash flow diagram from the **transportation agency's perspective** and indicate where the **present worth** is located.

40

A highway agency spent \$2500 on a new traffic signal system 7 years ago.

- The **annual revenue** generated from improved traffic management and toll savings has been **\$750**.
- The **maintenance cost** for the traffic signal system was **\$100 in the first year** and has **increased by \$25 each year**.
- The agency plans to **decommission and sell** the traffic signal system **at the end of next year for \$150**.

End of Year	Income	Cost	Net Cash Flow
-7	\$ 0	\$2500	\$-2500
-6	750	100	650
-5	750	125	625
-4	750	150	600
-3	750	175	575
-2	750	200	550
-1	750	225	525
0	750	250	500
1	750 + 150	275	625

#### Task:

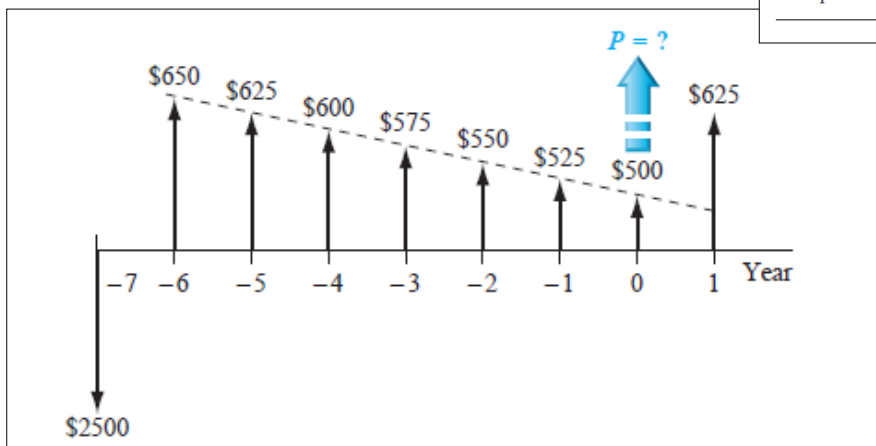
- Construct the cash flow diagram from the **transportation agency's perspective** and indicate where the **present worth** is located.

42

## Cash Flow Diagram

*Solution of Example 1.11*

End of Year	Income	Cost	Net Cash Flow
-7	\$ 0	\$2500	\$-2500
-6	750	100	650
-5	750	125	625
-4	750	150	600
-3	750	175	575
-2	750	200	550
-1	750	225	525
0	750	250	500
1	750 + 150	275	625



43

# Understanding Interest

44

## What is Interest?

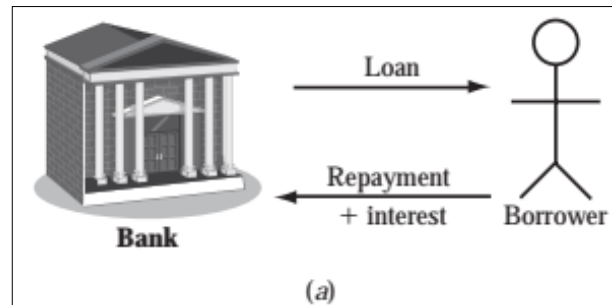
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- Interest is:**
  - the **cost of borrowing money**, or
  - the **return earned on an investment** over time.
- Interest may be:
  - **paid** (on loans), or
  - **earned** (on investments).
- Common Types of Interest:**
  - **Simple Interest:** Calculated **only on the principal amount**.
  - **Compound Interest:** Calculated on the **principal plus accumulated interest**.
- It is usually expressed as a **percentage of the principal amount**.

45

## Interest Paid

- ❑ Occurs when **money is borrowed**, requiring repayment with an **additional cost over time**.
- ❑ **Interest Paid** is the **extra amount paid above the principal** to the lender.
- ❑ Represents the **cost of borrowing funds**



$$\text{Interest Paid} = \text{Total Amount Owed} - \text{Principal}$$

46

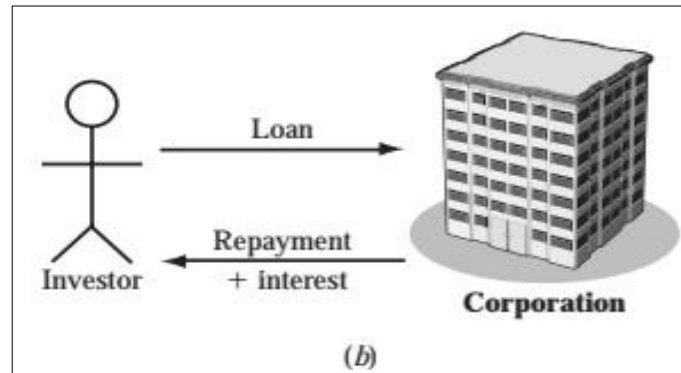
## Interest Paid – Example

- ❑ A transportation agency borrows **JD 10,000** from a bank to fund **bridge maintenance**.
- ❑ After **1 year**, the agency repays **JD 10,700**.
- ❑ **Solution**
  - Interest Paid = Total Amount Repaid – Principal
  - Interest Paid = 10,700 – 10,000 = **JD 700**
- ❑ **Interpretation**
  - Interest represents the **cost of borrowing**
  - Cash flow is **negative (-)** from the borrower's perspective

47

## Interest Earned

- ❑ Occurs when **money is invested**, generating a **return that grows over time**.
- ❑ **Interest Earned** is the **amount received beyond the initial principal**.
- ❑ **Formula**
- ❑ Represents the **reward for investing funds**



$$\text{Interest Earned} = \text{Total Amount Received} - \text{Principal}$$

48

## Interest Earned – Example

- ❑ A transportation authority invests **JD 20,000** in a project to upgrade **traffic monitoring systems**.
- ❑ After **1 year**, the investment grows to **JD 22,000**.
- ❑ **Solution**
  - Interest Earned = Total Amount Received – Principal
  - Interest Earned = 22,000 – 20,000 = **JD 2,000**
- ❑ **Interpretation**
  - Interest represents the **return on investment**
  - Cash flow is **positive (+)** from the investor's perspective

49

## Interest Period

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- ❑ The **interest period** is the **time interval** over which interest is **calculated and applied**.
- ❑ It determines **how often interest is added** to the principal.
- ❑ The **interest rate must match the interest period**.
- ❑ **Common Interest Periods:**
  - **Annually** – once per year
  - **Semi-annually** – twice per year
  - **Quarterly** – every three months
  - **Monthly** – every month
  - **Daily** – every day

50

## Interest Rate and Rate of Return

52

## Interest Rate

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### ❑ Interest Rate :

- The **interest rate** is the **percentage of the principal** that is **accrued as interest per time period**.

### ❑ General Formula

$$\text{Interest Rate (\%)} = \left( \frac{\text{Interest Accrued per Time Period}}{\text{Principal}} \right) \times 100$$

### ❑ It represents:

- the **cost of borrowing** (for loans), or
- the **rate of return** (for investments).

### ❑ Types of Interest Rate:

- **Interest Rate (Paid Interest)** – borrower's perspective
- **Rate of Return (ROR)** – investor's perspective

53

## Interest Rate or Paid Interest

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### ❑ The **interest rate (or Paid Interest)**

- is the **cost of borrowing money**
- expressed as a **percentage of the principal loan amount**.
- It represents the **additional amount** a borrower must pay to the lender for using borrowed funds over a **specific time period**.

### ❑ Formula

- $\text{Interest Rate (\%)} = \left( \frac{\text{Interest Accrued per Time Period}}{\text{Principal}} \right) \times 100$

54

## Interest Rate or Paid Interest

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- ❑ A business borrows **\$50,000** and pays **\$2,500** in interest over **1 year**.
  - Interest Rate =  $\left(\frac{2,500}{50,000}\right) \times 100 = 5\%$  per year
- ❑ A transportation agency borrows **\$20,000** to purchase traffic equipment and pays **\$1,800** in interest after **1 year**.
  - Interest Rate =  $\left(\frac{1,800}{20,000}\right) \times 100 = 9\%$  per year
- ❑ A contractor takes a **\$15,000 loan** for road maintenance and pays **\$750** in interest over **1 month**.
  - Interest Rate =  $\left(\frac{750}{15,000}\right) \times 100 = 5\%$  per *month*

55

## Rate of Return (ROR)

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- ❑ **Rate of Return (ROR)** measures the **profitability of an investment**,
- ❑ Expressed as a **percentage of the initial investment (principal)**.
- ❑ It represents the **gain earned** from investing money over a **specific time period**.
- ❑ **Formula**
- ❑ Rate of Return (%) =  $\left(\frac{\text{Net Gain}}{\text{Initial Investment}}\right) \times 100$

$$\text{Rate of return (\%)} = \frac{\text{interest accrued per time unit}}{\text{principal}} \times 100\% \quad [1.4]$$

56

## Rate of Return (ROR) – Worked Examples

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### ❑ Example 1

- An investor invests **\$20,000** in a project. After **1 year**, the value increases to **\$22,000**.
- $\text{ROR} = \left( \frac{22,000 - 20,000}{20,000} \right) \times 100 = 10\%$  per year

### ❑ Example 2

- A transportation authority invests **\$50,000** in a traffic management system. After **1 year**, the value rises to **\$55,000**.
- $\text{ROR} = \left( \frac{5,000}{50,000} \right) \times 100 = 10\%$  per year

### ❑ Example 3

- An investor invests **\$30,000** in road infrastructure equipment. After **1 Month**, the investment is worth **\$33,600**.
- $\text{ROR} = \left( \frac{3,600}{30,000} \right) \times 100 = 12\%$  per *Month*

57

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## Interest Rate and Rate of Return

### *Example 1.3*

58

58

- 
- A **transportation agency** borrows **\$10,000** on May 1 to fund the maintenance of a **highway bridge**.
  - The agency must **repay a total of \$10,700** exactly **1 year later** from collected toll revenues.

**Determine:**

- The interest amount**
- The interest rate paid**

59

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**Step 1: Calculate the Interest Amount**

$$\text{Interest} = \text{Total Amount Repaid} - \text{Principal}$$

$$\text{Interest} = 10,700 - 10,000$$

$$\text{Interest} = 700$$

**Step 2: Calculate the Interest Rate Paid**

$$\text{Interest Rate}(\%) = \left( \frac{\text{Interest}}{\text{Principal}} \right) \times 100$$

$$\text{Interest Rate} = \left( \frac{700}{10,000} \right) \times 100$$

$$\text{Interest Rate} = 7\%$$

60

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## Interest Rate and Rate of Return

### *Example 1.4*

61

61

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A **transportation agency** plans to borrow **\$20,000** from a bank for **1 year** at **9% interest** to fund the purchase of **new traffic management equipment**.

**Compute:**

- **The interest**
- **The total amount due after 1 year**

62

---

A **transportation agency** plans to borrow **\$20,000** from a bank for **1 year** at **9% interest** to fund the purchase of **new traffic management equipment**.

**Compute:**

- **The interest**
- **The total amount due after 1 year**

(a) Compute the total interest accrued by solving Equation [1.2] for interest accrued.

$$\text{Interest} = \$20,000(0.09) = \$1800$$

The total amount due is the sum of principal and interest.

$$\text{Total due} = \$20,000 + 1800 = \$21,800$$

63

# Inflation

64

## Inflation

- Inflation** is the rate at which the **general level of prices for goods and services increases over time**.
- As inflation rises, the **purchasing power of money decreases**.
- This means **the same amount of money buys fewer goods and services** in the future.

### Illustrative Example

- Price of a cup of coffee:
  - **1970:** \$0.25
  - **2019:** \$1.59



65

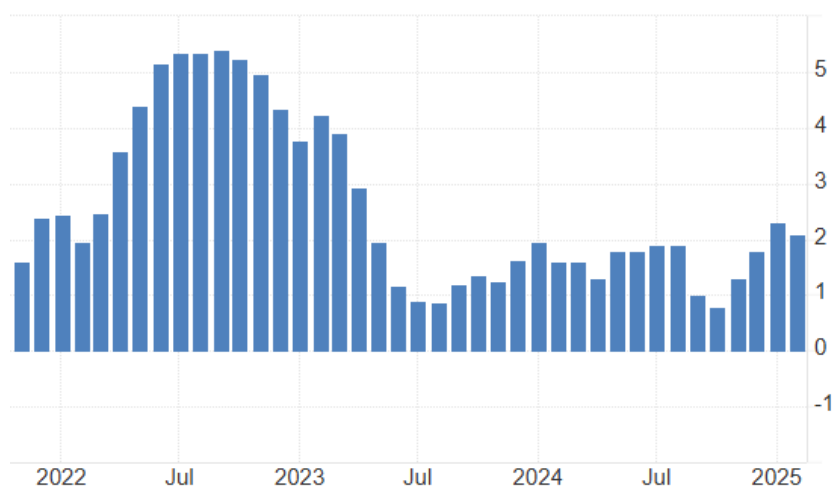
## How Inflation Rate Is Reported

- Inflation is usually reported as an **annual percentage rate**.
- It measures the **average increase in prices** of a selected group of goods and services.
- Example:**
  - Inflation rate = **4% per year**
  - Prices increase by **about 4% each year**, on average
- Reported By**
  - National statistical agencies (e.g., Central Bank, Department of Statistics)
  - International organizations (e.g., World Bank, IMF)

66

## Jordan Inflation Rate

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67

## Economic Meaning of Inflation Rate

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❑ An inflation rate of **4% per year** means:

- An item costing **\$100 today**
- Will cost approximately **\$104 next year**

❑ **Future Price = Current Price × (1 +  $f$ )**

• Where:

- $f$  = inflation rate per year
- Inflation reflects **loss of purchasing power**, not profit or growth.

68

## Importance of Considering Inflation in Engineering Economics

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### Accurate Project Cost Estimation

- Inflation affects **material, labor, and equipment costs**, making accurate cost forecasting essential.

### Realistic Financial Planning and Budgeting

- Accounting for inflation helps in **allocating sufficient funds** and **preventing budget shortfalls** over the project life.

### Ensuring Long-Term Project Feasibility

- Inflation influences **return on investment (ROI)** and overall **project viability**, especially for long-term projects.

- Engineering economic decisions must account for both time value of money and changes in price levels.**

69

## Example – Including vs Not Including Inflation

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### Illustrative Comparison

- Current cost: **\$1,000,000**
- Project life: **10 years**
- Inflation rate: **4%**

### Ignoring Inflation

- Future Cost = \$1,000,000

### Including Inflation

- Future Cost =  $1,000,000(1.04)^{10} = \$1,480,000$

- Ignoring inflation underestimates the project cost by 48%.**

70

## Interest Rate in Engineering Economic Studies

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- ❑ In engineering economic analysis, the **project interest rate (nominal rate)** usually includes:
  - **Real interest rate** → compensation for the **time value of money**
  - **Inflation rate** → compensation for **loss of purchasing power**
- ❑ **Relationship**  $1 + i = (1 + r)(1 + f)$ 
  - Where:
    - $i$  = **nominal (market) interest rate**
    - $r$  = **real interest rate**
    - $f$  = **inflation rate**
- ❑ **Key Interpretation**
- ❑ **The interest rate used in projects reflects both time and price changes**

71

## Example: Project Interest Rate Including Inflation

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- ❑ A project owner plans to invest in a transportation project.
- ❑ The owner requires a **real gain of 5% per year** (real interest rate).
- ❑ The expected **inflation rate is 3% per year**.
- ❑ Determine the required interest

72

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❑ **Step 1: Identify Components :**

- Real interest rate (owner's desired gain):  $r = 5\%$  per year
- Inflation rate:  $f = 3\%$  per year

❑ **Step 2: Compute the Nominal Interest Rate**  $1 + i = (1 + r)(1 + f)$

- $1 + i = (1.05)(1.03) = 1.0815$
- $i = 8.15\%$  per year

❑ **Interpretation**

- **5%** → owner's desired **real gain**
- **3%** → expected **inflation compensation**
- **8.15%** → **nominal interest rate** used in the engineering economic analysis
- This is the **interest rate normally used** when future cash flows include inflation.

# *Transportation Engineering and Planning*

Module | 4 | Engineering Economics with  
Transportation Applications

## 4.2 | Economic Equivalence

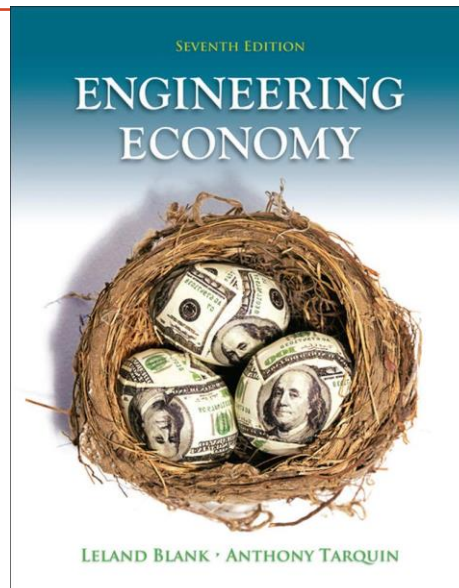
*Dr. Hamza Mohammad Alkuime*

1

## Engineering Economy

### References

- ↳ Leland Blank and Anthony Tarquin, **Engineering Economy**, 7<sup>th</sup> Edition, . McGraw-Hill, 2005



2

## Interest rate

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- **The amount charged** by a lender to a borrower for the use of assets.
- Typically noted on an **annual basis**
- Expressed as a percentage of principal

### ☐ Types

- Simple interest
- Compound interest

3

# Simple interest

4

## Simple interest

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- ❑ When the **total interest earned or charged** is linearly proportional to the initial amount of the loan (principal)
  - **the interest rate, and the number of interest periods**, the interest and interest rate are said to be **simple**.
- ❑ **Simple interest** is **calculated using the principal only**, ignoring any interest accrued in preceding interest periods.

$$\text{Simple interest} = (\text{principal})(\text{number of periods})(\text{interest rate}) \quad [1.7]$$

$$I = Pni$$

**The total amount repaid at the end of  $N$  interest periods is  $P + I$ .**

$P$  = principal amount lent or borrowed

$N$  = number of interest periods (e.g., years)

$i$  = interest rate per interest period

5

## Example 1.14

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- ❑ **City Transport Authority** provided a loan of **\$100,000** to a construction company to **upgrade a highway intersection** for improved traffic flow.
- ❑ The loan is for **3 years at 10% per year simple interest**.
- ❑ **How much money will the company repay at the end of 3 years?**

6

The interest for each of the 3 years is

$$\text{Interest per year} = \$100,000(0.10) = \$10,000$$

Total interest for 3 years from Equation [1.7] is

$$\text{Total interest} = \$100,000(3)(0.10) = \$30,000$$

The amount due after 3 years is

$$\text{Total due} = \$100,000 + 30,000 = \$130,000$$

The interest accrued in the first year and in the second year does not earn interest. The interest due each year is \$10,000 calculated only on the \$100,000 loan principal.

7

## Simple interests

### Key characters

- ↪ Same **interest amount** is added each period
- ↪ Growth is **linear over time**
- ↪ **No interest on interest**
- ↪ **Rarely used in engineering economic analysis**

#### ↪ Example 1

- *Principal = 1,000 JOD*  
*Interest rate = 10% per year*  
*Interest each year = **100 JOD***
- *After 1 year → Total = 1,100 JOD*  
*After 2 years → Total = 1,200 JOD*  
*After 3 years → Total = 1,300 JOD*

#### ↪ Example 2

- *Borrow 5,000 JOD at 6% simple interest for 4 years*  
*Interest per year = 300 JOD*  
*Total interest =  $300 \times 4 = 1,200$  JOD*  
***Total repayment = 6,200 JOD***

8

# Compound interest

9

## Compound interest

### Concept

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- ↪ Interest that is **computed on**:
  - the **original unpaid debt (principal)**
  - the **unpaid interest** (*interest on top of interest*)
- ↪ Because interest is added to the balance after each period, **the base amount increases over time.**
- ↪ **Interest amount changes every period**

In most **financial and engineering economic analyses**, **compound interest is assumed** because it reflects real-world behavior.

10

## Compound Interest – Simple Example

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### □ Given

- **Principal (P)** = 1,000 JOD
- **Interest rate (i)** = 10% per year
- **Time** = 3 years
- **Interest is compounded annually**

11

## Compound Interest – Simple Example □ Given

---

### □ Year 1

- $I_1 = P \times i = 1000 \times 0.10 = 100$
- Total after Year 1:  $1000 + 100 = 1100$

### □ Year 2

- Interest is now calculated on **principal + previous interest**:
- $I_2 = (1000 + 100) \times 0.10 = 110$
- Total after Year 2:  $1100 + 110 = 1210$

### □ Year 3

- $I_3 = (1000 + 100 + 110) \times 0.10 = 121$
- Total after Year 3:  $1210 + 121 = 1331$

- **Principal (P)** = 1,000 JOD
- **Interest rate (i)** = 10% per year
- **Time** = 3 years
- **Interest is compounded annually**

12

## Compound interest

### Formula

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

$I_t$  = interest for time period  $t$

$P$  = principal amount lent or borrowed

$t$  = time period

$i$  = interest rate per interest period

13

↪ For  $t = 1$

$$\triangleright I_1 = \left( P + \sum_{j=1}^0 I_j \right) i = P \times i$$

↪ For  $t = 2$

$$\triangleright I_2 = \left( P + \sum_{j=1}^1 I_j \right) i = (P + I_1) \times i$$

↪ For  $t = 3$

$$\triangleright I_3 = \left( P + \sum_{j=1}^2 I_j \right) i = (P + I_1 + I_2) \times i$$

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

$I_t$  = interest for time period  $t$

$P$  = principal amount lent or borrowed

$t$  = time period

$i$  = interest rate per interest period

14

## Total due after n years Compound Interest

### ❑ Step 1: What happens in one year

- You start with **principal**  $P$
- Interest rate per year =  $i$
- Interest earned in **1 year**:
  - $I_1 = Pi$

### ❑ Total amount after **1 year**:

- $P + Pi = P(1 + i)$

### ❑ After **1 year**, money becomes:

- $P(1 + i)$

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

15

## Total due after n years Compound Interest

### ❑ Step 2: What happens in second year

#### ❑ Amount at **start of year 2**:

- $P(1 + i)$

#### ❑ Interest earned in year 2:

- $P(1 + i)i$

#### ❑ Total after **2 years**:

- $P(1 + i) + P(1 + i)i$

#### ❑ Factor $P(1 + i)$ :

- $P(1 + i)(1 + i)$

#### ❑ So:

- $P(1 + i)^2$

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

16

## Total due after n years Compound Interest

- ❑ **Step 3: What happens in** third year
- ❑ At start of year 3:
  - $P(1+i)^2$
- ❑ Interest earned in year 3:
  - $P(1+i)^2i$
- ❑ Total after **3 years**:
  - $P(1+i)^2 + P(1+i)^2i$
- ❑ Factor:
  - $P(1+i)^2(1+i)$
- ❑ So:
- ❑  $P(1+i)^3$

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

17

## Future Value of a Loan With Compound Interest

$$\begin{aligned} \text{Total due after } n \text{ years} &= \text{principal}(1 + \text{interest rate})^n \text{ years} \\ &= P(1+i)^n \end{aligned} \quad [1.10]$$

$I_t$  = interest for time period  $t$

$P$  = principal amount lent or borrowed

$t$  = time period

$i$  = interest rate per interest period

18

## Example 1.15

- ❑ **A transportation agency** borrows **\$100,000** at **10% per year compound interest** to fund the **expansion of a railway station**.
- ❑ The agency will **repay the principal and all interest after 3 years**.
- ❑ **Tasks:**
  - Compute the **annual interest** and **total amount due after 3 years**.
  - Compare results with **simple interest**.

19

## Economic Equivalence

### *Solution of Example 1.15*

$$I_t = \left( P + \sum_{j=1}^{t-1} I_j \right) (i)$$

#### Simple interest:

Year 1: 10,000

Year 2: 10,000

Year 3: 10,000

Sum of interest= 30,000

Total due, year 3=

100,000+30,000= 130,000

#### Compounded interest

Interest, year 1: 100,000(0.10) = \$10,000

Total due, year 1: 100,000 + 10,000 = \$110,000

Interest, year 2: 110,000(0.10) = \$11,000

Total due, year 2: 110,000 + 11,000 = \$121,000

Interest, year 3: 121,000(0.10) = \$12,100

Total due, year 3: 121,000 + 12,100 = \$133,100

20

# Moving Cash Flows

Present to Future

22

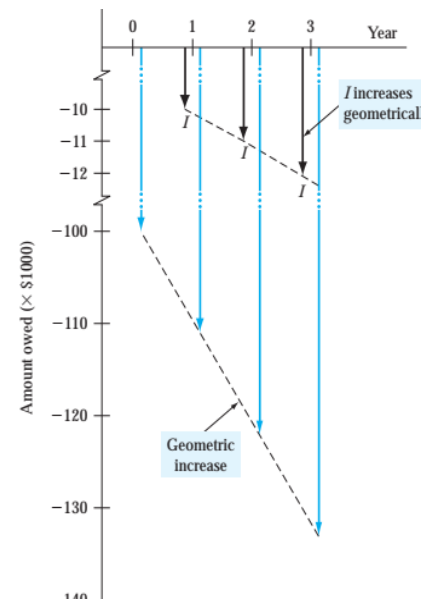
## Moving Cash Flows Along the Cash Flow Diagram

Interest, year 1:	$100,000(0.10) = \$10,000$
Total due, year 1:	$100,000 + 10,000 = \$110,000$
Interest, year 2:	$110,000(0.10) = \$11,000$
Total due, year 2:	$110,000 + 11,000 = \$121,000$
Interest, year 3:	$121,000(0.10) = \$12,100$
Total due, year 3:	$121,000 + 12,100 = \$133,100$

$$\text{Total due after } n \text{ years} = \text{principal}(1 + \text{interest rate})^n \text{ years} \quad [1.10]$$

$$= P(1 + i)^n$$

$$F = P \times (1 + i)^N$$



23

## Converting factor | Future Value (F) from Present (P)\_

---

$$\square F = P (1 + i)^N$$

$$\square (1 + i)^N$$

- is a factor that find that a **present amount, P**, can **grow into a future amount, F**, in **N time periods** at **interest rate i**

24

## Moving Cash Flows

Converting Between P, F, and A

26

## Conversion Between F and P

---

- **Future Value from Present (F/P):**

$$F = P(1 + i)^n$$

- **Present Value from Future (P/F):**

$$P = F(1 + i)^{-n}$$

27

## Conversion Between F and A

---

- **Future Value from Annual (F/A):**

$$F = A \left[ \frac{(1+i)^n - 1}{i} \right]$$

- **Annual from Future (A/F):**

$$A = F \left[ \frac{i}{(1+i)^n - 1} \right]$$

28

## Conversion Between P and A

---

- **Present Value from Annual (P/A):**

$$P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right]$$

- **Annual from Present (A/P):**

$$A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

29

Interest Tables

31

### Example :

---

□ Find the Equivalence Future value of **1000 JOD** at the following conditions

- $i = 2\%$ ,  $n = 1$
- $i = 4\%$ ,  $n = 2$
- $i = 6\%$ ,  $n = 3$
- $i = 8\%$ ,  $n = 4$

32

### Example :

---

□ Find the Equivalence Future value of 1000 JOD at the following conditions

- $i = 2\%$ ,  $n = 1$       † **Case 1:  $n = 1 \rightarrow$**   

$$F = 1000(1.08)^1 = \mathbf{1080.00 \text{ JOD}}$$
- $i = 4\%$ ,  $n = 2$       † **Case 2:  $n = 2 \rightarrow$**   

$$F = 1000(1.08)^2 = \mathbf{1166.40 \text{ JOD}}$$
- $i = 6\%$ ,  $n = 3$       † **Case 3:  $n = 3 \rightarrow$**   

$$F = 1000(1.08)^3 = \mathbf{1259.71 \text{ JOD}}$$
- $i = 8\%$ ,  $n = 4$       † **Case 4:  $n = 4 \rightarrow$**   

$$F = 1000(1.08)^4 = \mathbf{1360.49 \text{ JOD}}$$

33

### Example :

---

□ Find the Equivalence Future value of 1000 JOD at the following conditions

- $i = 2\%$ ,  $n = 2$
- $i = 4\%$ ,  $n = 2$
- $i = 6\%$ ,  $n = 6$
- $i = 8\%$ ,  $n = 6$

34

### Example :

---

□ Find the Equivalence Future value of 1000 JOD at the following conditions

- $i = 2\%$ ,  $n = 2$
- $i = 4\%$ ,  $n = 2$
- $i = 6\%$ ,  $n = 6$
- $i = 8\%$ ,  $n = 6$

Given: Present value  $P = 1000$  JOD

Formula used:  $F = P(1 + i)^n$

Case 1:  $i = 2\%$ ,  $n = 2 \rightarrow$

$$F = 1000(1.02)^2 = \mathbf{1040.40 \text{ JOD}}$$

Case 2:  $i = 4\%$ ,  $n = 2 \rightarrow$

$$F = 1000(1.04)^2 = \mathbf{1081.60 \text{ JOD}}$$

Case 3:  $i = 6\%$ ,  $n = 6 \rightarrow$

$$F = 1000(1.06)^6 = \mathbf{1418.52 \text{ JOD}}$$

Case 4:  $i = 8\%$ ,  $n = 6 \rightarrow$

$$F = 1000(1.08)^6 = \mathbf{1586.87 \text{ JOD}}$$

35

## What Are Pre-Calculated Interest Factors?

- **Pre-calculated interest factors** are values derived from standard formulas
- **Factors eliminate the need for manual calculations with:**
- Each factor corresponds to a financial conversion:
  - **Present to future (F/P)**
  - **Future to present (P/F)**
  - **future of a uniform annual amount (A/F)**

36

## Types of Interest Factors and Their Use

- **F/P (Single Payment Compound Amount Factor):**  
Find future value from a present value:  $F = P \times (F/P, i, n)$
- **P/F (Single Payment Present Worth Factor):**  
Find present value from a future value:  $P = F \times (P/F, i, n)$
- **F/A (Uniform Series Compound Amount Factor):**  
Find future value from equal annual payments:  $F = A \times (F/A, i, n)$
- **A/F (Sinking Fund Factor):**  
Find annual payment required to accumulate future amount:  $A = F \times (A/F, i, n)$
- **P/A (Capital Recovery Factor):**  
Find present value from equal annual payments:  $P = A \times (P/A, i, n)$
- **A/P (Uniform Series Present Worth Factor):**  
Find annual payments required to repay present investment:  $A = P \times (A/P, i, n)$

- **Future Value from Present (F/P):**  
 $F = P(1 + i)^n$
- **Present Value from Future (P/F):**  
 $P = F(1 + i)^{-n}$
- **Future Value from Annual (F/A):**  
 $F = A \left[ \frac{(1+i)^n - 1}{i} \right]$
- **Annual from Future (A/F):**  
 $A = F \left[ \frac{i}{(1+i)^n - 1} \right]$
- **Present Value from Annual (P/A):**  
 $P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right]$
- **Annual from Present (A/P):**  
 $A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]$

37

Interest tables present pre-calculated compound interest factors

8% TABLE 13 Discrete Cash Flow: Compound Interest Factors						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.00000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927
6	1.5869	0.6302	0.13632	7.3359	0.21632	4.6229
7	1.7138	0.5835	0.11207	8.9228	0.19207	5.2064
8	1.8509	0.5403	0.09401	10.6366	0.17401	5.7466
9	1.9990	0.5002	0.08008	12.4876	0.16008	6.2469

10% TABLE 15 Discrete Cash Flow: Compound Interest Factors						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908

38

Examples

39

Find the followings

- (P/F, 8%, 5)
- (F/P, 8%, 5)
- (P/A, 8%, 5)
- (A/P, 8%, 5)
- (F/A, 8%, 5)

40

## Present Worth Factor (P/F, 8%, 5)

The Present Worth Factor (P/F,  $i$ ,  $n$ ) is calculated using the formula

$$P/F = \frac{1}{(1+i)^n}$$

Given values:

- $i = 8\% = 0.08$
- $n = 5$

$$P/F = \frac{1}{(1+0.08)^5}$$

$$P/F = \frac{1}{(1.08)^5}$$

$$P/F = \frac{1}{1.4693}$$

$$P/F = 0.6806$$

8% TABLE 13 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.00000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927

41

F/P, 8%, 5

8% TABLE 13 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.0000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927

The Future Worth Factor (F/P, i, n) is calculated using the formula:

$$F/P = (1 + i)^n$$

Given values:

- $i = 8\% = 0.08$
- $n = 5$

$$F/P = (1 + 0.08)^5$$

$$F/P = (1.08)^5$$

$$F/P = 1.4693$$

42

(P/A, 8%, 5)

8% TABLE 13 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.0000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927

• Formula:

$$P/A = \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

• Given:

- Interest rate  $i = 8\%$  (0.08)
- Number of periods  $n = 5$

• Calculation:

$$P/A = \frac{(1.08)^5 - 1}{0.08(1.08)^5}$$

$$P/A = \frac{1.4693 - 1}{0.08 \times 1.4693}$$

$$P/A = \frac{0.4693}{0.1175} = 3.9927$$

43

**(A/P, 8%, 5)**

- Formula:

$$A/P = \frac{i(1+i)^n}{(1+i)^n - 1}$$

- Given:

- Interest rate  $i = 8\%$  (0.08)
- Number of periods  $n = 5$

- Calculation:

$$A/P = \frac{0.08(1.08)^5}{(1.08)^5 - 1}$$

$$A/P = \frac{0.08 \times 1.4693}{1.4693 - 1}$$

$$A/P = \frac{0.1175}{0.4693} = 0.2505$$

8% TABLE 13 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.0000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
4	1.3605	0.7350	0.22192	4.5061	0.30192	3.3121
5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927

44

**(F/A, 8%, 5)**

- Formula:

$$F/A = \frac{(1+i)^n - 1}{i}$$

- Given:

- Interest rate  $i = 8\%$  (0.08)
- Number of periods  $n = 5$

- Calculation:

$$F/A = \frac{(1.08)^5 - 1}{0.08}$$

$$F/A = \frac{1.4693 - 1}{0.08}$$

$$F/A = \frac{0.4693}{0.08} = 5.8666$$

8% TABLE 13 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0800	0.9259	1.0000	1.0000	1.08000	0.9259
2	1.1664	0.8573	0.48077	2.0800	0.56077	1.7833
3	1.2597	0.7938	0.30803	3.2464	0.38803	2.5771
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5	1.4693	0.6806	0.17046	5.8666	0.25046	3.9927

45

## Examples

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**Example:** \$2,500 at time zero is equivalent to how much **after six** years if the interest rate is **8%** per year?

**Example:** \$3,000 at the **end of year seven** is equivalent to how much **today (time zero)** if the interest rate is **6%** per year?

46

## Examples

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**Example:** \$2,500 at time zero is equivalent to how much **after six** years if the interest rate is **8%** per year?

$$F = \$2,500(F/P, 8\%, 6) = \$2,500(1.5869) = \$3,967$$

**Example:** \$3,000 at the end of year seven is equivalent to how much today (time zero) if the interest rate is **6%** per year?

$$P = \$3,000(P/F, 6\%, 7) = \$3,000(0.6651) = \$1,995$$

47

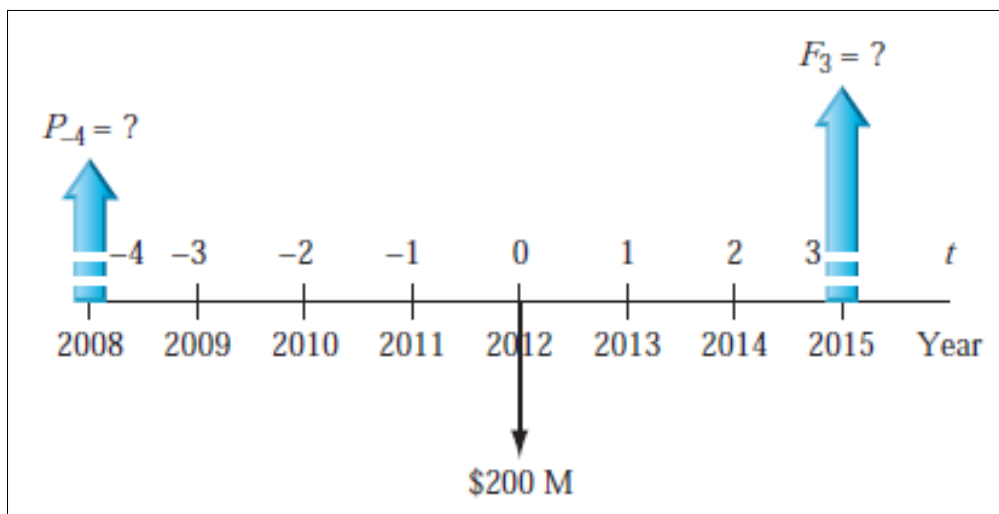
## Example

- ❑ A transportation project will require an investment of **\$200 million** to construct (year 2012).
- ❑ Delays beyond the anticipated implementation year of 2012 will **require additional money to construct the factory**.
- ❑ Assuming that the **cost of money is 10% per year**, compound interest
- ❑ determine the following:
  - (a) The equivalent investment needed **if the project is built in 2015**.
  - (b) The equivalent investment needed had the plant **been constructed in the year 2008**.

48

## Notation for Calculating a Present Value

*Solution of Example 2.2*



49

## Notation for Calculating a Present Value

### Solution of Example 2.2

10% TABLE 15 Discrete Cash Flow: Compound Interest Factors						
n	Single Payments			Uniform Series Payments		
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908

↪ (a) To find the equivalent investment required in 3 years, apply the F/P factor. Use \$1 million units and the tabulated value for 10% interest.

$$\text{➤ } F_3 = P(F/P, i, n) = 200(F/P, 10\%, 3) = 200(1.3310)$$

$$\text{➤ } = = \$266.2 \text{ } (\$266,200,000)$$

↪ (b) The year 2008 is 4 years prior to the planned construction date of 2012. To determine the equivalent cost 4 years earlier, consider the \$200 M in 2012 ( $t = 0$ ) as the future value  $F$  and apply the  $P/F$  factor for  $n = 4$  to find  $P_4$ .

$$\text{➤ } P_4 = F(P/F, i, n) = 200(P/F, 10\%, 4) = 200(0.6830)$$

$$\text{➤ } = = \$136.6 \text{ } (\$136,600,000)$$

50

## Example

- ❑ A transportation project will require an investment of **\$200 million** to construct (year 2012).
- ❑ The project may generate a **revenue base of \$50 million per year**.
- ❑ The president of the company may have reason to be quite pleased with this projection for the simple reason that over **the 5-year planning horizon, the expected revenue would total \$250 million**, which is **\$50 million more than the initial investment**. With money worth **10% per year**,
  - Will the initial investment be recovered over the **5-year horizon** with the time value of money considered?
  - If so, by **how much extra in present worth funds**?
  - If not, what is the **equivalent annual revenue base required** for **the recovery plus the 10% return** on money?

51

10% TABLE 15 Discrete Cash Flow: Compound Interest F						
n	Single Payments			Uniform Series Payments		
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908

❑  $P = 50(P/A, 10\%, 5) = 50(3.7908)$

• = \$189.54 (\$189,540,000)

❑ The **present worth value** is less than the **investment plus a 10% per year return**,

❑ To determine the minimum required to realize a 10% per year return, use the **A/P factor**.

•  $A = 200(A/P, 10\%, 5) = 200(0.26380)$

• = \$52.76 per year

• where **A** starts **1 year after P at t = 0 and n = 5**.

• The plant needs to generate \$52,760,000 per year to realize a 10% per year return over 5 years.

52

## Example

❑ How much will you have in **40 years** if you save **JOD 3,000 each year** and your account earns **8% interest each year**?

53

## Example

- ❑ How much will you have in **40 years** if you save **\$3,000 each year** and your account earns **8% interest each year**?

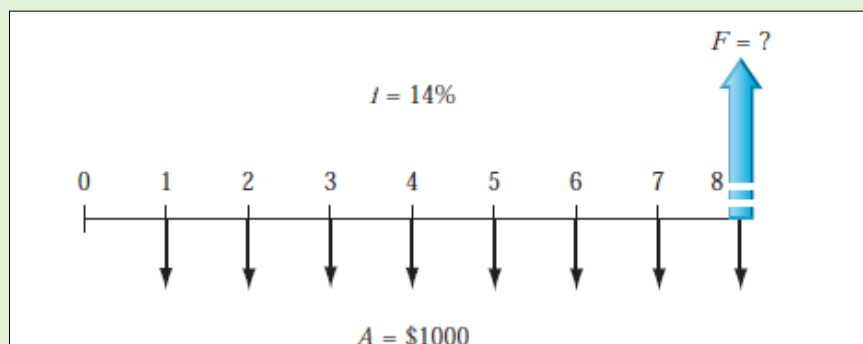
$$F = \$3,000(F/A, 8\%, 40) = \$3,000(259.0565) = \$777,170$$

54

## Example

The **Ministry of Transport** wants to determine the **equivalent future worth** of an **annual capital investment of 1 million JOD** for **8 years**, starting **1 year from now**.

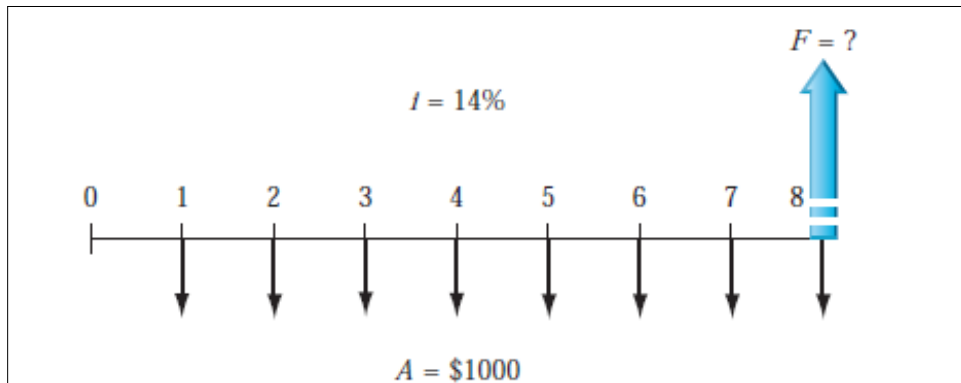
- ❑ The investment is aimed at **road maintenance and infrastructure development**, and the **expected rate of return is 14% per year**.



55

## Example

$$F = 1000(F/A, 14\%, 8) = 1000(13.2328) = \$13,232.80 * 1000 = \$13,232,800$$



56

solve for N or i.

57

---

## □ It can be challenging to solve for $N$ or $i$ .

- We may know  $P$ ,  $A$ , and  $i$  and want to find  $N$ .
- We may know  $P$ ,  $A$ , and  $N$  and want to find  $i$ .

58

## Finding $N$

---

- ↳ **Example:** Adam borrowed \$100,000 from a local bank, which charges them an interest rate of 7% per year.
- ↳ If Adam pays the bank \$8,000 per year, how many years will it take to pay off the loan?

59

## Finding N

---

↳ **Example:** Adam borrowed \$100,000 from a local bank, which charges them an interest rate of 7% per year. If Adam pays the bank \$8,000 per year, how many years will it take to pay off the loan?

$$\text{So, } \$100,000 = \$8,000(P/A, 7\%, N)$$

$$(P/A, 7\%, N) = \frac{\$100,000}{\$8,000} = 12.5 = \frac{(1.07)^N - 1}{0.07(1.07)^N}$$

This can be solved by using the interest tables and interpolation, but we generally resort to a computer solution.  $N = 30.7$  years

$$P = A \left[ \frac{(1+i)^N - 1}{i(1+i)^N} \right] = A(P/A, i\%, N)$$

60

## Finding i

---

↳ **Example:** Jill invested \$1,000 each year for five years in a local company and sold her interest after five years for \$8,000. What annual rate of return did Jill earn?

61

## Finding $i$

---

↳ **Example:** Jill invested \$1,000 each year for five years in a local company and sold her interest after five years for \$8,000. What annual rate of return did Jill earn?

$$\$8,000 = \$1,000(F/A, i\%, 5)$$

So,

$$(F/A, i\%, 5) = \frac{\$8,000}{\$1,000} = 8 = \frac{(1+i)^5 - 1}{i}$$

Again, this can be solved using the interest tables and interpolation, but we generally resort to a computer solution.  $i = 23.69\%$

$$F = A \left[ \frac{(1+i)^N - 1}{i} \right] = A(F/A, i\%, N)$$

# *Transportation Engineering and Planning*

Module | 4 | Engineering Economics with  
Transportation Applications

## 4.3 | Present Worth (PW) Analysis

*Dr. Hamza Mohammad Alkuime*

1

### **Basic elements of transportation planning**

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The transportation planning process comprises seven basic elements:

1. *Situation definition*
2. *Problem definition*
3. *Search for solutions*
4. *Analysis of performance*
5. **Evaluation of alternatives**
6. *Choice of project*
7. *Specification and construction*

2

2

## Evaluation and Selection of Economic Proposal

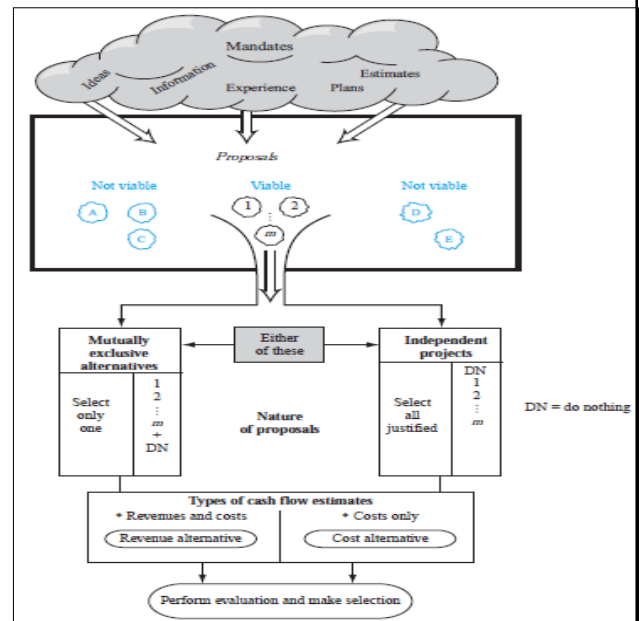
❑ The **evaluation and selection** of **economic proposals** require

1. **Cash flow estimates** over a stated period of time
2. **Mathematical techniques** to calculate the **measure of worth**
3. A **guideline** for selecting **the best proposal**

3

## Nature of Economic Proposals

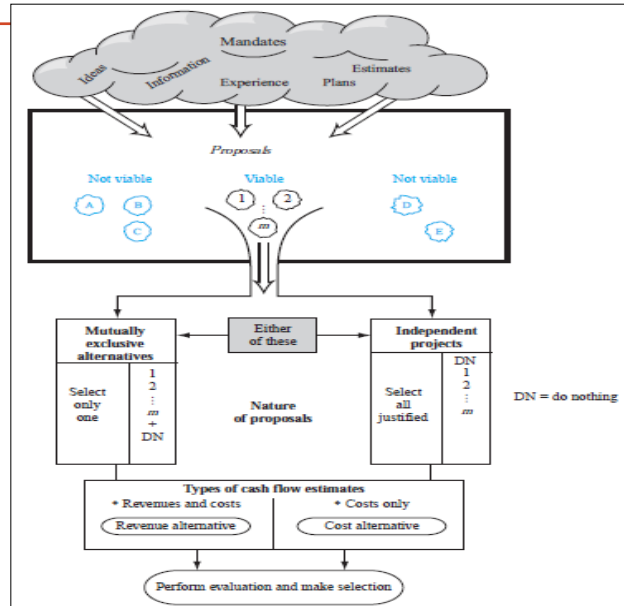
- **Proposals originate** from ideas, experience, estimates, and plans
- After screening, only **viable proposals** are considered for evaluation
- Two types of viable proposals:
  - **Mutually Exclusive Alternatives**
  - **Independent Projects**
  - **Do nothing**



4

## Do-Nothing (DN) Proposal

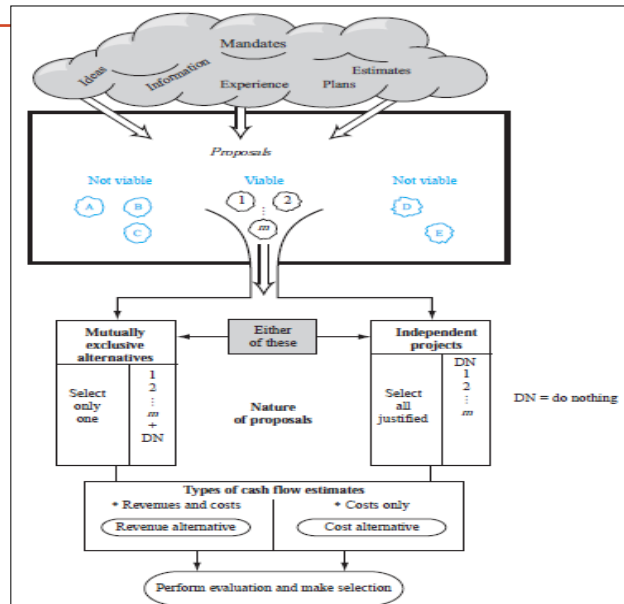
- ❑ Represents the **current approach**
- ❑ **No new costs, revenues, or savings**
- ❑ **Included** in **all economic analyses**
- ❑ Serves as the **baseline for comparison**
- ❑ **Key role of DN:**
- ❑ Answers: *Is doing something better than doing nothing?*
- ❑ **PW value:**
  - $PW_{DN} = 0$



5

## Independent Projects

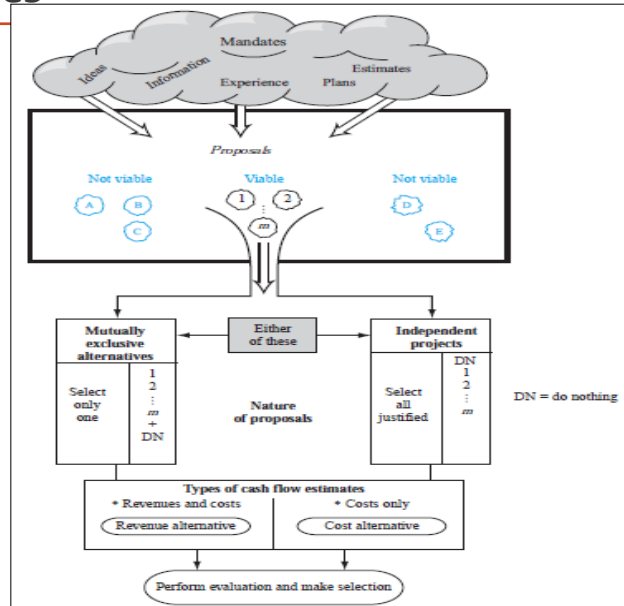
- ❑ **Multiple projects** may be selected
- ❑ Each viable proposal is called a **project**
- ❑ Projects do **not compete** with each other
- ❑ Evaluated **individually**, each against **Do-Nothing (DN)**
- ❑ **Typical examples:**
  - Several road maintenance projects
  - Independent intersection improvements
- ❑ **Decision rule (PW):**
  - Accept **all projects** with  $PW \geq 0$



6

## Mutually Exclusive Alternatives

- ❑ **Only one alternative** can be selected
- ❑ Each viable proposal is called an **alternative**
- ❑ Selection of one **eliminates all others**
- ❑ Compared **pairwise** and against the **Do-Nothing (DN)** alternative
- ❑ **Typical examples:**
  - Electric or Gas or Solar vehicle
  - One pavement design or one bridge alignment
- ❑ **Decision rule (PW):**
- ❑ Select the alternative with the **best PW** (highest PW or lowest PW of cost)



7

## Revenue in Transportation Projects

- ❑ Projects that **generate direct income** in addition to costs
- ❑ Evaluation considers **both revenues and costs**
- ❑ Objective: **maximize economic benefit**
- ❑ **Common transportation examples:**
  - Toll roads and express lanes
  - Paid parking facilities
  - Public transit systems with fare revenue

8

## Cost Alternatives in Transportation Projects

---

- ❑ Projects that **do not generate direct revenue**
- ❑ Only **costs** are considered in evaluation
- ❑ Objective: **minimize total cost while meeting service needs**
- ❑ **Common transportation examples:**
  - Road maintenance and rehabilitation
  - Traffic signal installation
  - Pavement management equipment

9

## Commonly used economic analysis methods are:

- **Present Worth (PW) Analysis:** Converts all cash flows to a single present value
- **Annual Worth Analysis:** Compares alternatives based on equivalent annual value
- **Benefit/Cost (B/C) Analysis:** Ratio of total benefits to total costs
- **Rate of Return (ROR) Analysis:** Finds interest rate at which net present worth is zero
- Used to **compare alternatives** and select **financially sound proposals**

10

# Present Worth (PW) Analysis

11

## Present Worth (PW) Analysis – Concept

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- PW analysis expresses all **cash flows** as an **equivalent single amount** at **present time**
- Commonly used for **public sector and infrastructure** projects
- Approaches
  - A. Present Worth (PW) Analysis of Equal-Life Alternatives
  - B. Present Worth Analysis of Different-Life Alternatives
  - C. Capitalized Cost Analysis

12

## Present Worth (PW) – Decision Criteria

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- For project
  - If **PW** > **0** → the project is **economically viable**
  - If **PW** = **0** → the project **breaks even**
  - If **PW** < **0** → the project is **not acceptable**
- For **multiple alternatives**:
  - Choose the **highest positive PW** (revenue alternatives)
  - Choose the **lowest PW of cost** (cost-only alternatives)

13

## Present Worth (PW) Analysis

### A. Present Worth (PW) Analysis of Equal-Life Alternatives

14

## PW Analysis of Equal-Life Alternatives

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- Used when **all alternatives have the same service life**
- Compares total **Present Worth (PW)** of cash flows for each alternative
- Types of alternatives:
  - **Cost alternatives** → choose option with **lowest PW of cost**
  - **Revenue alternatives** → choose option with **highest net PW**
- The **Do Nothing (DN)** alternative is also included in comparisons

15

Which alternative would you select ?

---

=

$PW_A$	$PW_B$
\$-2300	\$-1500
-500	+1000
+2500	+2000
+4800	-400

16

## Solution

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$PW_A$	$PW_B$	Selected Alternative
\$-2300	\$-1500	B
-500	+1000	B
+2500	+2000	A
+4800	-400	A

17

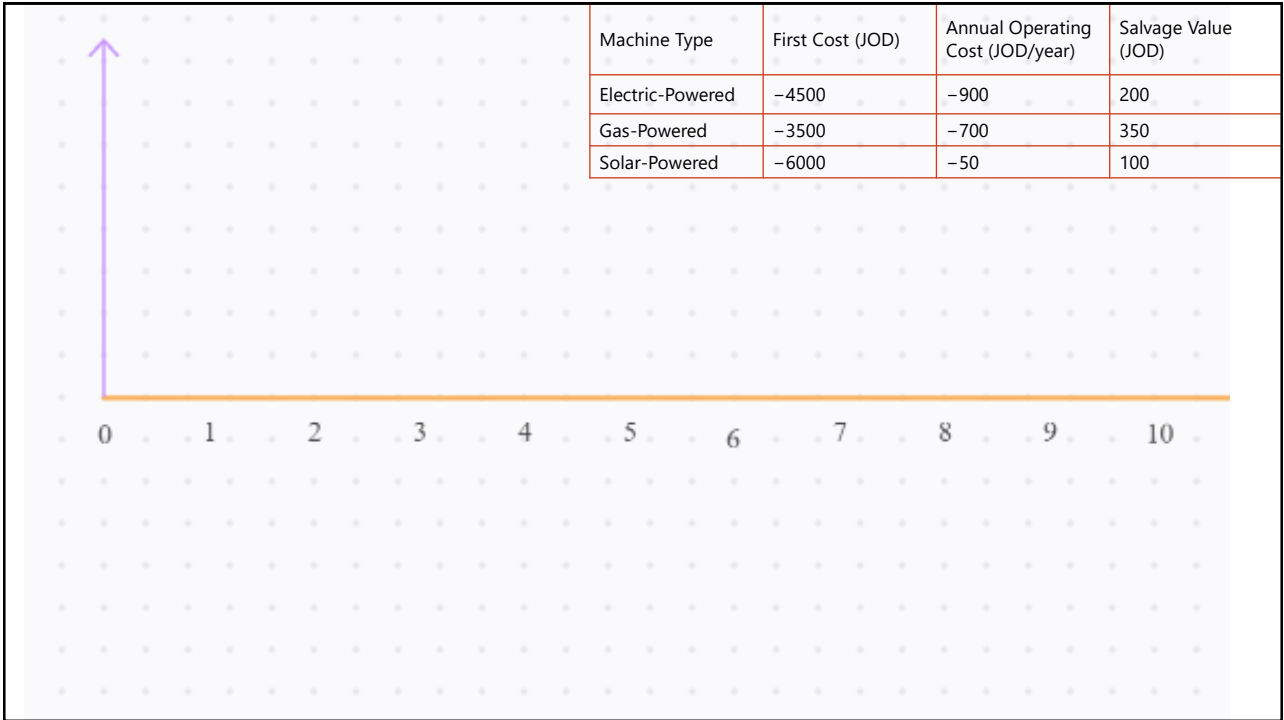
## Example

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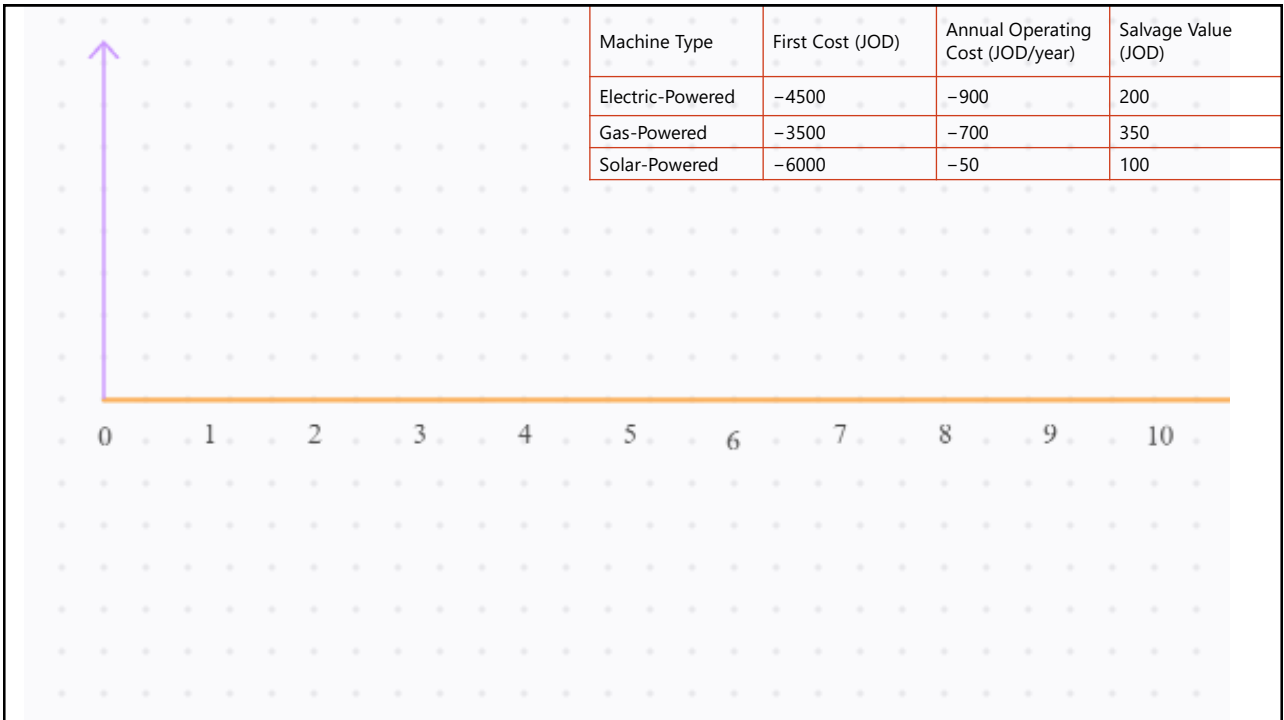
- ❑ A transportation authority is evaluating three equipment options to support **pavement condition monitoring** for the next **8 years**.
- ❑ The options include an **Electric-powered**, **Gas-powered**, and **Solar-powered** field data acquisition vehicle. Each machine has different first cost, annual operating cost, and expected salvage value.
- ❑ The authority uses a **Minimum Attractive Rate of Return (MARR)** of **10% per year**.
- ❑ Determine the most economical alternative using **Present Worth (PW) analysis**.

Machine Type	First Cost (JOD)	Annual Operating Cost (JOD/year)	Salvage Value (JOD)	Life (years)
Electric-Powered	-4500	-900	200	8
Gas-Powered	-3500	-700	350	8
Solar-Powered	-6000	-50	100	8

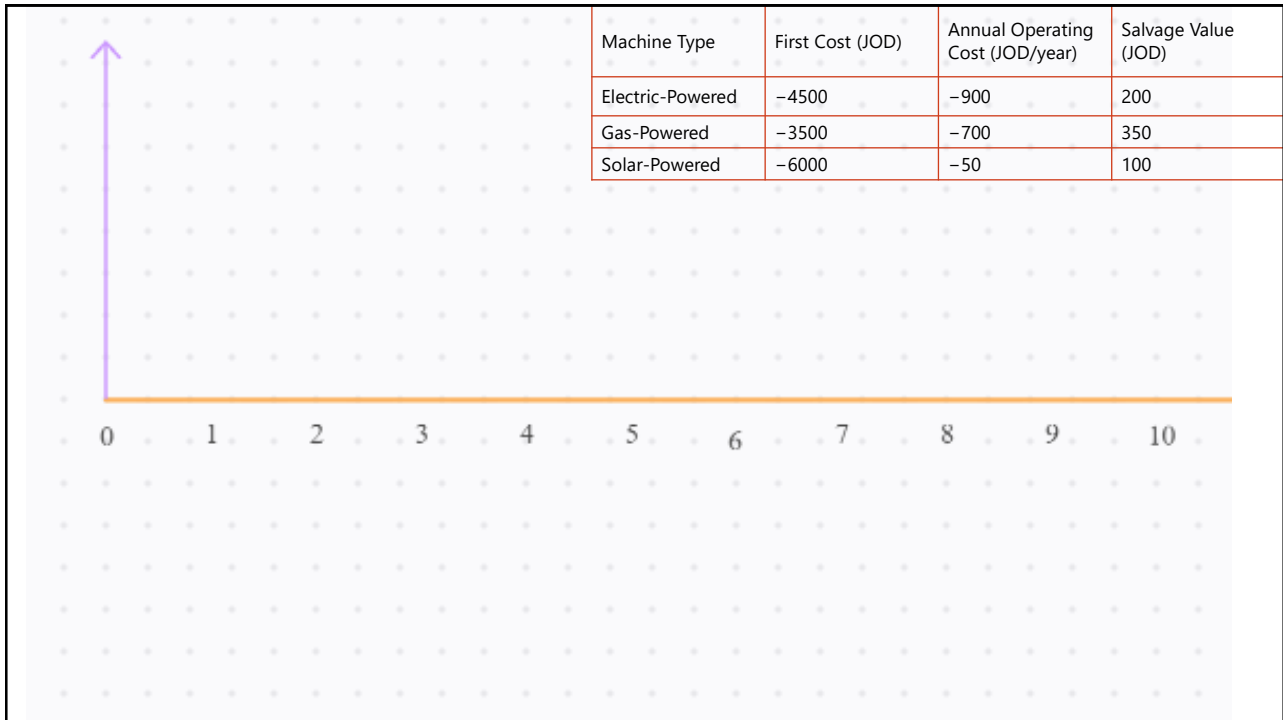
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21



22

**10%** **TABLE 15** Discrete Cash Flow: Compound Interest Factors

$n$	Single Payments		Uniform Series Payments			
	Compound Amount $F/P$	Present Worth $P/F$	Sinking Fund $A/F$	Compound Amount $F/A$	Capital Recovery $A/P$	Present Worth $P/A$
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908
6	1.7716	0.5645	0.12961	7.7156	0.22961	4.3553
7	1.9487	0.5132	0.10541	9.4872	0.20541	4.8684
8	2.1436	0.4665	0.08744	11.4359	0.18744	5.3349
9	2.3579	0.4241	0.07364	13.5795	0.17364	5.7590
10	2.5937	0.3855	0.06275	15.9374	0.16275	6.1446

23

## Step 1 – Use Present Worth (PW) Formula

---

- For cost alternatives:  

$$\text{PW} = \text{First Cost} + (\text{AOC} \times \text{P/A, } i\%, n) + (\text{Salvage} \times \text{P/F, } i\%, n)$$
- Use interest factors at  $i = 10\%$ ,  $n = 8$  years:
  - $(\text{P/A, } 10\%, 8) = 5.3349$
  - $(\text{P/F, } 10\%, 8) = 0.4665$

24

## Step 2 – Calculate PW for Each Alternative

---

### electric-Powered Vehicle:

$$\begin{aligned} \text{PW}_E &= -4500 - (900 \times 5.3349) + (200 \times 0.4665) \\ \text{PW}_E &= -4500 - 4801.41 + 93.30 = \mathbf{-9208 \text{ JOD}} \end{aligned}$$

### Gas-Powered Vehicle:

$$\begin{aligned} \text{PW}_G &= -3500 - (700 \times 5.3349) + (350 \times 0.4665) \\ \text{PW}_G &= -3500 - 3734.43 + 163.28 = \mathbf{-7071 \text{ JOD}} \end{aligned}$$

### ☐ Solar-Powered Vehicle:

$$\begin{aligned} \text{PW}_S &= -6000 - (50 \times 5.3349) + (100 \times 0.4665) \\ \text{PW}_S &= -6000 - 266.75 + 46.65 = \mathbf{-6220 \text{ JOD}} \end{aligned}$$

25

### Step 3 – Decision and Recommendation

---

- All options are **cost alternatives**, so we choose the one with the **lowest present cost**
- Present Worth results:
  - PW\_Electric = -9208 JOD
  - PW\_Gas = -7071 JOD
  - PW\_Solar = -**6220 JOD**

26

## B. Present Worth Analysis of Different-Life Alternatives

27

## B. Present Worth Analysis of Different-Life Alternatives

- Applied when **alternatives have unequal service lives**
- Objective: compare alternatives using **Present Worth (PW)** over a **common analysis period**
- Two common approaches:
  - **Least Common Multiple (LCM) Method:**
  - **Study Period or Co-Terminated Method:**

	Vendor A	Vendor B
First cost, \$	-15,000	-18,000
Annual M&O cost, \$ per year	-3,500	-3,100
Salvage value, \$	1,000	2,000
Life, years	6	9

28

## B. Present Worth Analysis of Different-Life Alternatives

Least common multiple (LCM) approach

30

## LCM Approach – PW Analysis of Different-Life Alternatives

- Used when alternatives have **unequal lives** and are **mutually exclusive**
- Establish a **common evaluation period** for fair comparison
- Choose the **Least Common Multiple (LCM)** of the alternatives' lives
- **Repeat alternatives** as needed to cover the LCM period
- Assume **replacements** with **same cost, performance, and salvage**

	Vendor A	Vendor B
First cost, \$	-15,000	-18,000
Annual M&O cost, \$ per year	-3,500	-3,100
Salvage value, \$	1,000	2,000
Life, years	6	9

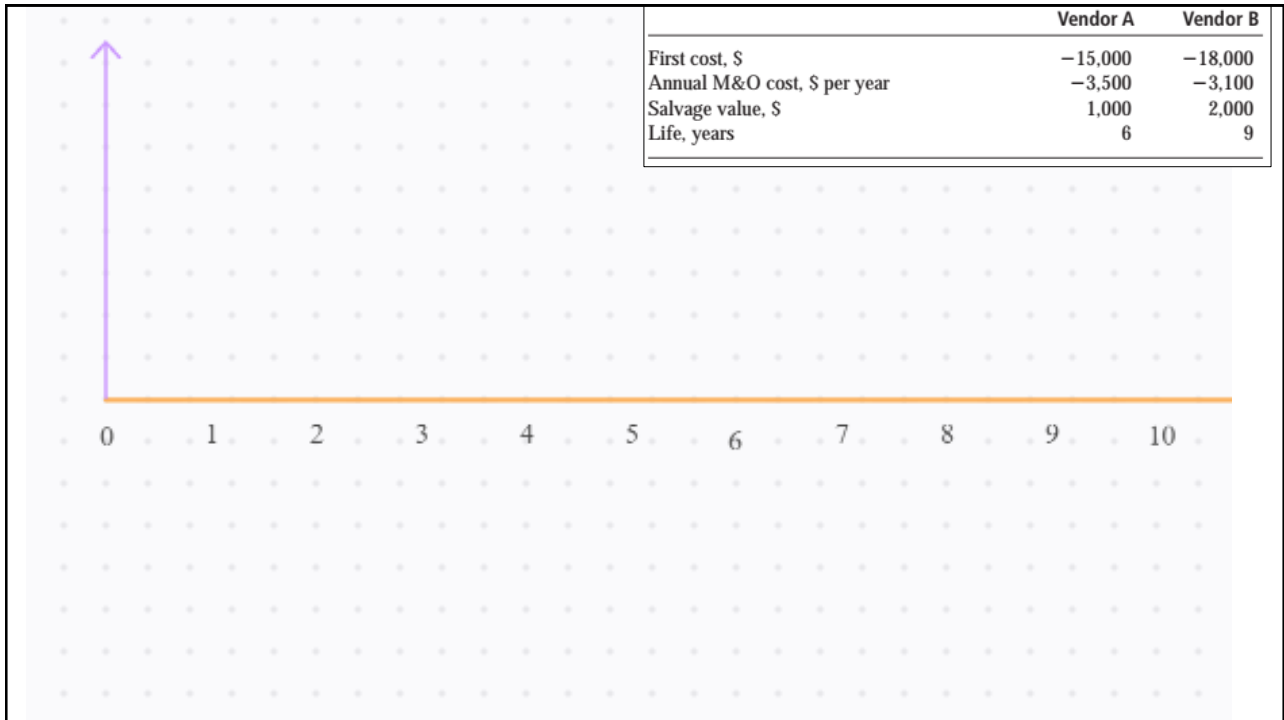
31

## Example | 3.3.1

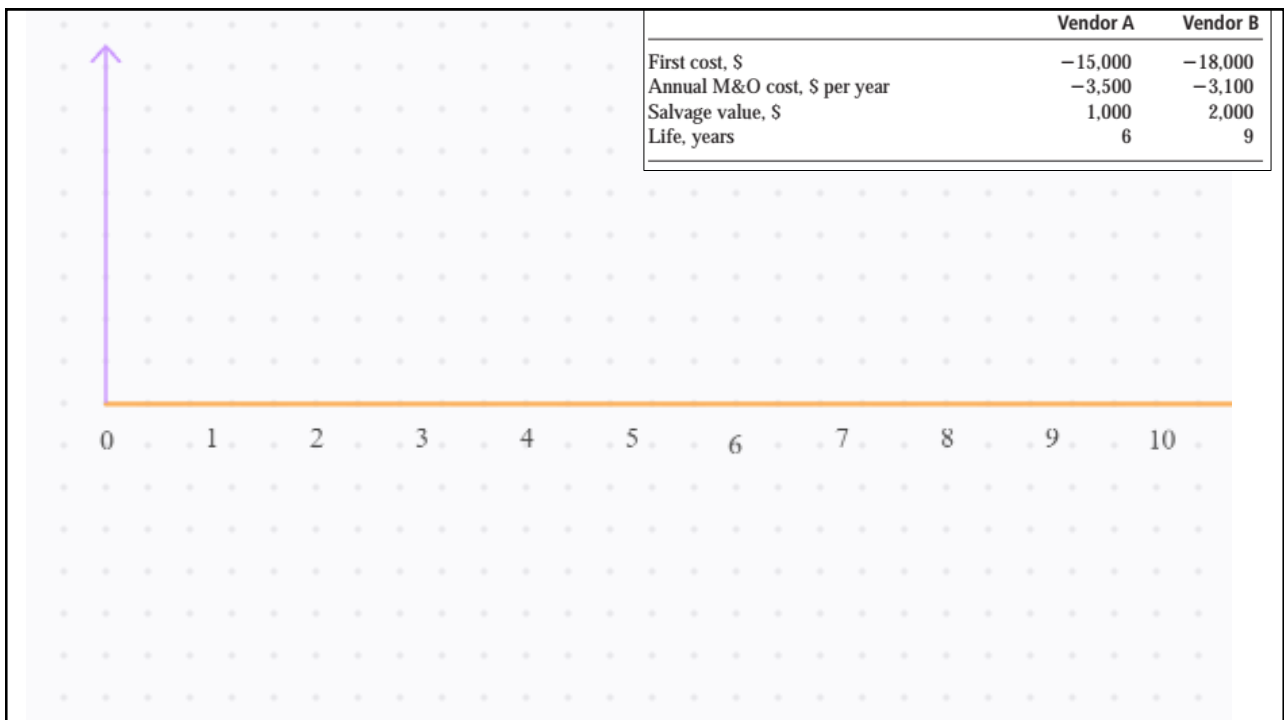
- ❑ A public transportation agency is evaluating two equipment procurement options for automated ticketing systems offered by **Vendor A** and **Vendor B**.
- ❑ These systems have **different service lives** and associated **installation and maintenance costs**.
- ❑ The agency uses a rate of return **of 15% per year**.
- ❑ Determine which offers the **most economical option** in each case, based on **JOD** costs.
- ❑ Compare the vendors using **Present Worth (PW)** based on their full life spans,

	Vendor A	Vendor B
First cost, \$	-15,000	-18,000
Annual M&O cost, \$ per year	-3,500	-3,100
Salvage value, \$	1,000	2,000
Life, years	6	9

32



33



34

## Example

- LCM of 6 years (Vendor A) and 9 years (Vendor B) = 18 years
- To ensure a fair comparison, **repeat each alternative over 18 years**

15% TABLE 19 Discrete Cash Flow: Compound Interest Factor

n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.1500	0.8696	1.00000	1.0000	1.15000	0.8696
2	1.3225	0.7561	0.46512	2.1500	0.61512	1.6257
3	1.5209	0.6575	0.28798	3.4725	0.43798	2.2832
4	1.7490	0.5718	0.20027	4.9934	0.35027	2.8550
5	2.0114	0.4972	0.14832	6.7424	0.29832	3.3522
6	2.3131	0.4323	0.11424	8.7537	0.26424	3.7845
7	2.6600	0.3759	0.09036	11.0668	0.24036	4.1604
8	3.0590	0.3269	0.07285	13.7268	0.22285	4.4873
9	3.5179	0.2843	0.05957	16.7858	0.20957	4.7716
10	4.0456	0.2472	0.04925	20.3037	0.19925	5.0188
11	4.6524	0.2149	0.04107	24.3493	0.19107	5.2337
12	5.3503	0.1869	0.03448	29.0017	0.18448	5.4206
13	6.1528	0.1625	0.02911	34.3519	0.17911	5.5831
14	7.0757	0.1413	0.02469	40.5047	0.17469	5.7245
15	8.1371	0.1229	0.02102	47.5804	0.17102	5.8474
16	9.3576	0.1069	0.01795	55.7175	0.16795	5.9542
17	10.7613	0.0929	0.01537	65.0751	0.16537	6.0472
18	12.3755	0.0808	0.01319	75.8364	0.16319	6.1280

35

## Solution

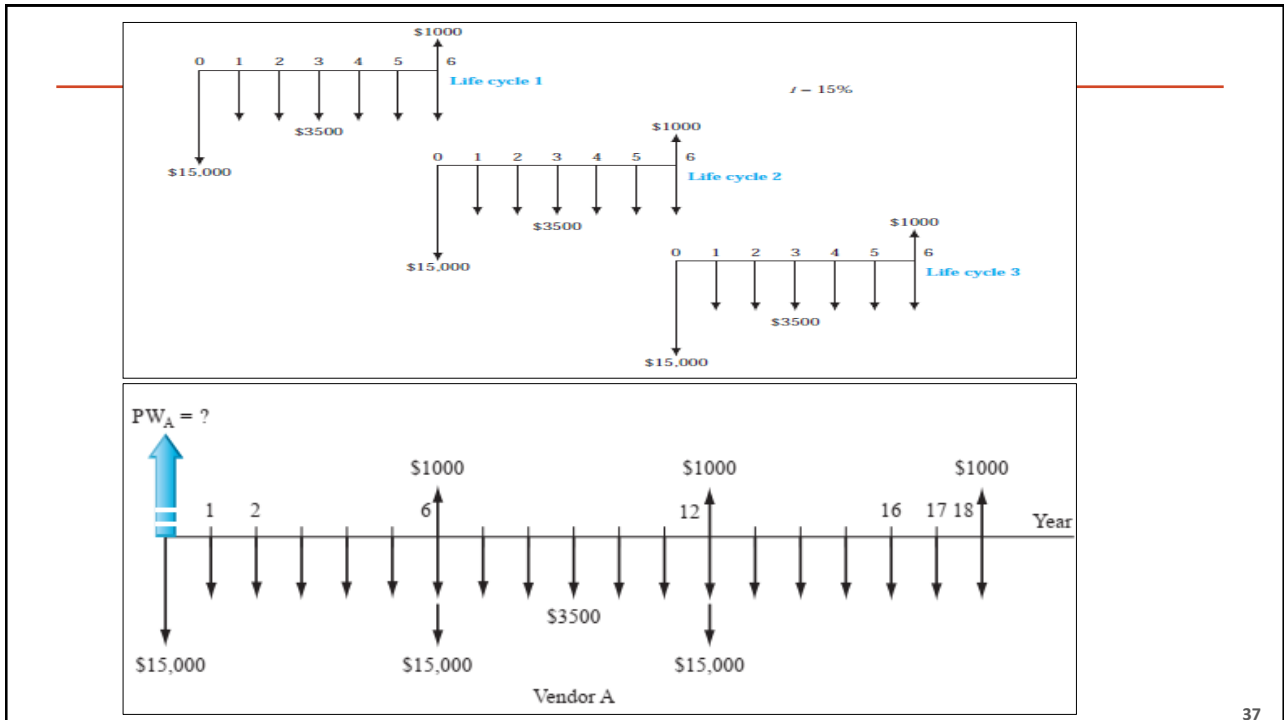
### Vendor A (6-year life):

- Replaced at years 0, 6, and 12
- Each replacement includes:
  - First cost
  - Annual M&O costs over 6 years
  - Salvage value at the end of each 6-year cycle

### Vendor B (9-year life):

- Replaced at years 0 and 9
- Each replacement includes:
  - First cost
  - Annual M&O costs over 9 years
  - Salvage value at the end of each 9-year cycle

36

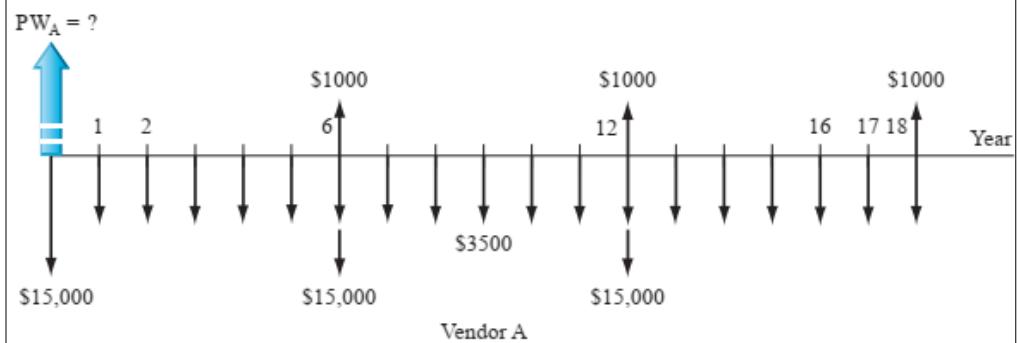


37

37

## Vendor A

$$\begin{aligned}
 PW_A &= -15,000 - 15,000(P/F, 15\%, 6) + 1000(P/F, 15\%, 6) \\
 &\quad - 15,000(P/F, 15\%, 12) + 1000(P/F, 15\%, 12) + 1000(P/F, 15\%, 18) \\
 &\quad - 3,500(P/A, 15\%, 18) \\
 &= \$-45,036
 \end{aligned}$$

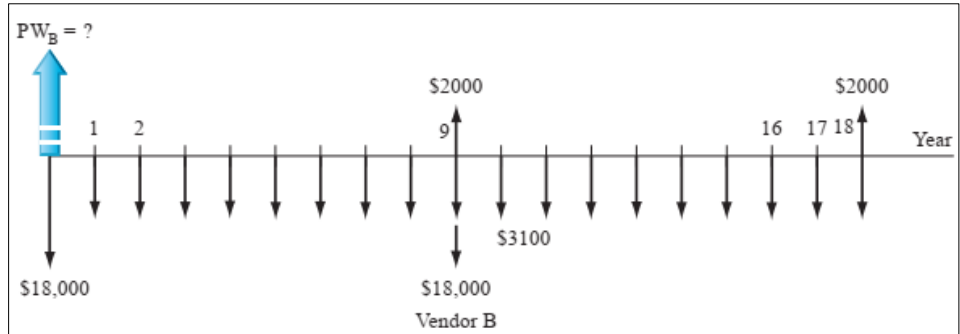


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38

## Vendor B

$$\begin{aligned} PW_B &= -18,000 - 18,000(P/F,15\%,9) + 2000(P/F,15\%,9) \\ &\quad + 2000(P/F,15\%,18) - 3100(P/A,15\%,18) \\ &= \$-41,384 \end{aligned}$$



39

39

## Solution

$$\begin{aligned} PW_A &= -15,000 - 15,000(P/F,15\%,6) + 1000(P/F,15\%,6) \\ &\quad - 15,000(P/F,15\%,12) + 1000(P/F,15\%,12) + 1000(P/F,15\%,18) \\ &\quad - 3,500(P/A,15\%,18) \\ &= \$-45,036 \end{aligned}$$

$$\begin{aligned} PW_B &= -18,000 - 18,000(P/F,15\%,9) + 2000(P/F,15\%,9) \\ &\quad + 2000(P/F,15\%,18) - 3100(P/A,15\%,18) \\ &= \$-41,384 \end{aligned}$$

Vendor B is selected

since it costs less in PW terms; that is, the  $PW_B$  value is numerically larger than  $PW_A$

40

40

## B. Present Worth Analysis of Different-Life Alternatives

### Study Period

41

#### Study Period Approach (PW Analysis)

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- A **specific time horizon (study period)** is selected for economic evaluation
- Only cash flows occurring within the study period** are considered in the analysis
- Cash flows **beyond the study period are ignored**
- An **estimated market (salvage) value** is required at the end of the study period
- Commonly used when:
  - Alternatives have **different service lives**
  - **Short-term planning goals** are important
  - Long-term forecasts are **uncertain**
- Important Note:**
- Changing the study period **may change the economic decision**

42

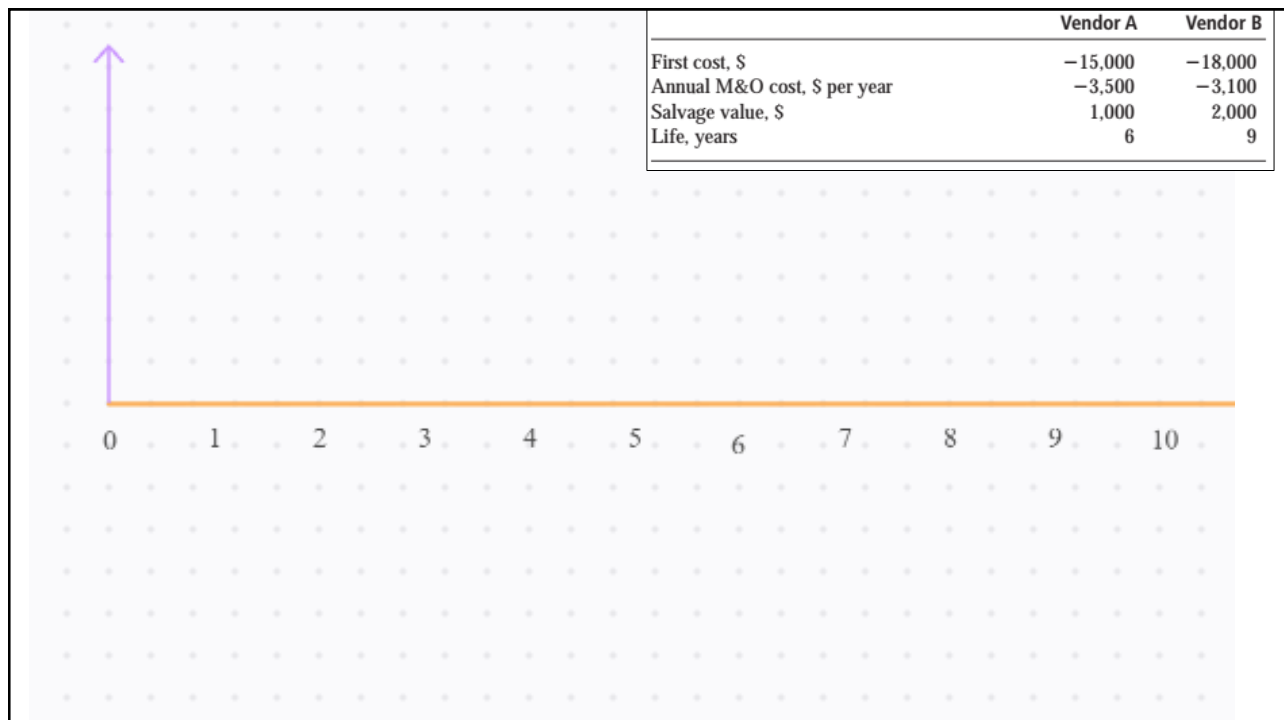
42

## Example|3.3.2

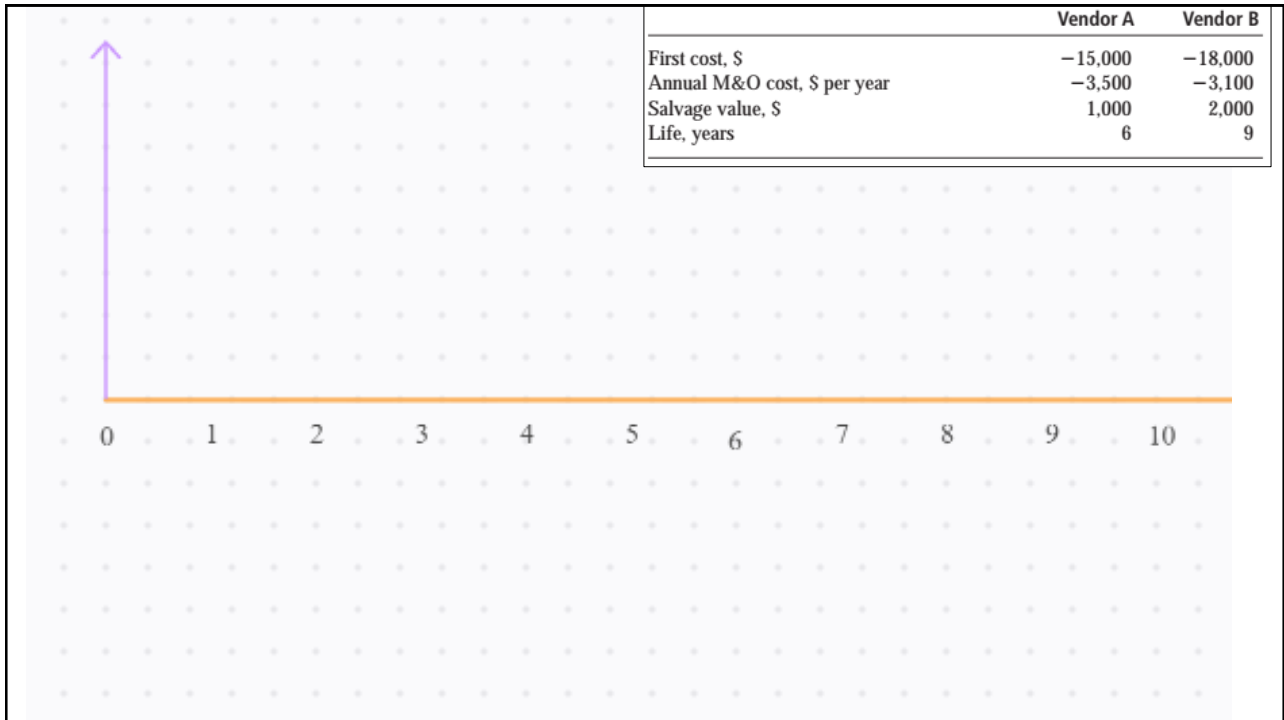
- ❑ A public transportation agency is evaluating two equipment procurement options for automated ticketing systems offered by **Vendor A** and **Vendor B**.
- ❑ These systems have **different service lives** and associated **installation and maintenance costs**.
- ❑ The agency uses a rate of return of **15% per year**.
- ❑ Compare the vendors using **Present Worth (PW)** based on study period of 5 years

	Vendor A	Vendor B
First cost, \$	-15,000	-18,000
Annual M&O cost, \$ per year	-3,500	-3,100
Salvage value, \$	1,000	2,000
Life, years	6	9

43

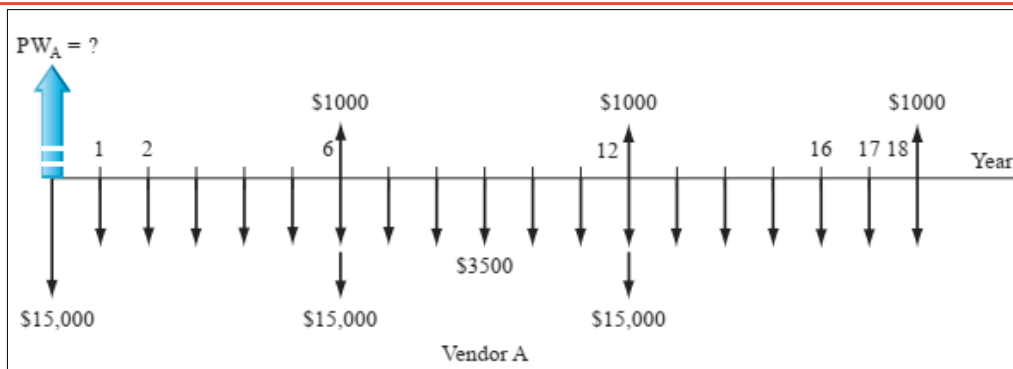


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## Vendor A

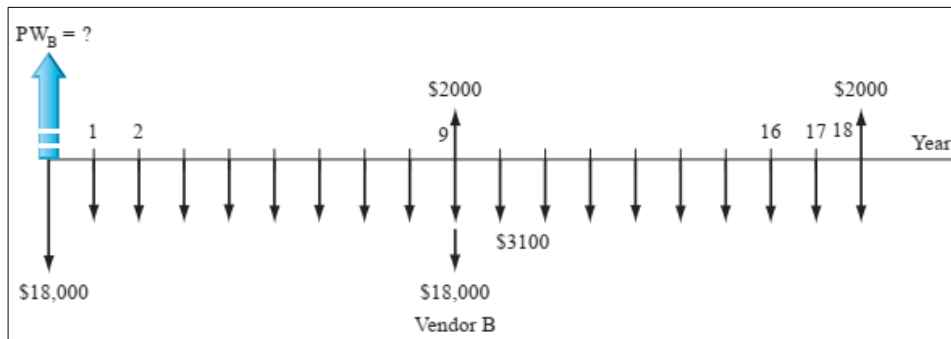


$$\begin{aligned}
 PW_A &= -15,000 - 3500(P/A, 15\%, 5) + 1000(P/F, 15\%, 5) \\
 &= \$-26,236
 \end{aligned}$$

46

46

## Vendor B



$$\begin{aligned} PW_B &= -18,000 - 3100(P/A,15\%,5) + 2000(P/F,15\%,5) \\ &= \$-27,397 \end{aligned}$$

47

47

(b) For a 5-year study period, no cycle repeats are necessary. The PW analysis is

$$\begin{aligned} PW_A &= -15,000 - 3500(P/A,15\%,5) + 1000(P/F,15\%,5) \\ &= \$-26,236 \end{aligned}$$

$$\begin{aligned} PW_B &= -18,000 - 3100(P/A,15\%,5) + 2000(P/F,15\%,5) \\ &= \$-27,397 \end{aligned}$$

- ↪ Study period of 5 years has caused a switch in the economic decision.
- ↪ In situations such as this, the standard practice of using a fixed study period should be carefully examined to ensure that the appropriate approach,

48

48

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## Present Worth (PW) Analysis

### *C. Capitalized Cost Analysis*

49

49

### Capitalized Cost Analysis

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- ❑ Represents the **present worth of a project** with a **very long or infinite life**
- ❑ Applied when:
  - Project life is **very long** (typically > **35–40 years**)
  - The **planning horizon** is considered **very long or infinite**
- ❑ Assumes the number of periods:  $n \rightarrow \infty$
- ❑ **Typical applications:**
  - Highways, bridges, tunnels
  - Public infrastructure and facilities
  - Assets requiring **continuous operation and maintenance**
- ❑ **Key Idea:**
  - Capitalized cost is the **single present value** equivalent of **all future costs forever**

50

## Capitalized Cost Explanation

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- The **present worth formula** for a uniform series is:

$$P = A \left[ \frac{1 - \frac{1}{(1+i)^n}}{i} \right]$$

- When the project life is **infinite** ( $n \rightarrow \infty$ ):
  - $(1+i)^{-n} \rightarrow 0$ , so the formula simplifies to:

$$P = \frac{A}{i}$$

- This means:

$$CC = \frac{A}{i} = PW$$

- Therefore, **Capitalized Cost (CC)** is simply the **present worth of a perpetual series** of equal annual cash flows

51

## Capitalized Cost Formula

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- The basic formula is:

$$CC = \frac{A}{i} \quad \text{or} \quad CC = \frac{AW}{i}$$

Where:

- A** = Uniform annual amount
- AW** = Annual Worth
- i** = Interest rate

52

## Types of Cash Flows

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□ The cash flows in a capitalized cost **calculation** are usually of **three types**:

- **Recurring ( R cash flows)**

- Repeat at set intervals (e.g., maintenance every few years)
- A rework cost estimated at \$40,000 every 12 years

- **Nonrecurring (P, F cash flows)**

- One-time costs at specific points in time
- Examples: Initial investment in Year 0, \$500,000 fee in Year 2

- **Annual (A)**

- Uniform costs or revenues every year
- Example: 10,000 /year

53

53

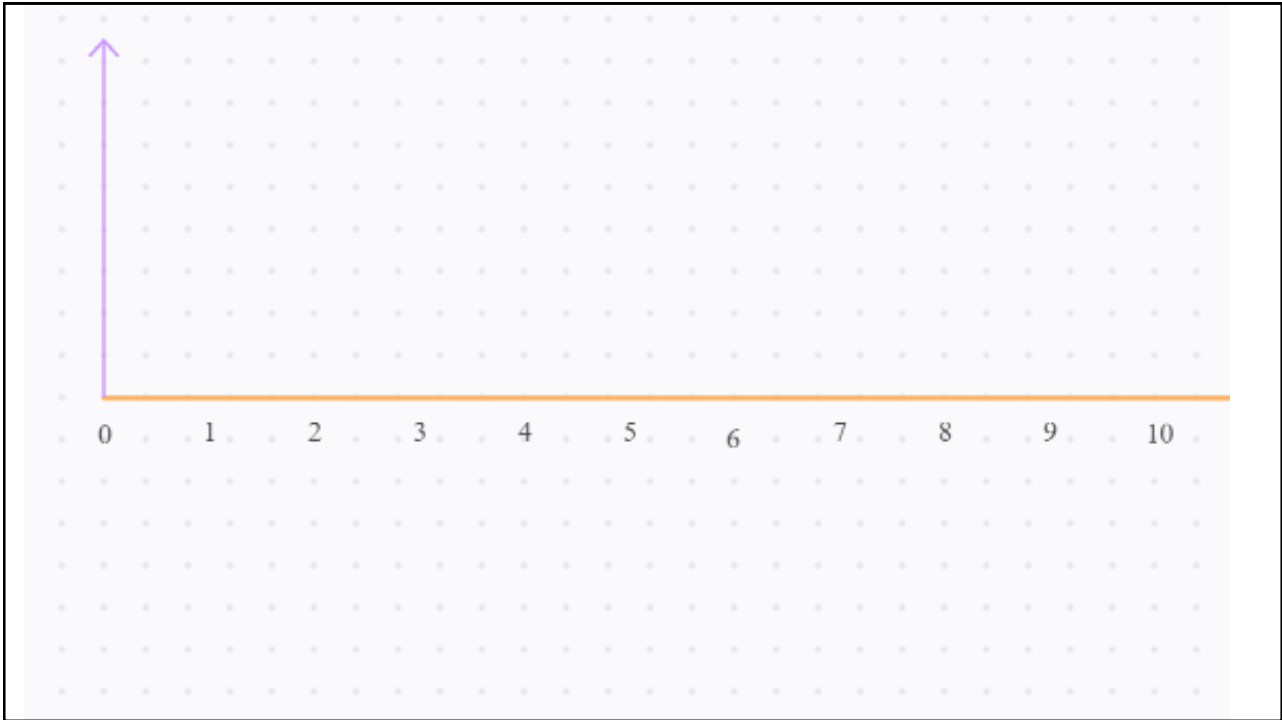
## Example | 3.3.3

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- ↻ The cost of grading and spreading gravel on a short rural road is expected to be \$300,000.
- ↻ The road will have to be maintained at a cost of \$25,000 per year.
- ↻ In addition, the road will have a recurring maintenance cost of \$50,000 every 5 years.
- ↻ Calculate the CC value using an interest rate of 5% per year

58

58



59

## Solution

**Given:**

- Initial construction cost = \$300,000 → **Nonrecurring**
- Annual maintenance cost = \$25,000/year → **Annual**
- Recurring cost = \$50,000 every 5 years → **Periodic recurring**
- Interest rate  $i = 5\%$

5% TABLE 10 Discrete Cash Flow: Compound Interest F						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0500	0.9524	1.00000	1.0000	1.05000	0.9524
2	1.1025	0.9070	0.48780	2.0500	0.53780	1.8594
3	1.1576	0.8638	0.31721	3.1525	0.36721	2.7232
4	1.2155	0.8227	0.23201	4.3101	0.28201	3.5460
5	1.2763	0.7835	0.18097	5.5256	0.23097	4.3295
6	1.3401	0.7462	0.14702	6.8019	0.19702	5.0757
7	1.4071	0.7107	0.12282	8.1420	0.17282	5.7864
8	1.4775	0.6768	0.10472	9.5491	0.15472	6.4632
9	1.5513	0.6446	0.09069	11.0266	0.14069	7.1078
10	1.6289	0.6139	0.07950	12.5779	0.12950	7.7217
11	1.7103	0.5847	0.07039	14.2068	0.12039	8.3064
12	1.7959	0.5568	0.06283	15.9171	0.11283	8.8633
13	1.8856	0.5303	0.05646	17.7130	0.10646	9.3936
14	1.9799	0.5051	0.05102	19.5986	0.10102	9.8986
15	2.0789	0.4810	0.04634	21.5786	0.09634	10.3797
16	2.1829	0.4581	0.04227	23.6575	0.09227	10.8378
17	2.2920	0.4363	0.03870	25.8404	0.08870	11.2741
18	2.4066	0.4155	0.03555	28.1324	0.08555	11.6896
19	2.5270	0.3957	0.03275	30.5390	0.08275	12.0853
20	2.6533	0.3769	0.03024	33.0660	0.08024	12.4622
21	2.7860	0.3589	0.02800	35.7193	0.07800	12.8212
22	2.9253	0.3418	0.02597	38.5052	0.07597	13.1630
23	3.0715	0.3256	0.02414	41.4305	0.07414	13.4886
24	3.2251	0.3101	0.02247	44.5020	0.07247	13.7986
25	3.3864	0.2953	0.02095	47.7271	0.07095	14.0939
26	3.5557	0.2812	0.01956	51.1135	0.06956	14.3752

60

## Convert all costs to their capitalized cost values

---

### 1. Nonrecurring Cost (Initial Construction)

Since this occurs at **Year 0**, the capitalized cost is:

$$CC_1 = 300,000$$

### 2. Annual Maintenance Cost

Use the capitalized cost formula for uniform annual cost:

$$CC_2 = A/i = 25,000/0.05 = 500,000$$

61

### ■ 3. Recurring Maintenance Cost Every 5 Years

Convert periodic cost to **annual worth** first:

$$A = 50,000 \cdot (A/F, 5\%, 5)$$

Use the A/F factor:

$$(A/F, 5\%, 5) = \frac{i}{(1+i)^n - 1} = \frac{0.05}{(1.05)^5 - 1} = \frac{0.05}{0.27628} = 0.18196$$

$$A = 50,000 \cdot 0.18196 = 9,098$$

Now convert this **annual equivalent** to capitalized cost:

$$CC_3 = \frac{9,098}{0.05} = 181,960$$

62

## Total Capitalized Cost

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$$CC_{Total} = CC_1 + CC_2 + CC_3$$

$$CC_{Total} = 300,000 + 500,000 + 181,960 = \boxed{981,960}$$

63

## Example | 3.3.4

---

- ↪ A Transportation Authority has just installed new software to charge and track toll fees. The director wants to know the total equivalent cost of all future costs incurred to purchase the software system. If the new system will be used for the indefinite future, **find the equivalent cost: now, a CC value**
- ↪ The system has an **installed cost of \$150,000** and an **additional cost of \$50,000 after 10 years**.
- ↪ The **annual software maintenance** contract cost is **\$5000 for the first 4 years and \$8000 thereafter**.
- ↪ In addition, there is expected to be **a recurring major upgrade cost of \$15,000 every 13 years**.
- ↪ Assume that  **$i = 5\%$**  per year for county funds.

64

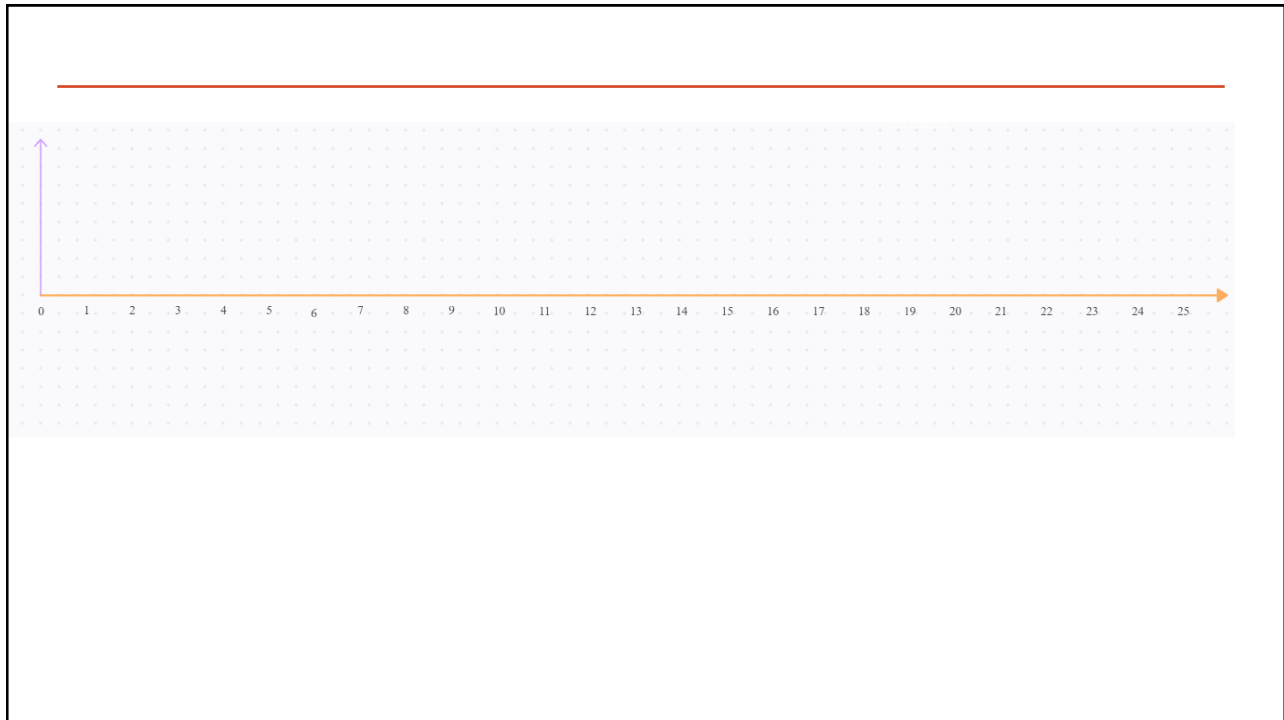
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5% TABLE 10 Discrete Cash Flow: Compound Interest Fa

n	Single Payments		Uniform Series Payments			
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10	1.6289	0.6139	0.07950	12.5779	0.12950	7.7217
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21	2.7860	0.3589	0.02800	35.7193	0.07800	12.8212
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23	3.0715	0.3256	0.02414	41.4305	0.07414	13.4886
24	3.2251	0.3101	0.02247	44.5020	0.07247	13.7986
25	3.3864	0.2953	0.02095	47.7271	0.07095	14.0939
26	3.5557	0.2812	0.01956	51.1135	0.06956	14.3752

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Identify and categorize all cash flows:

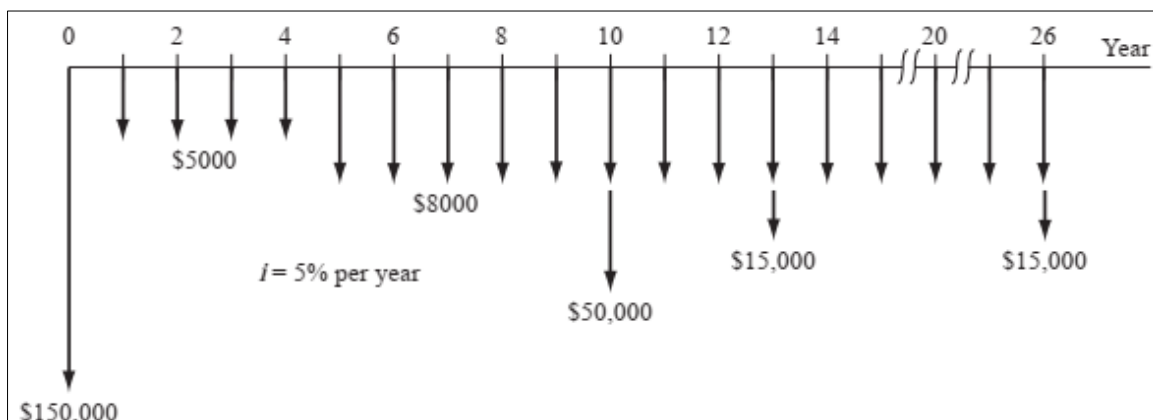
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- **Nonrecurring:**
  - -\$150,000 installed now (Year 0)
  - -\$50,000 after 10 years
- **Recurring (Periodic):**
  - -\$15,000 every 13 years (upgrade)
- **Annual:**
  - -\$5,000/year for first 4 years, then -\$8,000/year forever

67

**Draw Cash Flow Diagram**

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68

## Solution

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1. Draw a cash flow diagram for two cycles (Figure 5–5).
2. Find the present worth of the nonrecurring costs of \$150,000 now and \$50,000 in year 10 at  $i = 5\%$ . Label this  $CC_1$ .

$$CC_1 = -150,000 - 50,000(P/F,5\%,10) = \$-180,695$$

69

## Solution

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- 3 and 4.** Convert the \$15,000 recurring cost to an  $A$  value over the first cycle of 13 years, and find the capitalized cost  $CC_2$  at 5% per year using Equation [5.1].

$$A = -15,000(A/F,5\%,13) = \$-847$$

$$CC_2 = -847/0.05 = \$-16,940$$

There are several ways to convert the annual software maintenance cost series to  $A$  and  $CC$  values. A straightforward method is to, first, consider the \$-5000 an  $A$  series with a capitalized cost of

$$CC_3 = -5000/0.05 = \$-100,000$$

Second, convert the step-up maintenance cost series of \$-3000 to a capitalized cost  $CC_4$  in year 4, and find the present worth in year 0. (Refer to Figure 5–5 for cash flow timings.)

$$CC_4 = \frac{-3,000}{0.05} (P/F,5\%,4) = \$-49,362$$

70

## C. Capitalized Cost Analysis

*Example –Solution (Part a)*

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5. The total capitalized cost  $CC_T$  for Haverly County Transportation Authority is the sum of the four component CC values.

$$\begin{aligned}CC_T &= -180,695 - 16,940 - 100,000 - 49,362 \\ &= \$-346,997\end{aligned}$$

71

# *Transportation Engineering and Planning*

Module | 4 | Engineering Economics with  
Transportation Applications

## 4.4 | Annual Worth Analysis (AW)

*Dr. Hamza Mohammad Alkuime*

1

### What is Annual Worth (AW)?

---

- **AW** is the **equivalent uniform annual worth** of all expected **receipts and disbursements** throughout the project or alternative's life cycle.
- ❑  $AW = PW \times (A/P, i, n) = FW \times (A/F, i, n)$
- ❑ Converts Present or Future worth into an **annual equivalent value**.

2

## What is Annual Worth (AW)?

---

- ❑ **Annual Worth (AW)** is the **equivalent uniform annual value** of all expected **receipts and disbursements** over the life of a project or alternative
- ❑ Expresses the entire project in terms of a **constant annual amount**
- ❑ Useful for comparing alternatives based on **year-by-year performance**
- ❑ AW Relationships
  - $AW = PW(A/P, i, n)$
  - $AW = FW(A/F, i, n)$
- ❑ Converts **Present Worth (PW)** or **Future Worth (FW)** into an **annual equivalent value**
- ❑ **Key Takeaway:**
  - Annual Worth answers the question: *"What is this project worth per year?"*

3

## Annual Worth (AW) – Decision Criteria

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- ❑ **Projects**
  - **AW > 0** → Project is **economically acceptable**
  - **AW = 0** → Project **breaks even**
  - **AW < 0** → Project is **not acceptable**
- ❑ **For multiple alternatives:**
  - **Revenue alternatives** → choose the **highest AW**
  - **Cost alternatives** → choose the **lowest AW (annual cost)**

4

## Example 3.4.1

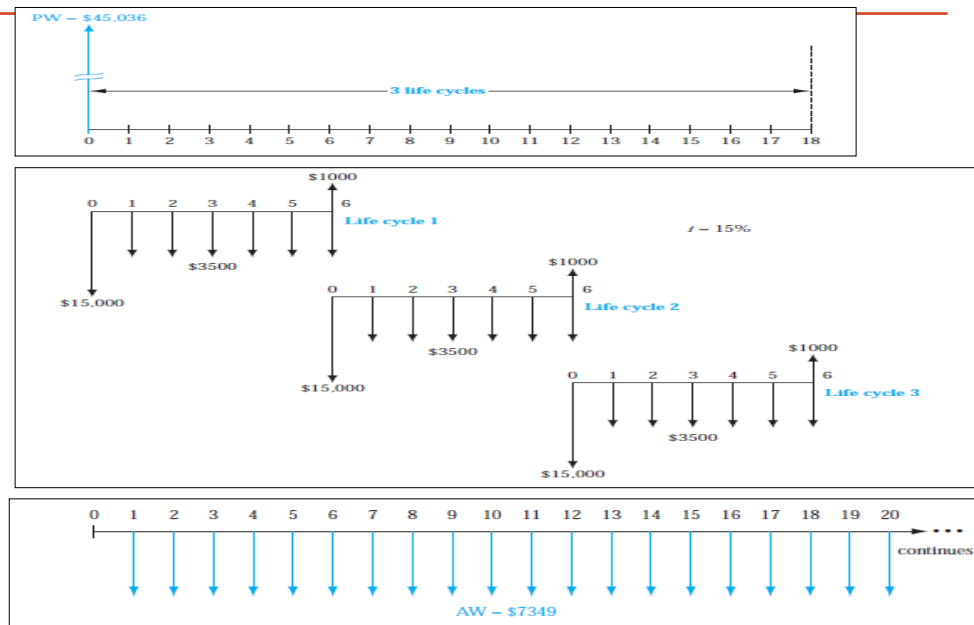
- Two manufacturers offered the estimates below.
- a. Determine which vendor should be selected on the basis of an Annual worth comparison, if the  $i$  is 15% per year.

	Vendor A	Vendor B
First cost, \$	-15,000	-18,000
Annual M&O cost, \$ per year	-3,500	-3,100
Salvage value, \$	1,000	2,000
Life, years	6	9

10

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## Solution



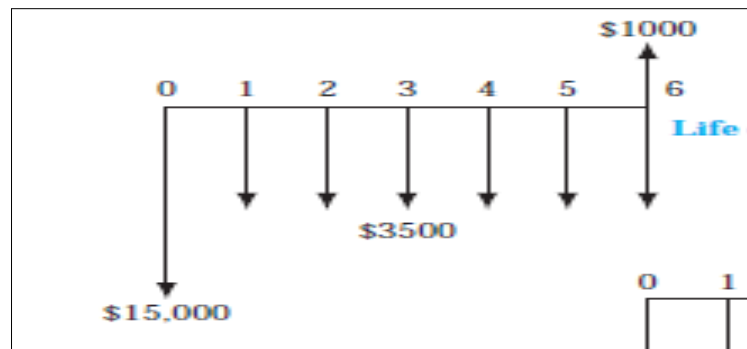
11

11

15% TABLE 19 Discrete Cash Flow: Compound Interest Factors						
n	Single Payments		Uniform Series Payments			
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.1500	0.8696	1.00000	1.0000	1.15000	0.8696
2	1.3225	0.7561	0.46512	2.1500	0.61512	1.6257
3	1.5209	0.6575	0.28798	3.4725	0.43798	2.2832
4	1.7490	0.5718	0.20027	4.9934	0.35027	2.8550
5	2.0114	0.4972	0.14832	6.7424	0.29832	3.3522
6	2.3131	0.4323	0.11424	8.7537	0.26424	3.7845
7	2.6600	0.3759	0.09036	11.0668	0.24036	4.1604
8	3.0590	0.3269	0.07285	13.7268	0.22285	4.4873
9	3.5179	0.2843	0.05957	16.7858	0.20957	4.7716
10	4.0456	0.2472	0.04925	20.3037	0.19925	5.0188
11	4.6524	0.2149	0.04107	24.3493	0.19107	5.2337
12	5.3503	0.1869	0.03448	29.0017	0.18448	5.4206
13	6.1528	0.1625	0.02911	34.3519	0.17911	5.5831
14	7.0757	0.1413	0.02469	40.5047	0.17469	5.7245
15	8.1371	0.1229	0.02102	47.5804	0.17102	5.8474
16	9.3576	0.1069	0.01795	55.7175	0.16795	5.9542
17	10.7613	0.0929	0.01537	65.0751	0.16537	6.0472
18	12.3755	0.0808	0.01319	75.8364	0.16319	6.1280

12

## Solution



### ◆ Vendor A (n = 6 years)

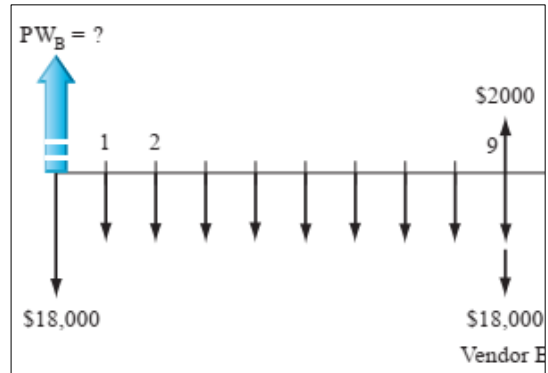
- $P = 15,000$ ,  $F = 1,000$ ,  $A = -3,500$
- $A/P(15\%, 6) = 0.2638$ ,  $A/F(15\%, 6) = 0.1055$

$$AW_A = -15,000(0.2638) + 1,000(0.1055) - 3,500$$

$$AW_A = -3,957 + 105.5 - 3,500 = -7,351.5$$

13

## Solution



### ◆ Vendor B (n = 9 years)

- $P = 18,000$ ,  $F = 2,000$ ,  $A = -3,100$
- $A/P(15\%, 9) = 0.2090$ ,  $A/F(15\%, 9) = 0.0690$

$$AW_B = -18,000(0.2090) + 2,000(0.0690) - 3,100$$

$$AW_B = -3,762 + 138 - 3,100 = -6,724$$

# *Transportation Engineering and Planning*

Module | 4 | Engineering Economics with  
Transportation Applications

## 4.5 | Benefit/Cost analysis

*Dr. Hamza Mohammad Alkuime*

1

### Salvage Value (S)

---

#### Salvage value

- is the **estimated remaining value of an asset** at the **end of the analysis period or service life**
- Represents the **amount recovered** from selling, reusing, or retaining the asset

#### Transportation Examples

- Remaining resale value of **maintenance equipment**
- Residual value of **vehicles, buses, or construction machinery**
- Reuse value of **steel, pavement materials, or structures**

2

## Costs

---

- ❑ Definition
  - **Costs** are the **estimated expenditures** to the government or agency for: Construction, Operation, Maintenance
  - Less any **expected salvage value**
  - Cost (C)=Expenditures–Salvage Value (S)
- ❑ Transportation Examples
  - Initial highway construction cost
  - Annual road maintenance and rehabilitation
  - Traffic signal installation and operation
  - Bridge inspection and repair costs
- ❑ **Key Idea:** Costs represent all **monetary resources consumed** by the project.

3

## Benefits

---

- ❑ Definition
  - **Benefits** are the **advantages experienced by owners or the public**
  - Represent **positive outcomes** of implementing the project
  - Often measured in **monetary terms**, even if originally non-monetary
- ❑ Transportation Examples
  - Travel time savings
  - Reduction in vehicle operating costs
  - Accident and injury reduction (safety benefits)
  - Reduced congestion and improved mobility
- ❑ **Key Idea:** Benefits measure **what society gains** from the transportation project.

4

## Disbenefits

---

### ❑ Definition

- **Disbenefits** are **undesirable or negative consequences** caused by the project
- May be **direct or indirect economic disadvantages**
- Usually assigned a **monetary equivalent** and treated as costs

### ❑ Transportation Examples

- Increased noise levels near highways
- Environmental impacts (air pollution, land use disruption)
- Increased travel delay during construction

### ❑ Key Idea:

- Disbenefits reduce the **net benefit** of a project and must be accounted for.

5

## What is Benefit/Cost (B/C) Analysis?

---

- A **decision-making tool** used in evaluating infrastructure projects
- Compares the **monetary value of benefits** to the **costs incurred**
- Helps determine if a project is **economically justifiable**
- Expressed as a **ratio**:

$$\text{B/C Ratio} = \frac{\text{Present Worth or Annual Worth of Benefits}}{\text{Present Worth or Annual Worth of Costs}}$$

8

## Benefit/Cost (B/C) Analysis of a Single Project

10

## Benefit/Cost (B/C) Analysis of a Single Project

---

$$B/C = \frac{\text{PW of benefits}}{\text{PW of costs}} = \frac{\text{AW of benefits}}{\text{AW of costs}} = \frac{\text{FW of benefits}}{\text{FW of costs}} \quad [9.1]$$

The *conventional B/C ratio*, probably the most widely used, is calculated as follows:

$$B/C = \frac{\text{benefits} - \text{disbenefits}}{\text{costs}} = \frac{B - D}{C} \quad [9.2]$$

11

11

## Interpreting the Benefit/Cost (B/C) Ratio

B/C Ratio Value	Interpretation
$B/C > 1.0$	✅ <b>Accept the project</b> – benefits outweigh costs; project is economically viable
$B/C = 1.0$	⚖️ <b>Break-even</b> – benefits equal costs; decision depends on other factors
$B/C < 1.0$	❌ <b>Reject the project</b> – costs exceed benefits; not economically justified

12

### Example 3.5.1

From the following estimates, determine the B/C ratio for a project that has a 20-year life. Use an interest rate of 8% per year.

Consequences to the People		Consequences to the Government	
Annual benefits	\$90,000 per year	First cost	\$750,000
Annual disbenefits	\$10,000 per year	Annual cost	\$50,000 per year
		Annual savings	\$30,000 per year

13

13

## Annual Worth of Benefit Calculation

---

- **Annual Benefit from the Project: \$90,000/year**
- **Annual Disbenefit: \$10,000/year**
- Net Annual Benefit Calculation:

$$AW_{\text{Benefit}} = 90,000 - 10,000 = \boxed{80,000 \text{ per year}}$$

15

## Annual Worth of Cost Calculation

---

- Initial (First) Cost: \$750,000
- Annual Operating Cost: \$50,000
- Annual Savings: \$30,000
- Net Annual Operating Cost:

$$50,000 - 30,000 = 20,000$$

- Convert First Cost to Annual Worth (A/P, 8%, 20):

$$AW_{\text{First Cost}} = 750,000 \times 0.10185 = 76,388$$

- Total Annual Worth of Cost:

$$AW_{\text{Cost}} = 76,388 + 20,000 = \boxed{96,388 \text{ per year}}$$

16

## Benefit/Cost (B/C) Ratio Calculation

---

- Annual Worth of Benefits: \$80,000
- Annual Worth of Costs: \$96,388
- B/C Ratio Formula:

$$\text{B/C Ratio} = \frac{AW_{\text{Benefit}}}{AW_{\text{Cost}}}$$

- Calculation:

$$\text{B/C Ratio} = \frac{80,000}{96,388} = \boxed{0.83}$$

- Interpretation:  
Since  $\text{B/C} < 1$ , the project is **not economically justified**

17

## Example 3.5.2

---

- ↪ The cost of grading and spreading gravel on a short rural road is expected to be \$300,000.
- ↪ The road will have to be maintained at a cost of \$25,000 per year.
- ↪ The improved accessibility has led to a 150% increase in the property values along the road.
  - If the previous market value of a property was \$900,000,
- ↪ Calculate the B/C ratio using an interest rate of 6% per year and a 20-year study period



18

18

## Example 3.5.2 – Given Data

---

- **Initial Construction Cost:** \$300,000
- **Annual Maintenance Cost:** \$25,000/year
- **Property Value Increase:**
  - 150% increase due to improved accessibility
  - Previous property value = \$900,000
- **Interest Rate:** 6% per year
- **Study Period:** 20 years
- **Objective:** Calculate the **Benefit/Cost (B/C) Ratio**

19

## Present Worth of Benefit

---

- **One-Time Benefit:**
  - **Benefit** =  $1.5 \times 900,000 = \$1,350,000$  (one-time gain)
  - Property value increase = **\$1,350,000**
- **Occurs in Year 0** → **Already in Present Worth**
- **Therefore, PW (Benefit) = \$1,350,000 - 900,000 = 450,000**

20

## Present Worth of Cost

---

- Initial Cost (Year 0):
  - \$300,000
- Annual Maintenance Cost:
  - \$25,000/year for 20 years
  - Interest rate  $i = 6\%$ ,  $N = 20$
  - $PW = \$25,000 \times (P/A, 6\%, 20)$
  - $P/A = 11.46992$
  - $PW = \$25,000 \times 11.46992 = \$286,748$
- Total PW of Cost:
  - $\$300,000 + \$286,748 = \$586,748$

21

## Benefit/Cost (B/C) Ratio Calculation

---

- Present Worth of Benefit:
  - $PW_B = 450,000$
- Present Worth of Cost:
  - $PW_C = 586,748$
- Formula:
 
$$B/C = \frac{PW_B}{PW_C} = \frac{450,000}{586,748}$$
- Result:
 
$$B/C = 0.767$$
- Interpretation:
  - $B/C < 1 \rightarrow$  The project is not economically justified

22

### Example 3.5.3

Calculate the B/C ratio for the following cash flow estimates at a discount rate of 7% per year.

Item	Cash Flow
FW of benefits, \$	30,800,000
AW of disbenefits, \$ per year	105,000
First cost, \$	1,200,000
M&O costs, \$ per year	400,000
Life of project, years	20

23

23

First convert all cash flows to AW values

Item	Cash Flow
FW of benefits, \$	30,800,000
AW of disbenefits, \$ per year	105,000
First cost, \$	1,200,000
M&O costs, \$ per year	400,000
Life of project, years	20

$$\begin{aligned} B &= 30,800,000(A/F, 7\%, 20) \\ &= 30,800,000(0.02439) \\ &= \$751,212 \end{aligned}$$

$$D = \$105,000$$

$$\begin{aligned} C &= 1,200,000(A/P, 7\%, 20) + 400,000 \\ &= 1,200,000(0.09439) + 400,000 \\ &= \$513,268 \end{aligned}$$

$$\begin{aligned} B/C &= (751,212 - 105,000)/513,268 \\ &= 1.26 \end{aligned}$$

24

# Incremental Benefit/Cost (B/C) Analysis

25

## What is Incremental Benefit/Cost (B/C) Analysis?

---

- **Definition:**  
A decision-making method used to determine whether the **extra cost** of a more expensive alternative is **justified by additional benefits**.
- **Purpose:**  
Compare **mutually exclusive alternatives** that differ in cost.
- **Concept:**  
Focuses only on the **difference (increment)** between alternatives:

$$\text{Incremental B/C Ratio} = \frac{\Delta \text{Benefit}}{\Delta \text{Cost}}$$

26

## Decision Rule for Incremental B/C Analysis

---

- ◆ Step 1: Determine Equivalent Total Costs
  - Compute **PW** or **AW** for both alternatives.
- ◆ Step 2: Order Alternatives
  - Arrange by increasing cost: **Lower-cost first**, then **higher-cost**.
- ◆ Step 3: Calculate Incremental Cost ( $\Delta C$ )
  - $\Delta C = \text{Cost}_{\text{high}} - \text{Cost}_{\text{low}}$

27

## Decision Rule for Incremental B/C Analysis

---

- ◆ Step 4: Determine Equivalent Total Benefits
  - Compute **PW** or **AW** of benefits (and disbenefits if any).
- ◆ Step 5: Calculate Incremental Benefit ( $\Delta B$ )
  - $\Delta B = \text{Benefit}_{\text{high}} - \text{Benefit}_{\text{low}}$
- ◆ Step 6: Compute the Incremental B/C Ratio
  - $\frac{\Delta B}{\Delta C}$
- ◆ Step 7: Apply the Decision Rule
  - If  $\Delta B/\Delta C > 1.0$  → Select the **higher-cost** alternative (economically justified).
  - If  $\Delta B/\Delta C < 1.0$  → Select the **lower-cost** alternative.

28

## Why Choose the Higher-Cost Alternative When $\Delta B/\Delta C > 1.0$

- Incremental B/C Ratio:

$$\Delta B/\Delta C = \frac{\text{Extra Benefits}}{\text{Extra Costs}}$$

- When  $\Delta B/\Delta C > 1.0$ :
  - You gain more than \$1 in benefit for every \$1 of extra cost
  - The additional investment is economically justified
- Decision Rule:
  - Choose the higher-cost alternative
  - Because its extra cost is outweighed by its added value

29

## Example 3.5.3 – Evaluation of Highway Designs (JOD)

- The following estimates are to be considered to determine which **highway design** to recommend to the Ministry of Public Works.
- The **user cost** represents the estimated **annual travel time and vehicle operation costs** borne by road users.
- The **discount rate is 5%**, and the **life of the highway project is estimated at 30 years**.
- Use **incremental Benefit/Cost (B/C) analysis** to select **Design A or Design B**.

	Design A	Design B
Construction cost, JOD	10,000,000	15,000,000
Annual maintenance cost, JOD	35,000	55,000
Annual user cost saving (JOD/year)	200,000	450,000

30

## Annual Worth of Costs – Design Alternatives

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### ◆ Design A:

- Construction Cost = 10,000,000 JOD
  - Maintenance Cost = 35,000 JOD/year
  - AW of Construction =  $10,000,000 \times 0.06505 = 650,500$  JOD/year
  - Total AW of Costs =  $650,500 + 35,000 = 685,500$  JOD/year
- 

### ◆ Design B:

- Construction Cost = 15,000,000 JOD
- Maintenance Cost = 55,000 JOD/year
- AW of Construction =  $15,000,000 \times 0.06505 = 975,750$  JOD/year
- Total AW of Costs =  $975,750 + 55,000 = 1,030,750$  JOD/year

31

## Annual Worth of benefits – Design Alternatives

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Design	AW of Benefits (JOD/year)
A	200,000
B	450,000

32

## Incremental Values Between Design B and Design A

Item	Design B	Design A	$\Delta$ (B – A)
AW of Benefits (JOD/year)	450,00	200,000	<b>+250,000</b>
AW of Costs (JOD/year)	1,030,750	685,500	<b>+345,250</b>
Incremental B/C Ratio	–	–	<b>+0.724</b>

- The incremental B/C ratio is less than 1.0
- This indicates that the extra costs associated with Design B are not justified
- Design A provides higher user benefits and lower annual cost
- Design A is selected for the construction bid

33

## Example 3.5.2

- ↪ Table 9–1 (top section) summarizes the estimates for each proposal, including the present worth of the initial construction cost and anticipated annual revenue. The annual M&O costs are expected to be the same for all locations. Use incremental B/C analysis at **7% per year** and an **8-year study period** to advise the board of directors if they should consider any of the offers to be economically attractive

**TABLE 9–1** Incremental B/C Analysis of Water Park Proposals, Example 9.6

	City 1	City 2	City 3	City 4
First cost, \$ million	38.5	40.1	45.9	60.3
Entrance fee costs, \$/year	500,000	450,000	425,000	250,000
Annual revenue, \$ million/year	7.0	6.2	10.0	10.4
Initial cash incentive, \$	250,000	350,000	500,000	800,000
Property tax reduction, \$/year	25,000	35,000	50,000	80,000
Sales tax sharing, \$/year	310,000	320,000	320,000	340,000

34

34

**B** TABLE 9–1 Incremental B/C Analysis of Water Park Proposals, Example 9.6

	City 1	City 2	City 3	City 4
First cost, \$ million	38.5	40.1	45.9	60.3
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Property tax reduction, \$/year	25,000	35,000	50,000	80,000
Sales tax sharing, \$/year	310,000	320,000	320,000	340,000
AW of total costs, \$ million/year	6.948	7.166	8.112	10.348
AW of total benefits, \$ million/year	7.377	6.614	10.454	10.954

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35

TABLE 9–1 Incremental B/C Analysis of Water Park Proposals, Example 9.6

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First cost, \$ million	38.5	40.1	45.9	60.3
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Sales tax sharing, \$/year	310,000	320,000	320,000	340,000
AW of total costs, \$ million/year	6.948	7.166	8.112	10.348
AW of total benefits, \$ million/year	7.377	6.614	10.454	10.954
Overall B/C	1.06	0.92	1.29	1.06
Alternatives compared	1-to-DN	B/C < 1.0	3-to-1	4-to-3
Incremental costs $\Delta C$ , \$/year	6.948		1.164	2.236
Incremental benefits $\Delta B$ , \$/year	7.377		3.077	0.50
$\Delta B/C$	1.06		2.64	0.22
Increment justified?	Yes	Eliminated	Yes	No
City selected	1		3	3

36

36

	City 1	City 2	City 3	City 4
Overall B/C	1.06	0.92	1.29	1.06
Alternatives compared	1-to-DN	B/C < 1.0	3-to-1	4-to-3
Incremental costs $\Delta C$ , \$/year	6.948		1.164	2.236
Incremental benefits $\Delta B$ , \$/year	7.377		3.077	0.50
$\Delta B/C$	1.06		2.64	0.22
Increment justified?	Yes	Eliminated	Yes	No
City selected	1		3	3

- ◆ **1. Rank Alternatives**
  - Order from **lowest to highest AW cost** (or first cost if AW is not available)
- ◆ **2. Select Base Alternative**
  - Start with the **least-cost option**
  - Must have **B/C  $\geq 1$**  to be eligible

37

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	City 1	City 2	City 3	City 4
Overall B/C	1.06	0.92	1.29	1.06
Alternatives compared	1-to-DN	B/C < 1.0	3-to-1	4-to-3
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$\Delta B/C$	1.06		2.64	0.22
Increment justified?	Yes	Eliminated	Yes	No
City selected	1		3	3

- ◆ **3. Compare Next Higher Alternative**
  - Compute:
 
$$\Delta C = AW_{\text{higher}} - AW_{\text{base}}$$

$$\Delta B = AW_{\text{Benefits}_{\text{higher}}} - AW_{\text{Benefits}_{\text{base}}}$$

$$\frac{\Delta B}{\Delta C} = \text{Incremental B/C Ratio}$$
- ◆ **4. Decision Rule**
  - If  $\Delta B/\Delta C \geq 1$ , **accept** the higher-cost alternative
  - If  $\Delta B/\Delta C < 1$ , **reject** the alternative
  - Use the **accepted option as new base**, repeat steps
- ◆ **5. Final Selection**
  - Last alternative with **justified increment** is the preferred option

38

38

# *Transportation Engineering and Planning*

Module | 5 | Evaluation of Transportation Alternatives

## 5.1|Evaluation of Transportation Alternatives

*Dr. Hamza Mohammad Alkuime*

1

Overview

2

## Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
1. Introduction to transportation systems	1/3	1
2. Transportation planning	1	3
3. Demand forecasting using 4 steps modeling	4	12
4. Engineering economy in transportation	3	9
5. Evaluation of transportation alternatives	2	6
6. Urban mass transit systems	3 2/3	11
7. Airports	1	3
Total	15	45

3

## Basic Elements of Transportation Planning

The transportation planning process comprises **seven basic elements**,

1. Situation definition
2. Problem definition
3. Search for solutions
4. Analysis of performance
5. Evaluation of alternatives
6. Choice of project
7. Specification and construction

4

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## Why Evaluate Transportation Alternatives?

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- To **identify the most cost-effective solution**.
- To **maximize benefits** such as safety, accessibility, and mobility.
- To reduce **environmental and social impacts**.
- To ensure **budget optimization** and proper **resource allocation**.
- To compare **long-term impacts** of multiple alternatives.

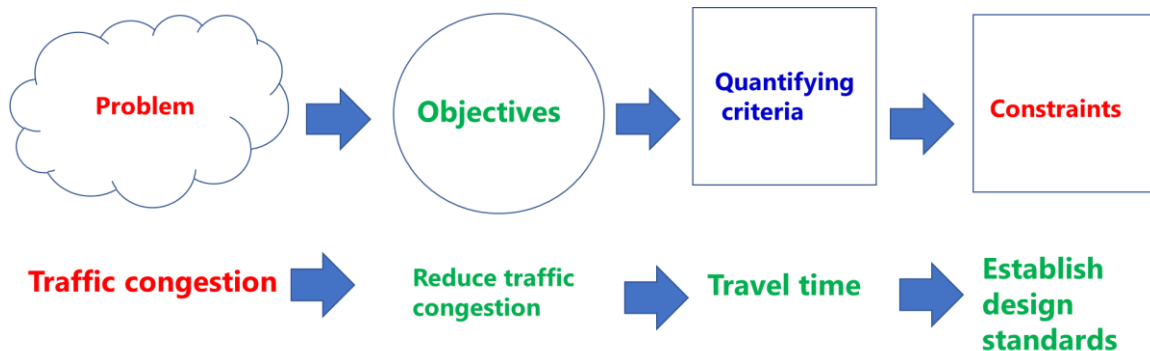
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## Evaluation (Quantifying) Criteria

6

## Evaluation (Quantifying) Criteria


- Evaluation criteria are **measurable indicators** used to compare transportation alternatives.
- They help quantify and assess the **impacts, costs, and benefits** of each option.



7

## Types of Evaluation Criteria

Transportation alternatives are evaluated using multiple performance criteria:

- Economic Criteria**
  - Cost-benefit analysis (C/B), Net present value (NPV), Internal rate of return (IRR)
- Technical Criteria**
  - Engineering feasibility, Durability and reliability
- Environmental Criteria**
  - Emissions and air quality, Land use impacts, Ecological footprint
- Social Criteria**
  - Equity and fairness, Public acceptance, Accessibility
- Operational Criteria**
  - Capacity, Efficiency, Level of service (LOS)
-  *No single criterion is sufficient—decisions require a balanced evaluation.*

8

## Selecting Evaluation Criteria

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- ❑ A transportation project is designed to achieve specific **goals and objectives**, which must be translated into **operational evaluation criteria** to allow systematic comparison among alternatives.
- ❑ **Appropriate evaluation criteria should:**
  - Be **directly and explicitly related** to the project's stated objectives
  - Be **measurable** using available, reliable, and consistent data
  - Be **sensitive to variations** among alternatives, so that meaningful differences can be detected
- ❑ It is generally advisable to **limit the number of evaluation criteria** to those that:
  - Contribute most effectively to **sound decision-making**
  - Keep the evaluation **analytically manageable** for both analysts and decision-makers
- ❑ **Emphasis:** The effectiveness of an evaluation depends more on the *relevance and quality* of criteria than on their quantity.

9

## Selecting Evaluation Criteria

Review

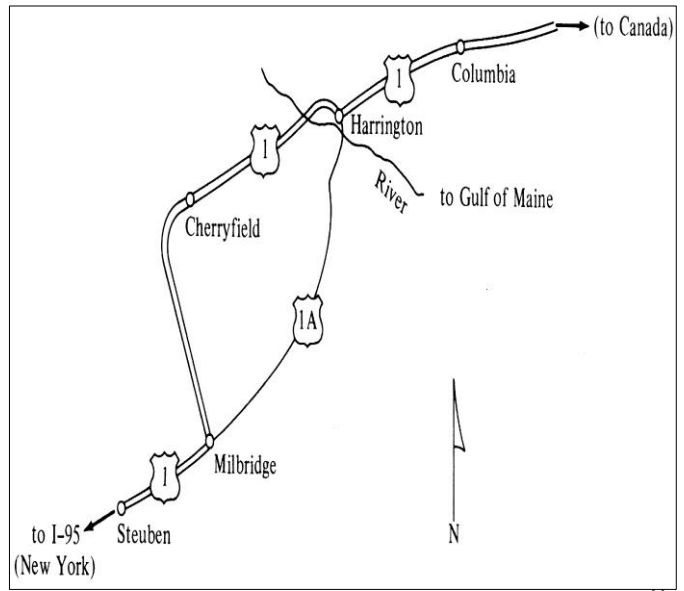
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## Basic Elements of Transportation Planning

### *Case study : Planning the relocation of a rural road*

#### Step 2- Problem definition

- ↪ Problems
  - High accident rate on 1A route
  - Low level of service for through traffic
- ↪ Objective
  - Reduce the high accident rate on this road
  - Improve the level of service for through traffic by increasing the average speed on the relocated highway.

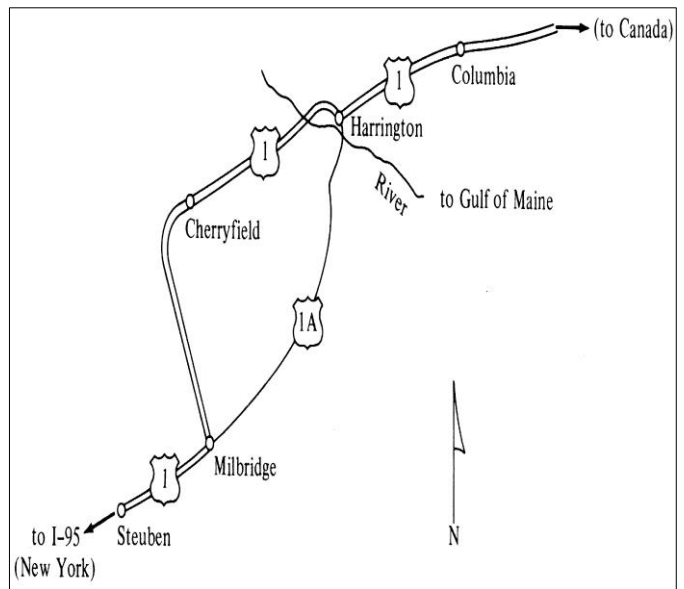


11

### *Case study : Planning the relocation of a rural road*

#### Step 2- Problem definition

- ↪ Quantifying criteria
  1. Accident rate
  2. Travel time
  3. Construction cost
  4. Changes in noise levels and air quality
  5. Number of businesses and residences that would be displaced



12

## Basic Issues in Evaluation

### Measures of Effectiveness

<i>Criteria</i>	<i>Alternatives</i>				
	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
Speed (mi/h)	25	55	30	30	55
Distance (mi)	3.7	3.2	3.8	3.8	3.7
Travel time (min)	8.9	3.5	7.6	7.6	4.0
Accident factor (Relative to statewide average)	4	1.2	3.5	2.5	0.6
Construction cost (\$ million)	0	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0
City traffic					
Present	2620	1400	2620	2520	1250
Future (20 years)	4350	2325	4350	4180	2075
Air quality ( $\mu\text{g}/\text{m}^3$ CO)	825	306	825	536	386
Noise (dBA)	73	70	73	73	70
Tax loss	None	Slight	High	Moderate	Slight
Trees removed (acres)	None	Slight	Slight	25	28
Runoff	None	Some	Some	Much	Much

13

13

## Evaluation approaches

14

## Evaluation Approaches

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- ❑ **Measures of Effectiveness (MOEs)** are quantitative or qualitative indicators used to **evaluate and compare transportation alternatives** in a systematic manner.
- ❑ MOEs provide a means to **quantify how well each alternative satisfies the defined project objectives**, thereby linking planning goals to decision-making.
- ❑ Based on the nature of the criteria and available data, **transportation evaluation is commonly conducted using two main approaches:**
  - **Common Unit Approach**
  - **Evaluation Based on Multiple Criteria:**
- ❑ **Emphasis:** The selection of an evaluation approach depends on project objectives, data availability, and the need to balance economic efficiency with non-monetary considerations.

15

## Evaluation Approaches

### Common Unit Approach

16

## Approach One: Common Unit Approach

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- ❑ The **Common Unit Approach** evaluates transportation alternatives by converting all **measures of effectiveness (MOEs)** into a **single common unit**, most commonly **monetary value**.
- ❑ This conversion allows for **direct economic comparison** among competing alternatives by expressing diverse impacts—such as travel time, safety, and operating costs—on a common basis.

17

## Procedure of the Common Unit Approach

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- ❑ **Step 1:** Identify all relevant **measures of effectiveness (MOEs)** associated with project objectives.
- ❑ **Step 2:** Convert each MOE into a **monetary equivalent**, using appropriate **unit values** (e.g., value of time in \$/hour, cost per accident avoided).
- ❑ **Step 3:** Compute the **total monetary value of benefits and costs** for each alternative over the analysis period.
- ❑ **Step 4:** Compare alternatives using **Net Benefits** or the **Benefit–Cost Ratio (BCR)** to identify the economically preferred option.

18

## Example

You are part of a transportation planning team tasked with evaluating five relocation alternatives for a rural road project.

The following table summarizes key performance criteria for each alternative, including travel time, accident factor, construction cost, and social/environmental impacts.

### Your Task:

Using the **Common Unit Approach**, evaluate and recommend the most cost-effective alternative based on the following:

### Assumptions (Unit Costs):

- Value of accident reduction = **\$700,000 per unit decrease**
- Value per displaced residence = **\$200,000**
- Construction costs as provided in millions of dollars

### Question:

**Which alternative provides the highest incremental benefit cost ratio an economic point of view?**

Support your answer with cost-benefit calculations using the provided data.

Criteria	Alternative 0	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Accident factor	4.0	1.2	3.5	2.5	0.6
Construction cost	0.00	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0

23

## Example : Alternative 1 vs. 0

### Step 1: Select Key Criteria for Monetization

- Accident reduction
- Construction cost
- Residences displaced

Criteria	Alternative 0	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Accident factor	4.0	1.2	3.5	2.5	0.6
Construction cost	0.00	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0

24

## Step 2: Assign Unit Costs

Impact	Unit Cost
Accident factor	\$700,000 per accident avoided
Residences displaced	\$200,000 per house
Construction cost	As given (\$ million)

Criteria	Alternative 0	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Accident factor	4.0	1.2	3.5	2.5	0.6
Construction cost	0.00	1.50	1.58	1.18	1.54
Residences displaced	0	0	7	3	0

25

## Step 3: Convert to Monetary Terms :

### Accident Reduction – Monetary Benefits

### Given

- Baseline accident factor (Alternative 0) = **4.0**
- Unit value = **\$700,000 per unit reduction**

### Formula

Alternative	Accident Factor	Reduction from Baseline	Monetary Benefit (\$)
0	4.0	0.0	0
1	1.2	2.8	1,960,000
2	3.5	0.5	350,000
3	2.5	1.5	1,050,000
4	0.6	3.4	2,380,000

26

### Step 3: Convert to Monetary Terms :

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#### Construction Cost – Monetary Costs

**Given** : Construction cost provided in **\$ million**

**Formula** : Construction Cost (\$) = Cost (\$ million) × 1,000,000

Alternative	Construction Cost (\$ million)	Monetary Cost (\$)
0	0.00	0
1	1.50	1,500,000
2	1.58	1,580,000
3	1.18	1,180,000
4	1.54	1,540,000

27

### Step 3: Convert to Monetary Terms :

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#### Residence Displacement – Monetary Costs

**Given** : Unit value = **\$200,000 per displaced residence**

**Formula** Displacement Cost = No. of Residences × 200,000

Alternative	Residences Displaced	Monetary Cost (\$)
0	0	0
1	0	0
2	7	1,400,000
3	3	600,000
4	0	0

28

## Step4 : Total Benefits and Total Costs

### □ Definition

- **Total Benefit (\$)** = Accident-reduction benefit
- **Total Cost (\$)** = Construction cost + Residence displacement cost
- **Baseline:** Alternative 0 (Do-Nothing)

Alternative	Total Cost (\$)	Total Benefit (\$)
0	\$0	\$0
1	\$1,500,000	\$1,960,000
4	\$1,540,000	\$2,380,000
3	\$1,780,000	\$1,050,000
2	\$2,980,000	\$350,000

29

## Incremental B/C Analysis Table

Alternative	Total Cost (\$)	Total Benefit (\$)	Δ Cost (\$)	Δ Benefit (\$)	Incremental B/C Ratio
0	\$0	\$0	—	—	—
1	\$1,500,000	\$1,960,000	1,500,000	1,960,000	<b>1.31</b>
4	\$1,540,000	\$2,380,000	40,000	420,000	<b>10.50</b>
3	\$1,780,000	\$1,050,000	240,000	-1,330,000	-5.54
2	\$2,980,000	\$350,000	1,200,000	-700,000	-0.58

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## Limitations of Economic Evaluation Methods

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- **Difficulties in Monetization**  
Converting all criteria (e.g., safety, environmental quality) into **dollar values** is often complex and subjective.
- **Interest Rate & Service Life Assumptions**  
Selecting appropriate values for **interest rate** and **service life** can significantly affect results and vary by context.
- **Incomplete Cost Accounting**  
Important **external costs**, such as **air pollution**, **traffic noise**, and **congestion impacts**, are frequently excluded or underestimated, resulting in an incomplete representation of total societal costs

31

## Evaluation Approaches

Evaluation Based on Multiple Criteria

32

## Evaluation Based on Multiple Criteria – Definition

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- ❑ **Evaluation based on multiple criteria** is a structured decision-making approach that:
  - Considers **multiple performance indicators** simultaneously (e.g., cost, safety, environmental impact, social equity).
  - Integrates both **quantitative and qualitative measures**, allowing a more comprehensive assessment of transportation alternatives.
- ❑ Enables **comparison among project alternatives** even when impacts **cannot be reliably converted into monetary terms**.

33

## Types of Measures

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- ❑ **Quantitative Measures**
  - Numerically defined and directly measurable
  - Examples: Travel time savings, Number of passengers, Accident rates
- ❑ **Qualitative Measures**
  - Descriptive or judgment-based indicators
  - Not always expressible in numerical form
  - Examples: User satisfaction, Public acceptance, Visual impact

34

## Evaluation Based on Multiple Criteria

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**Evaluation based on multiple criteria can be applied at different stages of the transportation project lifecycle, as follows:**

### ■ Before Construction

*1. Rating and Ranking*

*2. Cost-Effectiveness*

### ● After Construction (Finished Projects)

*1. Evaluation of completed projects*

*2. Evaluating effects of transportation on social and natural systems*

35

## Evaluation Based on Multiple Criteria

Rating and Ranking method

36

## Rating and Ranking

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- Converts each **measure of effectiveness (MOE)** to a **numerical score**
- If a project **performs well** on a criterion → assign a **high score**
- If a project **performs poorly** → assign a **low score**
- Useful when impacts are **non-monetary** or difficult to price

37

## Rating and Ranking Method Steps

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- Step 1** : Identify the goals and objectives of the project
- Step 2.** Determine the relative weight for each objective
- Step 3.** Define an appropriate measure of effectiveness for each objective
- Step 4 .** Develop the alternatives that will be tested.
- Step 5.** Determine the value of each measure of effectiveness for the selected alternatives
- Step 6.** Compute a score and ranking for each alternative

38

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## Rating and Ranking method

### Example 13.2

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39

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### Example 13.2

↪ A transportation agency is considering the construction of a light-rail transit line from the center of town to a growing suburban region.

↪ The transit agency wishes to examine five alternative alignments

➤ I

➤ II

➤ III

➤ IV

➤ V

40

40

# Rating and Ranking method

## Step 1: Identify the Goals and Objectives of the Project

41

### Step 1: Identify the Goals and Objectives of the Project

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- ↪ This step establishes **what the project is intended to achieve** and provides the **foundation for all subsequent evaluation steps**.
- ↪ **Objectives** translate goals into **specific, measurable targets** that can be evaluated using defined criteria.

42

## Step 1 : Identify the goals and objectives of the project

No.	Objective
1	Net revenue generated by fares should be as large as possible with respect to the capital investment
2	Ridership on the transit line should be maximized.
3	Service on the system should be comfortable and convenient
4	The transit line should extend as far as possible to promote development and accessibility
5	The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion

43

43

## Rating and Ranking method

Step 2. Determine the relative weight for each objective

44

## Step 2. Determine the relative weight for each objective

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- ↪ This step assigns **relative importance** to **each project objective**, reflecting how much each objective should influence the final decision.
- ↪ Weighting recognizes that **not all objectives are equally important**; some objectives may carry more significance due to policy priorities, stakeholder concerns, or project context.
- ↪ Determining relative weights involves **subjective judgment** by the evaluation group and may vary among:
  - Individuals
  - Stakeholder groups
  - Institutional and political interests


45

45

## Step 2. Determine the relative weight for each objective

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### *Relative Weight Approaches*

- ↪ **Approach 1: Allocate Weights on a 100-Point Scale**
  - A total of **100 points** is distributed among all objectives.
  - Objectives considered more important receive **more points**.
  - The sum of all weights equals **100**.
- ↪ **Advantages:**
  - Simple and intuitive
  - Easy to explain and interpret
  - Commonly used in practice and teaching
  -  *This approach directly reflects decision-maker priorities.*

46

## Step 2. Determine the relative weight for each objective

↳ Using the **100-point scale approach**, a total of **100 points** is distributed among the objectives based on their **relative importance**.

No.	Objective	Allocated Weight (Points)	Weight (%)
1	Net revenue generated by fares relative to capital investment	30	30%
2	Maximize ridership on the transit line	25	25%
3	Provide comfortable and convenient service	15	15%
4	Extend the transit line to promote development and accessibility	15	15%
5	Divert auto users to reduce peak-hour congestion	15	15%
<b>Total</b>		100	100%

47

## Step 2. Determine the relative weight for each objective

### *Relative Weight Approaches*

#### ↳ Approach 2: Ranking with Proportional Weights


➤ Objectives are first **ranked in order of importance** (most important → least important).

↳ A **formula of proportionality** is then applied to convert ranks into **relative weights**.

➤ **Higher-ranked objectives receive larger weights.**

#### ↳ Advantages:

- Useful when exact weight values are difficult to assign
- Reduces complexity by starting with simple ranking
- Provides a systematic way to derive weights

↳  *This approach emphasizes relative importance rather than absolute values.*

48

## Step 2. Determine the relative weight for each objective

No. (j)	Objective	Rank	Relative Weight (Wj)	Weighting Factor (Kj) X 100
1	Net revenue generated by fares should be as large as possible with respect to the capital investment	1	5	30%
2	Ridership on the transit line should be maximized.	2	4	24%
3	Service on the system should be comfortable and convenient	3	3	17%
4	The transit line should extend as far as possible to promote development and accessibility	3	3	17%
5	The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion	4	2	12%
<b>Total</b>			<b>17</b>	<b>100</b>

49

49

## Rating and Ranking method

Step 3. Define an appropriate measure of effectiveness for each objective

50

### Step 3: Define an Appropriate Measure of Effectiveness (MOE) for Each Objective

- ❑ This step translates each **project objective** into a **measurable indicator**, known as a **Measure of Effectiveness (MOE)**.
- ❑ MOEs specify **how performance will be evaluated**, providing a direct link between objectives and the scoring process used later in the analysis.
- ❑ An appropriate MOE should:
  - Clearly represent the **intended objective**
  - Be **measurable or assessable** using available data
  - Allow **comparison among alternatives**
  - Have a clear direction of preference (higher or lower is better)
- ❑ Measures of effectiveness can be:
  - **Quantitative** (numerical and directly measured), such as travel time, ridership, or cost
  - **Qualitative** (descriptive or judgment-based), such as comfort, convenience, or visual impact

51

### Step 3. Define an appropriate measure of effectiveness for each objective

No.	Objective	Measure of Effectiveness	Relationship
1	Net revenue generated by fares should be as large as possible with respect to the capital investment	Net annual revenue divided by annual capital cost	Direct (Higher is better)
2	Ridership on the transit line should be maximized.	Total daily ridership	Direct (Higher is better)
3	Service on the system should be comfortable and convenient	Percent of riders seated during the peak hour	Direct (Higher is better)
4	The transit line should extend as far as possible to promote development and accessibility	Length of line (mi)	Direct (Higher is better)
5	The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion	Number (or percent) of auto users diverted during peak hour	Direct (Higher is better)

52

52

# Rating and Ranking method

Step 4 . Develop the alternatives that will be tested.

53

## Step 4 . Develop the alternatives that will be tested.

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- ↪ The transit agency wishes to examine five alternative alignments,
  - I, II, III, IV, V
- ↪ Each of which has advantages and disadvantages in terms of cost, ridership, and service provided.
- ↪ The alternatives differ in
  - Length of the line,
  - Location, types of vehicles used
  - Seating arrangements
  - Operating speeds
  - Numbers of stops.

54

54

# Rating and Ranking method

Step 5. Determine the value of each measure of effectiveness for the selected alternatives

55

## Step 5: Determine the Value of Each Measure of Effectiveness (MOE)

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- ❑ **What does this step really do?**
  - After defining the **MOEs** (Step 3), we now determine **how well each alternative performs** for every MOE.
  - However, MOEs are measured in **different units**:
    - passengers/day, miles, percentages emissions, noise, delay, etc.
  - 🖱️ These raw values **cannot be compared directly**.
- ❑ Therefore, Step 5 does **two things**:
  - Records the **actual MOE values** for each alternative
  - **Standardizes** these values so they are:
    - Dimensionless, Comparable, Consistent with “better” performance logic
- ❑ This standardization depends on whether the MOE has a **direct or indirect** relationship with performance.

56

## Direct Relationship (Higher Is Better)

- ❑ **When is this used?** Use a **direct relationship**
- ❑ **when:** Larger values indicate **better performance**
- ❑ **Common examples :** Total ridership, Capacity, Safety score, Revenue, Service quality indicators
- ❑ **Standardization Formula (Direct)**
- ❑ Normalized Value<sub>*i*</sub> =  $\left( \frac{\text{Value of alternative } i}{\text{Maximum value among all alternatives}} \right) \times \text{Weight}$
- ❑ **How to interpret this**
  - The **best alternative** (maximum value) gets a score of **100% × weight**
  - Other alternatives receive a **fraction of the best**
  - Scores range between **0 and the assigned weight**
  - *This preserves the idea: More is better*

57

## Example

- ❑ **Measure of Effectiveness: Total Daily Ridership**
- ❑ **Relationship:** Direct (Higher values indicate better performance)
- ❑ **Assigned Weight:** 0.40 (40%)
- ❑ Normalized Score<sub>*i*</sub> =  $\left( \frac{\text{Value of alternative } i}{\text{Maximum value among all alternatives}} \right) \times \text{Weight}$

Alternative	Raw Value (Total Ridership)	Formula	Normalized Score
A1	10,000	$\frac{10,000}{10,000} \times 0.4 = 1.0 \times 0.4$	0.40
A2	8,000	$\frac{8,000}{10,000} \times 0.4 = 0.8 \times 0.4$	0.32
A3	6,000	$\frac{6,000}{10,000} \times 0.4 = 0.6 \times 0.4$	0.24

58

## Indirect Relationship (Lower Is Better)

### ❑ When is this used?

- Use an **indirect relationship** when:
- Smaller values indicate **better performance**

### ❑ Common examples: Pollution, Noise, Delay, Cost, Accidents

### ❑ Standardization Formula (Indirect)

- Normalized Value<sub>*i*</sub> =  $\left( \frac{\text{Minimum value among all alternatives}}{\text{Value of alternative } i} \right) \times \text{Weight}$

### ❑ How to interpret this

- The **best alternative** (minimum value) gets a score of **100% × weight**
- Higher (worse) values produce **smaller scores**
- Scores again range between **0 and the assigned weight**
- This preserves the idea: *Less is better*.

59

## Example

### ❑ Measure of Effectiveness (MOE): Pollution Level

### ❑ Decision Rule: Lower pollution → better performance

### ❑ Assigned Weight: 0.30 (30%)

### ❑ Normalized Score<sub>*i*</sub> = $\left( \frac{\text{Minimum pollution value among all alternatives}}{\text{Pollution value of alternative } i} \right) \times \text{Weight}$

Alternative	Raw Value (Pollution Index)	Formula	Normalized Score
A1	50	$\frac{30}{50} \times 0.3 = 0.6 \times 0.3$	0.18
A2	40	$\frac{30}{40} \times 0.3 = 0.75 \times 0.3$	0.225
A3	30 ( <i>Best</i> )	$\frac{30}{30} \times 0.3 = 1.0 \times 0.3$	0.30

60

### Step 5. Determine the value of each measure of effectiveness for the selected alternatives

No.	Objective	Measure of Effectiveness	Alternatives				
			I	II	III	IV	V
1	Net revenue generated by fares should be as large as possible with respect to the capital investment	Net annual revenue divided by annual capital cost (Annual return on investment (%))	13	14	11	13.5	15
2	Ridership on the transit line should be maximized.	Total daily ridership (1000s )	25	23	20	18	17
3	Service on the system should be comfortable and convenient	Percent of riders seated during the peak hour (%)	25	35	40	50	50
4	The transit line should extend as far as possible to promote development and accessibility	Length of line (mi)	8	7	6	5	5
5	The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion	Auto drivers diverted (1000s)	3.5	3	2	1.5	1.5

61

61

### Step 5. Determine the value of each measure of effectiveness for the selected alternatives

No.	Weighting Factor (Kj) X 100	Measure of Effectiveness	Relationship	Alternatives				
				I	II	III	IV	V
1	30%	Net annual revenue divided by annual capital cost (Annual return on investment (%))	Direct (Higher is better)	13	14	11	13.5	15
2	24%	Total daily ridership (1000s )	Direct (Higher is better)	25	23	20	18	17
3	17%	Percent of riders seated during the peak hour (%)	Direct (Higher is better)	25	35	40	50	50
4	17%	Length of line (mi)	Direct (Higher is better)	8	7	6	5	5
5	12%	Auto drivers diverted (1000s)	Direct (Higher is better)	3.5	3	2	1.5	1.5

62

62

## Step 5. Determine the value of each

### Objective #1:

↻ **Measure of Effectiveness (MOE):** Net annual revenue ÷ annual capital cost

↻ **Relationship:** Direct (Higher is better)

↻ **Weight (  $K_1$  ): 30% = 0.30**

↻ The maximum MOE value among all alternatives is **15% (Alternative V)**.

↻ The normalized score for each alternative is calculated using:

$$\text{Normalized Score}_i = \left( \frac{\text{MOE value of alternative } i}{15} \right) \times 0.30$$

↻ **Results:**

➤ Alternative I:  $\frac{13}{15} \times 0.30 = 0.26$

➤ Alternative II:  $\frac{14}{15} \times 0.30 = 0.28$

➤ Alternative III:  $\frac{11}{15} \times 0.30 = 0.22$

➤ Alternative IV:  $\frac{13.5}{15} \times 0.30 = 0.27$

➤ Alternative V:  $\frac{15}{15} \times 0.30 = 0.30$

No.	Weighting Factor (Kj) X 100	Measure of Effectiveness Direct (Higher is better)	Alternatives				
			I	II	III	IV	V
1	30%	Net annual revenue divided by annual capital cost (Annual return on investment %)	13	14	11	13.5	15
2	24%	Total daily ridership (1000s)	25	23	20	18	17
3	17%	Percent of riders seated during the peak hour (%)	25	35	40	50	50
4	17%	Length of line (mi)	8	7	6	5	5
5	12%	Auto drivers diverted (1000s)	3.5	3	2	1.5	1.5

63

## Step 5. Determine the value of each

### Objective #2:

↻ **Measure of Effectiveness (MOE):** Total daily ridership (×1000 passengers)

↻ **Relationship:** Direct (Higher is better)

↻ **Weight (  $K_2$  ): 24% = 0.24**

↻ The maximum ridership value among all alternatives is **25 (Alternative I)**.

↻ The normalized score for each alternative is calculated using:

$$\text{Normalized Score}_i = \left( \frac{\text{Ridership of alternative } i}{25} \right) \times 0.24$$

↻ **Results:**

↻ Alternative I:  $\frac{25}{25} \times 0.24 = 0.24$

↻ Alternative II:  $\frac{23}{25} \times 0.24 = 0.22$

↻ Alternative III:  $\frac{20}{25} \times 0.24 = 0.19$

↻ Alternative IV:  $\frac{18}{25} \times 0.24 = 0.17$

↻ Alternative V:  $\frac{17}{25} \times 0.24 = 0.16$

No.	Weighting Factor (Kj) X 100	Measure of Effectiveness Direct (Higher is better)	Alternatives				
			I	II	III	IV	V
1	30%	Net annual revenue divided by annual capital cost (Annual return on investment %)	13	14	11	13.5	15
2	24%	Total daily ridership (1000s)	25	23	20	18	17
3	17%	Percent of riders seated during the peak hour (%)	25	35	40	50	50
4	17%	Length of line (mi)	8	7	6	5	5
5	12%	Auto drivers diverted (1000s)	3.5	3	2	1.5	1.5

64

## Step 5. Determine the value of each

Objective	Weight	Alt I	Alt II	Alt III	Alt IV	Alt V	No.	Weighting Factor (K) X 100	Measure of Effectiveness Direct (Higher is better)	Alternatives				
										I	II	III	IV	V
1. Net annual revenue ÷ annual capital cost	0.30	0.26	0.28	0.22	0.27	0.30	1	30%	Net annual revenue divided by annual capital cost (Annual return on investment %)	13	14	11	13.5	15
2. Total daily ridership (1000s)	0.24	0.24	0.22	0.19	0.17	0.16	2	24%	Total daily ridership (1000s)	25	23	20	18	17
3. Percent of riders seated (peak hour)	0.17	0.09	0.12	0.14	0.17	0.17	3	17%	Percent of riders seated during the peak hour (%)	25	35	40	50	50
4. Length of line (mi)	0.17	0.17	0.15	0.13	0.11	0.11	4	17%	Length of line (mi)	8	7	6	5	5
5. Auto drivers diverted (1000s)	0.12	0.12	0.10	0.07	0.05	0.05	5	12%	Auto drivers diverted (1000s)	3.5	3	2	1.5	1.5

65

## Step 5. Determine the value of each

Objective	Weight	Alt I	Alt II	Alt III	Alt IV	Alt V
1. Net annual revenue ÷ annual capital cost	30	26	28	22	27	30
2. Total daily ridership (1000s)	24	24	22	19	17	16
3. Percent of riders seated (peak hour)	17	9	12	14	17	17
4. Length of line (mi)	17	17	15	13	11	11
5. Auto drivers diverted (1000s)	12	12	10	7	5	5

66

# Rating and Ranking method

**Step 6.** Compute a score and ranking for each alternative

67

## **Step 6. Compute a score and ranking for each alternative**

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- ✎ The score for each alternative is computed by considering each measure of effectiveness and **awarding the maximum score** to the alternative with the highest value and a proportionate amount to the other alternatives.

68

68

### Step 5. Determine the value of each

Objective	Weight	Alt I	Alt II	Alt III	Alt IV	Alt V
1. Net annual revenue ÷ annual capital cost	30	26	28	22	27	30
2. Total daily ridership (1000s)	24	24	22	19	17	16
3. Percent of riders seated (peak hour)	17	9	12	14	17	17
4. Length of line (mi)	17	17	15	13	11	11
5. Auto drivers diverted (1000s)	12	12	10	7	5	5
Total	100%	88%	87%	75%	77%	79%

69

## Evaluation Based on Multiple Criteria

Cost Effectiveness method

71

## Cost-Effectiveness Analysis

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- ❑ A form of **economic evaluation** that compares the **relative costs** and the **levels of effectiveness** of different project alternatives.
- ❑ Focuses simultaneously on:
  - **Cost** (investment, operating, or social costs), and
  - **Effectiveness** (the degree to which objectives are achieved)
- ❑ **Unlike cost-benefit analysis**, cost-effectiveness analysis:
  - **Does not require monetizing all benefits**, and
  - **Does not yield a single “optimal” solution**, but instead presents trade-offs among alternatives.
- ❑ **Key Benefits**
  - Provides a **deeper and more transparent understanding** of how each alternative performs relative to its cost.

72

## Example 13.3

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➤ **Five alternative system plans** are being considered for a **major metropolitan area**.

- **Plan A** : Retains the status quo with no major improvements
- **Plan B** : An all-rail system
- **Plan C** : All highways system
- **Plan D** : A mix of rail transit and highways
- **Plan E** : A mix of express buses and highways

73

73

## B. Evaluation Based on Multiple Criteria

### Example 13.3

#### Objective (Plans are intended to provide)

1. Added capacity
2. Improved levels of service
3. Reductions in travel time during peak hours.

#### Measure of effectiveness

1. Persons and Businesses displaced
2. Annual total fatal accidents and personal injuries
3. Annual transit passengers
4. Average door-to-door auto trip speed (mi/h)
5. Daily emissions of carbon monoxide (tons)

74

74

## B. Evaluation

### Example 13.3

#### - Solution

**Table 13.9** Measure of Effectiveness Data for Alternative Highway–Transit Plans

Measure of Effectiveness	Plan A	Plan B	Plan C	Plan D	Plan E
	Null	All Rail	All Highway	Rail and Highway	Bus and Highway
Persons displaced	0	660	8000	8000	8000
Businesses displaced	0	15	183	183	183
Annual total fatal accidents	159	158	137	136	134
Annual total personal injuries	6767	6714	5596	5544	5517
Daily emissions of carbon monoxide (tons)	2396	2383	2233	2222	2215
Daily emissions of hydrocarbons (tons)	204	203	190	189	188
Average door-to-door auto trip speed (mi/h)	15.9	16.2	21.0	21.2	21.5
Average door-to-door transit trip speed (mi/h)	6.8	7.6	6.8	7.6	7.8
Annual transit passengers (millions)	154.2	161.7	154.2	161.7	165.2
Total annual cost (\$ millions)	2.58	31.16	106.72	129.38	123.44
Interest rate (%)	8.0	8.0	8.0	8.0	8.0

Adapted from *Alternative Multimodal Passenger Transportation Systems*, NCHRP Report 146, Transportation Research Board, National Research Council, Washington, D.C., 1973

75

75

## B. Evaluation Based on Multiple Criteria

### Example 13.3 - Solution

#### ↳ B/C analysis

**Table 13.8** Benefit–Cost Comparisons for Highway and Transit Alternatives

<i>Plan Comparisons</i>	<i>Annual Cost Difference (\$ million)</i>	<i>Annual Savings (\$ million)</i>	<i>BCR</i>
A versus B	28.58	21.26	0.74
A versus C	104.14	116.15	1.12
C versus D	22.66	17.16	0.76
C versus E	16.73	19.75	1.18

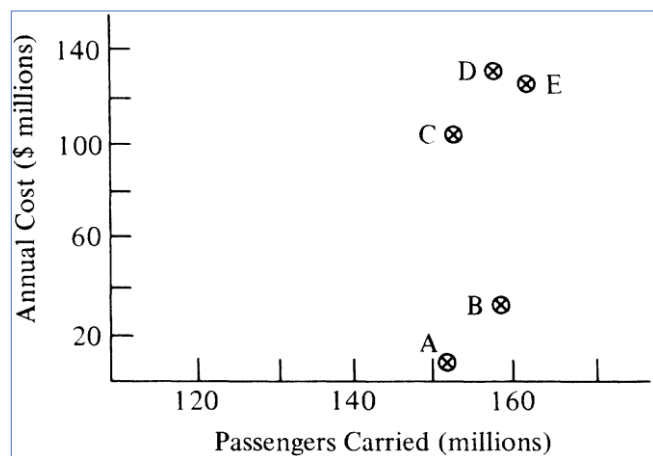
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76

## Example 13.3 - Solution

### Key Insights:

- **Alternative A:**
  - Most cost-effective
  - Delivers high benefit for the **lowest cost**
- **Alternative B:**
  - Slight improvement in effectiveness, but with a **much higher cost**
- **Alternatives C, D, and E:**
  - Offer increased effectiveness, but at **disproportionately higher costs**
  - **Diminishing returns:** More money is spent for relatively smaller gains



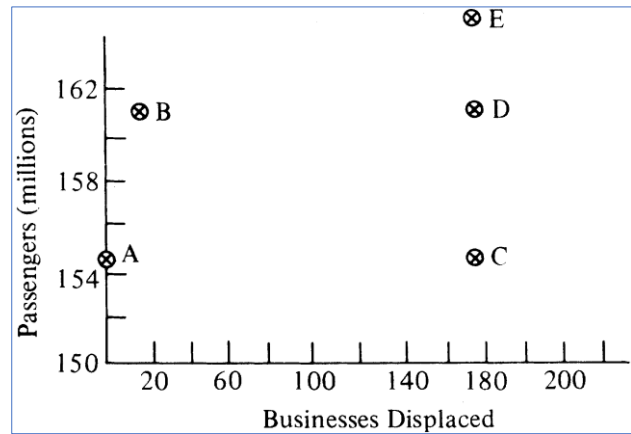
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77

## Example 13.3 - Solution

### Key Insights:

- **Alternative B**
  - Delivers **the highest number of passengers** (~162 million)
  - Causes **minimal business displacement** (~20)
  - **Most favorable trade-off**
- **Alternative A**
  - Slightly fewer passengers than B
  - Also has **very low business displacement**
  - **A strong, low-impact option**
- **Alternatives C, D, and E**
  - Carry **only slightly more passengers** than A or B
  - Cause **significantly more displacement** (C: ~180, D: ~160, E: ~200 businesses)



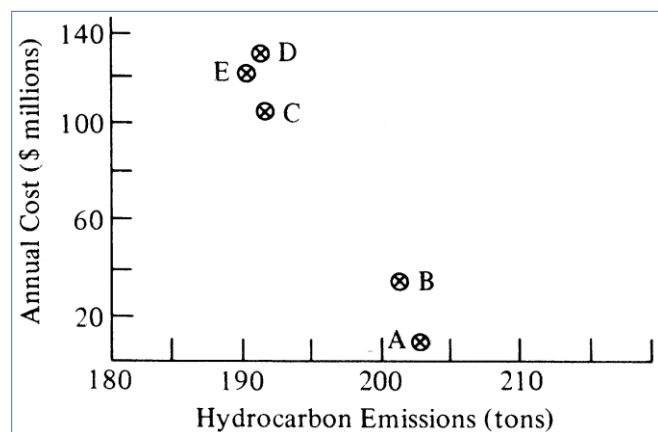
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78

## Example 13.3 - Solution

### Key Insights:

- **Alternative A**
  - **Lowest cost and highest emissions** (~205 tons)
  - Baseline option with minimal investment
- **Alternative B**
  - Moderate cost (~\$60M)
  - Slight reduction in emissions compared to A (~200 tons)
  - **⚠ Limited environmental benefit for added cost**
- **Alternative C**
  - Significant cost increase (~\$105M)
  - **Noticeable reduction in emissions** (~193 tons)
  - **✅** May be justified for pollution reduction goals
- **Alternatives D & E**
  - **Highest costs** (over \$120M)
  - Minimal additional improvement over C
  - **✗** Exhibit **diminishing returns**



79

79

# Evaluation Based on Multiple Criteria

## Evaluation of Completed Projects

80

## Post-Evaluation of Transportation Projects

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- Conducted **after project implementation** to assess **actual outcomes**

### Objectives:

- Evaluate **how effective** the project has been in achieving its objectives
- Identify **lessons learned** to guide future projects
- Recommend **changes** to **improve** ongoing outcomes
- Decide whether the project should be **continued** or **abandoned**

### Relation to Experimental Design:

- Similar to **medical trials**:
  - Compare a **control group** (no intervention) and an **experimental group** (with project intervention)
  - Measure differences **before and after** for both groups
  - The net difference is attributed to the **impact of the project**

81

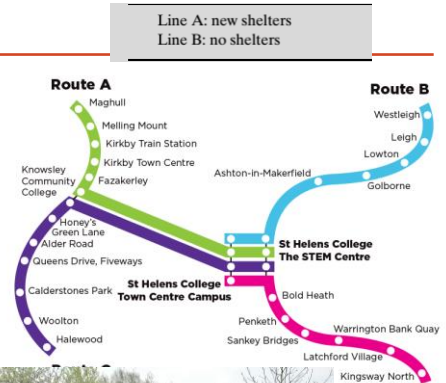
# Evaluation of Completed Projects

## Example 13.4

# Evaluation of Completed Projects

## Example 13.4

- ↪ A transit authority wishes to evaluate the effectiveness of **new bus shelters** on transit ridership as well as acceptance by the community.
- ↪ A series of new shelters was built **along one bus route** but not on the other lines.
- ↪ Do the shelters affect ridership?



## Evaluation of Completed Projects

### Example 13.4 – Solution

**Solution:** Bus ridership has been measured before and after the shelters had been installed on the test line and on a control line where nothing new had been added. Both lines serve similar neighborhoods. The ridership results are shown in Table 13.10. The line with new shelters increased ridership by 13.3%, whereas the line without shelters increased by only 2.5%. It should be stressed that only in the absence of any other factors can we conclude that the effect of the new shelters was to increase ridership by  $(13.3 - 2.5) = 10.8\%$ .

**Table 13.10** Transit Ridership

	<i>Before</i>	<i>After</i>	<i>Change (%)</i>
Line A: new shelters	1500	1700	13.3
Line B: no shelters	1950	2000	2.5

84

84

## Evaluation of Completed Projects

### Example 13.5

85

85

## Evaluation of Completed Projects

### Example 13.5

- ↪ Compare the effectiveness of rail and bus based on the experience with
  - A rail transit line serving downtown Philadelphia and a suburb of New Jersey
    - ❖ known as the Lindenwold Line,
    - ❖ Serves 12 stations with 24-hour service per day,
  - An express bus line connecting downtown Washington, D.C., with the Virginia suburbs.
    - ❖ known as the Shirley Highway,
    - ❖ Extends for 11 miles, with no stations along the way and with bus service provided on exclusive lanes only during the peak hour.



- ↪ Determine the relative effectiveness

86

86

## Evaluation of Completed Projects

### Example 13.5 – Solution

- ↪ A comparative analysis of each project was made after they had been in operation for several years was performed
- ↪ Measures of effectiveness were considered from the viewpoint of
  - The passenger
  - The operator
  - The community
- ↪ A detailed evaluation for each parameter was prepared that both
  - Described how each system performed
  - Discussed its advantages and disadvantages.

87

87

## Evaluation of Completed Projects

### *Example 13.5 – Solution*

↪ A summary of the comparative evaluations of the two systems is shown in Table 13.11

**Table 13.11** Comparative Evaluation of Completed Rail and Bus Transit

<i>Measure of Effectiveness</i>	<i>Lindenwold (Rail)</i>	<i>Shirley (Bus)</i>	<i>Higher Rated System</i>
Investment cost	Very poor	Fair	Bus
Operating cost	Good	Fair	Rail
Capacity	Good	Poor	Rail
Passenger attraction	Very good	Good	Rail
System impact	Very good	Good	Rail

88

88

## Evaluation Based on Multiple Criteria

Evaluating Effects of Transportation on Social and Natural Systems

89

## Evaluating Effects of Transportation on Social and Natural Systems

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- Transportation projects impact both **social systems** (communities, lifestyles) and **natural systems** (environmental resources)
- Evaluation must go **beyond cost and ridership metrics** to **consider broader implications**

### Key Areas of Evaluation:

- **Social Impacts:**
  - Displacement of residents or businesses, Equity of access across different population groups, Changes in land use or neighborhood cohesion
- **Natural System Impacts:**
  - Air and water pollution, Habitat fragmentation or loss, Noise and visual intrusion
- ❑ **Purpose:** To ensure that transportation decisions promote **sustainable development**, minimize negative impacts, and **enhance community well-being**

90

## Steps for Evaluating Effects of Transportation on Social and Natural Systems

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### 👉 Step 1: Assess the Need for the Project.

- Addresses the question: **Why do it at all?**
  - ❖ That is, **how does the proposed project advance the stated goals and objectives**
  - ❖ **Does the project represent the best use of funds when compared with other options?**

### 👉 Step 2: Conduct a Feasibility Analysis of the Alternatives.

- Addresses the question : **Why do it this way?**
  - ❖ That is, **has the project been demonstrated to be a feasible one from an engineering perspective?**
  - ❖ **What are the costs involved in the project?**
  - ❖ **Are there other methods or approaches that could achieve a similar result at a lower cost in time and money?**

91

91

## Steps for Evaluating Effects of Transportation on Social and Natural Systems

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### Step 3: Analyze the Impact of the Project.

➤ Addresses the question: If the project is feasible, what will be its impact on affected groups?

↳ Affected groups include

1. The users of the transportation improvement
2. The community
3. Other stakeholders who will be impacted by the construction of the project.

↳ These effects are categorized into three major effects.

- A. Transportation system effects
- B. Social and economic effects
- C. Natural systems effects

92

92

## Steps for Evaluating Effects of Transportation on Social and Natural Systems

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### ↳ Step 3 (a): Transportation System Effects.

➤ These are effects experienced by the travelers who use the transportation facility,

❖ such as motorists, transit riders, and commercial vehicles.

➤ They comprise the following elements.

- ❖ Changes in travel time
- ❖ Changes in safety
- ❖ Changes in vehicle operating costs

93

93

## Steps for Evaluating Effects of Transportation on Social and Natural Systems

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### ↩ Step 3 (b): Social and Economic Effects.

- These are analyzed to determine the impact that a transportation project could have on the community and its residents.
- These studies are also conducted to meet federal and state requirements regarding environmental impact, civil rights, and environmental justice.
- They comprise the following elements:
  - ❖ Accessibility
  - ❖ Community cohesion
  - ❖ Economic development
  - ❖ Traffic noise
  - ❖ Visual quality
  - ❖ Property values

94

94

## Steps for Evaluating Effects of Transportation on Social and Natural Systems

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### ↩ Step 3 (c): Natural Systems Effects.

- These refer to those impacts of transportation projects that are related to the environment within which the project will be located.
- ↩ Among the natural elements that may be affected are
  - Air and water quality
  - Endangered species
  - Wildlife
  - Greenhouse gas emissions
  - Archeological sites
  - Energy conservation
  - Areas of cultural or historic significance

95

95

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# Is the Evaluation of Transportation Projects Important ?

96

96

## Is the Evaluation of Transportation Projects Important?

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### In the Context of Jordan's Infrastructure Development

- **Limited national budget** requires making **well-informed investment decisions**
- Evaluation ensures that projects like the **BRT (Bus Rapid Transit)** and **Desert Highway upgrades** deliver **maximum public benefit**
- Helps identify **economic, social, and environmental trade-offs** before construction

97

## Examples of Transportation Project Evaluation in Jordan

### 1. Amman BRT System

- **Objective:** Improve urban mobility and reduce congestion
- **Estimated Cost:** ~\$166 million JOD

### 2. Desert Highway Rehabilitation (Amman–Aqaba)

- **Objective:** Enhance safety and regional trade flow
- **Estimated Cost:** ~\$230 million JOD (funded with USAID and Gulf grants)

### 3. Queen Alia International Airport Access Road Upgrades

- **Objective:** Improve airport connectivity and reduce delays
- **Estimated Cost:** ~\$60 million JOD

98

## Is the Evaluation of Transportation Projects Important ?

### Amman Bus Rapid Transit

- is a **166 million (JD)** under-construction bus rapid transit transportation system in Amman, Jordan



“آراء مغايرة؟

“المختص في هندسة الطرق والمرور في جامعة العلوم التطبيقية، شاكر محادين، ينتقد الكلفة العالية للمشروع ومتطلباته، ويشكك في جدواه. "طول مسار الباص السريع ٣٢ كم يتخلله ٢١ موقفا يعني أن الباص لم يعد سريعا وأن الوقت الزمني للرحلة طويل  
"موقع عمان نت ٢٠١١،



99

99

## Optimum transportation system for the city of Amman

Al-Habahbeh O. M., Al-Sous H., Al-Omari M.  
Mechatronics Engineering Department, The University of Jordan  
Technical Report, June 2018

*Keywords: Transportation, Monorail, Bus Rapid Transit, Ridership, Route, PPHPD*

### Abstract

The inefficient transportation system in Amman results in difficulties such as traffic jams and long passenger waiting times, which means wasting time, money, and efforts. Therefore, the public is demanding a solution to this problem. Building an effective transportation system is considered one of the most important aspects of becoming a smart city. Other aspects include e-government, health and social services, as well as education and culture. In Amman, the number of population has multiplied several times over the past decades, causing a huge transportation problem. In this study, the optimum transportation system for the city of Amman is investigated. The problem is addressed using a systematic approach, where different transportation alternatives are analyzed and compared, especially as to their suitability to the city of Amman. That includes its size, topography, and population density. These alternatives include normal buses, underground Subway, Monorail, light rail transit (LRT), Tram, and bus rapid transit (BRT) system. Cost-effective solutions are proposed based on the results of the study. Eventually, it is recommended that monorail system is the best transportation solution for Amman.

100

100

## Comparison Between Monorail System and BRT System in Amman City

Scientific Paper of Fourth Jordan International Conference and Exhibition for Roads and Traffic

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101

101

# *Transportation Engineering and Planning*

Module | 6 | Urban Mass transit

## 6.1 | Urban mass transit systems Definitions And Classification

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1

## Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
1. Introduction to transportation systems	1/3	1
2. Transportation planning	1	3
3. Demand forecasting using 4 steps modeling	4	12
4. Engineering economy in transportation	3	9
5. Evaluation of transportation alternatives	2	6
<b>6. Urban mass transit systems</b>	3 2/3	11
7. Airports	1	3
Total	15	45

2

2

# Overview

3

## Introduction to Transport Systems

### ↪ Definition:

- *An organized network that moves people and goods between locations using vehicles, infrastructure, and operations.*

### ↪ Core Elements:

- *Modes, infrastructure, control systems, and operational policies.*

### ↪ Purpose:

- *Enable safe, efficient, and reliable movement to meet economic, social, and environmental needs.*

### ↪ Types:

- *Passenger transport, freight transport, or combined systems.*

### ↪ Jordan Example:

- *National road network, Amman BRT, Aqaba Port, and Queen Alia International Airport.*

4

4

## Urban Transportation Modes

- ↪ ▪ **Definition:**  
Various methods used to move people (and sometimes goods) efficiently within urban areas
- ↪ ▪ **Key Characteristics:**  
Designed to provide mobility, accessibility, and connectivity within cities
- ↪ ▪ **Role in Urban Systems:**  
Support daily travel needs, economic activities, and urban development
- ↪ ▪ **Common Examples:**  
Buses, private cars, taxis, ride-hailing services, light rail, and metro systems
- ↪ ▪ **Importance:**  
Influence traffic conditions, energy use, environmental impacts, and quality of life in cities

5

5

## Urban Transportation Modes classification

- ↪ **Urban transportation modes can be classified according to several bases:**
  - ☐ **By Type of Usage** – Private, public, and for-hire (paratransit) services.
  - ☐ **By Transit Modes** – Right-of-way, technology, and service type.
  - ☐ **By Generic Classes of Transit Modes** – Street, semirapid, and rapid transit (most important).
- ↪ **Purpose of Classification:**
  - ☐ **Improve Planning & Operations:**  
*Structure and organize diverse transportation options efficiently*
  - ☐ **Enable Performance Comparison:**  
*Evaluate modes based on cost, capacity, speed, and service quality*
  - ☐ **Support Decision-Making:**  
*Guide policy formulation, infrastructure investment, and system design*

6

6

# Transport Systems and Classification

## *1. Classification by type of Usage*

7

7

## Classification by Type of Usage — What is it?

- ↪ **Classification by type of usage** means grouping transportation modes based on **who uses them and how they are accessed**.
- ↪ In simple terms, it focuses on the **user perspective** rather than the technology or infrastructure.

8

8

# Primary Classification of Transport

## ↩ Private Transport

- ❑ Used by individuals or households
- ❑ Fully controlled by the owner
- ❑ Examples: cars, motorcycles, bicycles

## ↩ Public Transport ( Mass transit)

- ❑ Open to everyone
- ❑ Operates on fixed routes and schedules
- ❑ Shared by many passengers
- ❑ Examples: buses, metro, trains

## ↩ For-Hire / Paratransit

- ❑ Available on demand or flexible routes
- ❑ Paid per trip or service
- ❑ More flexible than public transport
- ❑ Examples: taxis, ride-hailing (Uber), minibuses

9

9

# For-Hire Urban Passenger Transportation (Paratransit)

## ↩ Definition:

- Flexible transport service provided by a driver or company, available to anyone who pays a fare, with routes and services adaptable to passenger needs

## ↩ Demand-Responsive Services:

- No fixed routes or schedules
- Operate based on passenger requests
- High flexibility (door-to-door or shared service)
- Examples: Uber, Careem, Dial-a-Ride

## ↩ Fixed-Route / Fixed-Schedule Services:

- Operate on predefined routes and timetables
- Shared, semi-formal transport
- Examples: Jitneys, shared minibuses

## ↩ Key Characteristics:

- More flexible than public transport
- Intermediate between private and public modes
- Often informal or semi-regulated



10

10

## Secondary Classification of Transport

- ↪ **Definition:**  
Classification based on **who shares the vehicle during the trip**
- ↪ **Individual Transport:**
  - Vehicle serves **one person or a pre-arranged group**
  - Offers **high privacy and exclusivity**
  - Example: *Private car*
- ↪ **Group Transport:**
  - Vehicle carries **multiple unrelated passengers**
  - Focus on **shared use and higher efficiency**
  - Examples: *Bus, metro, shared taxi*
- ↪ **Key Insight:**
  - Individual transport prioritizes **comfort and flexibility**
  - Group transport prioritizes **capacity and efficiency**

12

12

## Transport Systems and Classification

### Classification by Type of Usage

**Table 2.1** Classification of urban passenger transportation by type of usage

Characteristic	Usage type				
	Private	For-hire		Public or Common Carrier	
Common designation	Private transportation	Paratransit		Transit	
Service availability	Owner	Individuals, groups		Public	
Service supplier	User	Carrier		Carrier	
Route determination	User (flexible)	User (carrier)		Carrier (fixed)	
Time-schedule determination	User (flexible)	User (carrier)		Carrier (fixed)	
Cost-price	User absorbs	Fixed rate		Fixed fare	
Carrier type	Individual		Group		
Modes	Walking Bicycle Motorcycle Automobile	Carpools Vanpools	(Rental car) Car sharing Taxi	Dial-a-ride Jitney (Charter bus)	Street transit (bus, trolleybus, streetcar) Semirapid transit (bus rapid transit, light rail transit) Rapid transit (rail and rubber-tired metros, regional rail) Specialized modes
Optimum (but not exclusive) domain of operation					
Area density	Low-medium	Origin: low; Destination: high	Any	High-medium	
Routing	Dispersed	Radial	Dispersed	Concentrated (radial), ubiquitous	
Time	Off-peak	Peak only	All times	Peak, daily hours	
Trip purposes	Recreation, shopping, business, other	Work only	Business Special services	Work, school, business, social, other emergency	

13

13

# Transport Systems and Classification

## Classification by Type of Usage



14

14

# Transport Systems and Classification

## *2. Classification by transit Modes*

15

15

# Transport Systems and Classification

## Classification by Transit Modes



### Definition:

Classification of transportation systems based on their **operational characteristics**, including infrastructure, technology, and service type



**Key Idea:** Transit modes are classified based on **how they operate**, not who uses them

Classification is based on three key aspects:



### Right-of-Way (ROW):

- The path or corridor where transit vehicles operate
- Determines the level of separation from other traffic
- Greater separation leads to higher speed, safety, and reliability



### System Technology:

- Refers to vehicle and infrastructure features
- Includes propulsion type (diesel, electric) and guidance system (road, rail)
- Affects system performance, capacity, and cost



### Type of Service:

- Describes how the system operates for passengers
- Includes service patterns such as local, express, and peak-only services

16

16

# Transport Systems and Classification

## Classification by transit Modes

### A. Right-of-way (ROW) category

17

17

# Transit Mode Classification

## A. Right-of-way (ROW)

↪ **Definition:** The **travel corridor or pathway** (road, track, or lane) where transit vehicles operate

↪ **What ROW Represents:**

- The **degree of separation** between transit vehicles and other traffic
- A key factor that influences **speed, safety, reliability, and system performance**



18

18

# Transit Mode Classification

## A. Right-of-way (ROW) category

↪ **Three ROW Categories:**

- **Category C (Mixed Traffic):**  
Transit operates **within general traffic** with no separation
- **Category B (Partially Separated):**  
Transit has **some priority or dedicated space**, but still interacts with traffic
- **Category A (Fully Separated):**  
Transit operates on **exclusive corridors** with no interference

↪ **As We Move from C → A:**

- Increasing **separation from other traffic**
- Improved **performance** (higher speed, capacity, reliability)
- Increased **infrastructure and investment costs**

↪ **Key Insight:** Greater separation leads to **better service quality**, but requires **higher cost**

19

19

## A. Right-of-way (ROW) category

### Category C

- ↪ **Definition:**  
Transit operates on **surface streets shared with general traffic (no separation)**
- ↪ **Advantages:**
  - *Lowest capital and operating cost*
  - *Minimal infrastructure requirements*
  - *Low environmental and urban disruption*
- ↪ **Limitations:**
  - *Lowest service performance*
  - *Travel speed and reliability depend on traffic conditions*
  - *High susceptibility to congestion and delays*
- ↪ **Possible Improvements:**
  - *Marked reserved lanes within roadway*
  - *Transit signal priority at intersections*



20

20

## A. Right-of-way (ROW) category

### Category B

- ↪ **Definition:**
  - ROW where transit is **physically separated from general traffic along parts or all of its route**
- ↪ **Separation Methods:**
  - *Curbs* : Physical raised edges along the roadway.
  - *Barriers* : Stronger physical divisions, such as concrete walls, guardrails.
  - *Grade separation* : Different transport streams are placed at different vertical levels (e.g., overpasses, underpasses).
- ↪ **Common Uses:**
  - *Light Rail Transit (LRT) systems*
  - *High Occupancy Vehicle (HOV) lanes*
  - *Bus Rapid Transit (BRT) corridors (partially separated)*
- ↪ **Key Feature:** Provides **better traffic flow** than general lanes but **does not separate** public from private vehicles.



21

## A. Right-of-way (ROW) category Category B

Tram in Rotterdam, Netherlands



Tram in Portland, Oregon



Bus in transit mall, Denver, Colorado



22

## A. Right-of-way (ROW) category High occupancy vehicle (HOV) lanes

### ↩ Also Known As:

- HOV lane, carpool lane, diamond lane, 2+ lane
- Transit lane (T2 or T3 lanes)

### ↩ Definition:

- A **restricted traffic lane** reserved exclusively for vehicles with a driver **and** one or more passengers.

### ↩ Common Users:

- Carpools
- Vanpools
- Transit buses



[https://en.wikipedia.org/wiki/High-occupancy\\_vehicle\\_lane](https://en.wikipedia.org/wiki/High-occupancy_vehicle_lane)

23

23

## A. Right-of-way (ROW) category Category A

- ↪ **Definition:**  
A fully access-controlled and physically separated ROW, with no intersections or interference from other vehicles or pedestrians
- ↪ **Also Referred To As:**
  - *Grade-separated ROW, Exclusive ROW, Private ROW*
- ↪ **Key Characteristics:**
  - *Complete separation from all other traffic*
  - *Uninterrupted flow (no signals or crossings)*
  - *Highest levels of speed, capacity, and reliability*
- ↪ **Typical Forms:**
  - *Underground tunnels, Elevated (aerial) structures, At-grade exclusive corridors (fully protected)*
- ↪ **Key Idea:** Category A provides the **highest performance and service quality**, but requires the **highest investment cost**



24

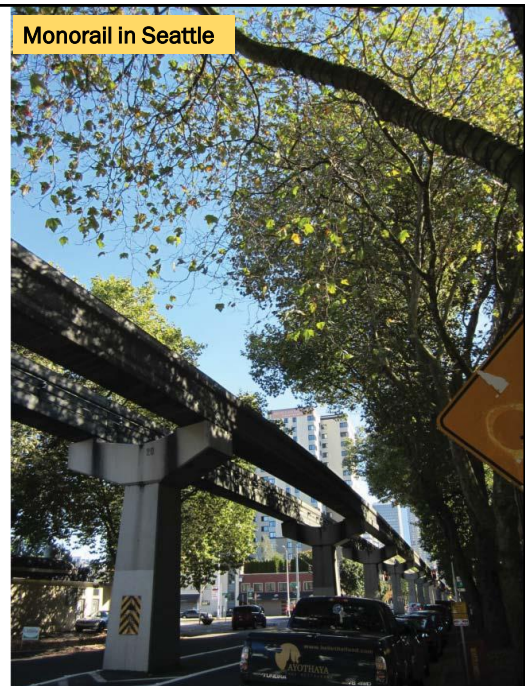
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## A. Right-of-way (ROW) category Category A

Light rail transit in Los Angeles



Monorail in Seattle



25

25

Feature	Category C	Category B	Category A
<b>Separation from Other Traffic</b>	Mixed with general traffic	Physically separated by curbs, barriers, or grade separation	Fully access-controlled, no intersections or external access
<b>Investment Requirement</b>	Low	Medium	High
<b>Cost</b>	Lowest	Moderate	Highest
<b>Service Performance</b>	Lowest (depends on general traffic flow)	Moderate	Highest (independent from traffic)
<b>Preferential Treatment</b>	Reserved lanes or signals possible	Separation plus priority for transit	Exclusive use for transit
<b>Impact on General Traffic</b>	High (competes for space)	Medium	Low (separate facility)

↗ **As moving From C → A:**

- Greater separation from other traffic.
- Higher performance (speed, capacity, reliability).
- Higher investment costs.

26

## A. Right-of-way (ROW) category

What do you think ?



The photograph shows a wide, multi-lane urban street with heavy traffic. There are several lanes in each direction, with cars and some larger vehicles. The street is flanked by buildings and some greenery. The overall scene depicts a typical high-traffic urban environment.

27

## A. Right-of-way (ROW) category

*What do you think ?*



28

28

# Transport Systems and Classification

## 2. Classification by transit Modes

### B. System technology

29

29

# Transit Mode Classification

## B. System technology

- ↪ **Definition:** Refers to the **mechanical and operational characteristics** of transit vehicles and their infrastructure
- ↪ **Four Key Features:**
- ↪ **Support:**
  - Method by which the vehicle is physically **supported and carried**
  - Examples: wheels on rails, rubber tires on pavement, magnetic levitation
- ↪ **Guidance:**
  - Means of **directing vehicle movement** along a defined path
  - Examples: rails, guided busways, automated steering systems
- ↪ **Propulsion:**
  - Type of **power source and traction method**
  - Examples: electric motors, internal combustion engines, cable-driven systems
- ↪ **Control:**
  - System used to **manage and regulate vehicle movement**
  - Examples: signaling systems, automated train control, driver operation

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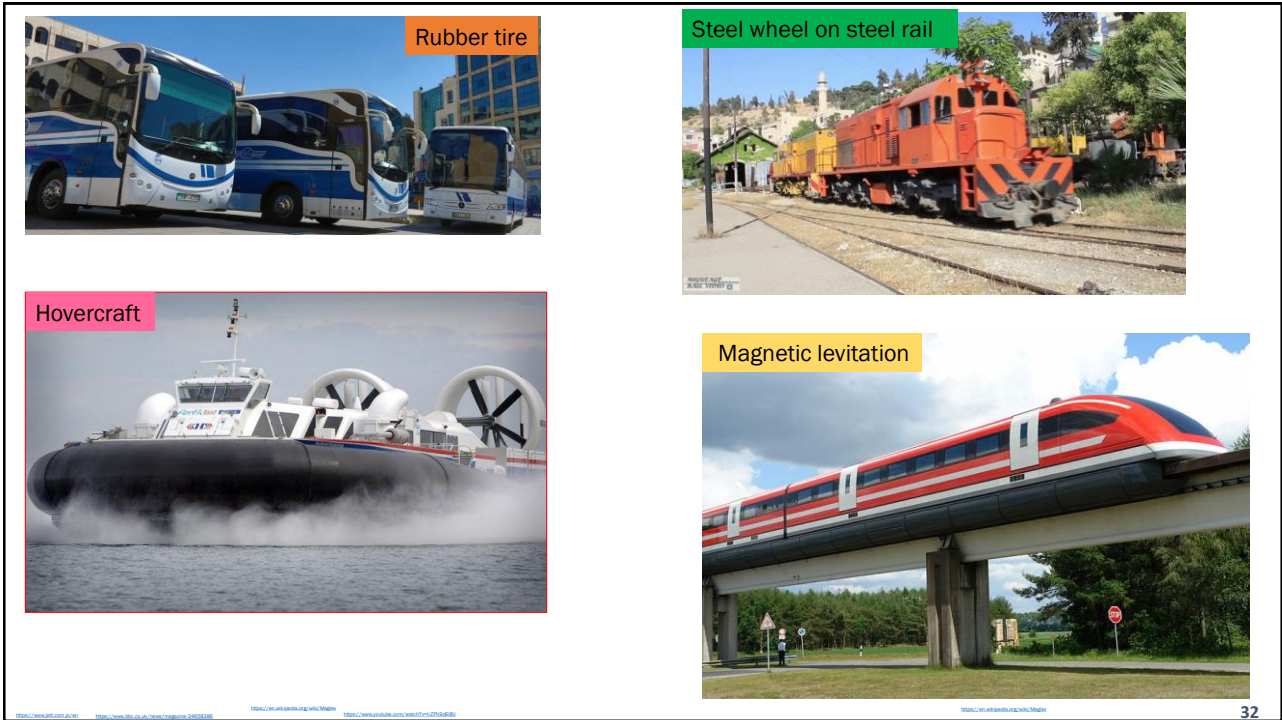
# B. System technology

## Support

- ↪ **Definition:**
  - The **physical interface between the vehicle and the surface** that supports and carries it
  - Transfers **vehicle weight and traction forces**
  - Determines how the vehicle is **physically sustained and stabilized**
- ↪ **Support Types:**
  - **Common Systems:**
    - ❖ Rubber tires on pavement (e.g., buses, cars)
    - ❖ Steel wheels on steel rails (e.g., trains, trams)
  - **Alternative Systems:**
    - ❖ Water support (boats, hydrofoils)
    - ❖ Air cushion systems (hovercraft)
    - ❖ Magnetic levitation (maglev trains)

31

31



# Transport Systems and Classification

## 2. Classification by transit Modes

### C. Types of Service

33

## 2. Classification by transit Modes

### Types of Service

#### ↪ Definition:

- Describes **how transit services are operated and provided to passengers**

#### ↪ Classification is based on three main characteristics:

##### ➤ **Type of Routes and Trips Served:**

Defines the **pattern of movement** (e.g., local, express, regional routes)

##### ➤ **Stopping Pattern / Operation Type:**

Determines **how frequently vehicles stop**  
(e.g., all stops, limited-stop, express service)

##### ➤ **Time of Operation:**

Specifies **when the service runs**  
(e.g., peak hours, off-peak, all-day service)

34

34

## C. Types of Service Classification

### 1. Types of routes and trips served

#### ↪ Classified into:

##### ↪ **A. Short-Haul Transit:**

- Low- to medium-speed services operating within **small, high-density areas**
- Serves locations such as, **campuses, airports areas**

##### ↪ **B. City Transit (Most Common):**

- Covers **entire urban areas** with multiple transit lines
- Operates on **any ROW category (C, B, or A)**
- Designed for **daily urban travel**

##### ↪ **C. Regional Transit:**

- Provides **long-distance, high-speed services** with fewer stops
- Connects areas within a **metropolitan or regional scale**
- Examples include **regional rail and express bus services**

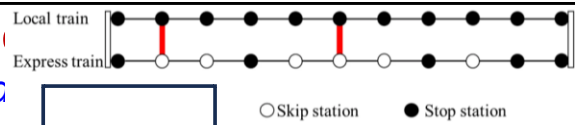


35

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## C. Types of Service Classification

### 2. Stopping schedule or type of operation



#### Classified into:

##### A. Local Service:

- All transit units **stop at every station or stop**
- May also stop **on demand (as requested by passengers)**
- Provides **maximum accessibility but lower speed**

##### B. Accelerated Service (Skip-Stop):

- Transit units **stop at selected stations only**
- Different vehicles **serve different sets of stops**
- Operates on a **predefined schedule**
- Improves **travel time while maintaining reasonable coverage**

##### C. Express Service:

- Transit units **stop only at widely spaced major stations**
- Often runs **parallel to local service**
- Serves **fewer stops for faster travel over longer distances**

36

36

## C. Types of Service Classification

### 3. by time of operation Classified into:

##### A. Regular (All-Day) Service:

- Operates during **most hours of the day**
- Forms the **core public transit network**
- Provides **continuous, reliable service for daily travel**
- Example: City bus services from **early morning to late evening**

##### B. Commuter (Peak-Hour) Service:

- Operates mainly during **rush hours (morning and evening)**
- Designed for **work trips to and from major activity centers**
- Complements regular service but **does not replace it**
- Example: Express buses connecting **residential areas to downtown**

##### C. Special or Irregular Service:

- Operates only during **specific events or exceptional conditions**
- Not part of the regular daily schedule
- Used to manage **temporary or unusual travel demand**
- Example: Shuttle services for **events, festivals, or emergencies**



37

37

## C. Types of Service Classification (Summary Table)

Basis of Classification	Type of Service	Definition	Examples
1. By Routes / Trips Served	Short-haul transit	Low/medium speed service in small high-density areas (CBDs, campuses, airports)	Campus shuttle, airport people-mover
	City transit	Transit serving entire city, may operate on any ROW (C, B, A)	Regular city bus, tram
	Regional transit	High-speed, long lines with few stops, serving regional trips	Regional rail, express buses
2. By Stopping Schedule / Operation	Local service	All vehicles stop at all stops as required	Local city bus
	Accelerated service	Skip-stop operation; successive vehicles skip different stops	Some subway lines (e.g., NYC skip-stop trains)
	Express service	Stops only at major or widely spaced stations; parallels local service	Express buses, commuter rail
3. By Time of Operation	Regular / All-day service	Runs during most daily hours; backbone service	City buses, metro lines
	Commuter (Peak-hour) service	Runs only at rush hours; radial to CBD; work-oriented	Commuter trains, peak-only express buses
	Special / Irregular service	Runs only during special events or emergencies	Event shuttles, emergency evacuation buses

38

38

# Transport Systems and Classification

## 4. Classification by generic Classes of Transit Modes

39

39

## Transport Systems and Classification

- ↳ Urban transportation modes and operational concepts can be classified according to several different bases include
  - Classification by type of Usage
  - Classification by transit Modes
  - Classification by generic Classes of Transit Modes (Most important)

40

40

## Classification by Generic Classes of Transit Modes — What Is It?

- ↳ **Definition:**  
Classification of transit systems into **broad functional groups** based on their **overall level of performance, speed, and degree of separation from traffic**
- ↳ **Main Idea:**  
It groups transport modes into **general categories** rather than focusing on detailed technical features
- ↳ **Key Idea:**  
This classification shows the **progression from low-performance to high-performance systems**
- ↳ **Important Note:**  
It is based **mainly (but not only)** on **Right-of-Way (ROW)** and operational efficiency

41

41

# Transport Systems and Classification

## 3. Generic Classes of Transit Modes

- ↪ The most important classification of transit modes is into three generic classes include
  - A. *Street transit (or surface transit)*
  - B. *Semirapid transit*
  - C. *Rapid transit*
  - D. *Specialized Transit*

42

42

## 4. Generic Classes of Transit Modes

### A. *Street transit (surface transit)*

- ↪ **Definition:**  
Operates on **urban streets in mixed traffic** (ROW Category C) with no physical separation
- ↪ **Common Modes:**
  - **Buses:** *Conventional city buses operating in traffic*
  - **Trolleybuses:** *Electric buses powered by overhead wires*
  - **Streetcars / Trams:** *Rail vehicles running on city streets*



43

## 4. Generic Classes of Transit Modes

### A. Street transit (surface transit)

#### ↩ Key Characteristics:

- **Reliability:** Strongly affected by traffic conditions (congestion, signals, accidents)
- **Speed:** Generally **low and variable** due to frequent stops and traffic interference
- **Flexibility:** High route flexibility and easy network coverage
- **Capacity:** Relatively low compared to higher transit classes

#### ↩ Key Idea:

Street transit offers **high accessibility and flexibility**, but **lower speed and efficiency** due to operation in mixed traffic



44

## 4. Generic Classes of Transit Modes

### B. Rapid transit

↩ **Definition:**  
Operates **exclusively on fully separated ROW (Category A)** with no interaction with other traffic

#### ↩ Examples:

- Metro / Subway systems
- High-capacity urban rail (e.g., Dubai Metro)

#### ↩ Key Features:

- **Very high speed, capacity, and reliability**
- **Fully independent of road traffic conditions**
- Uses **guided systems** (rail or automated rubber-tire)
- Equipped with **advanced signaling and control systems**

#### ↩ Performance:

- Enables **high passenger throughput**
- Provides **continuous, uninterrupted service**
- Suitable for **major urban corridors with high demand**



45

45

## 4. Generic Classes of Transit Modes

### C. Semirapid transit

↪ **Definition:** Transit systems operating **mainly on partially separated ROW (Category B)**, with some sections on mixed traffic (C) or fully separated ROW (A)

↪ **Examples:**

- **Low-end:** Buses or Light Rail Transit (LRT) sharing space with street traffic
- **High-end:** LRT systems with **grade separation** (tunnels or elevated sections)

↪ **Key Characteristics:**

- **Moderate speed and capacity** compared to other classes
- Operates with **partial priority or dedicated lanes**
- **Reduced interaction with traffic** compared to street transit

↪ **Performance Factors:**

- **ROW Separation:** Greater separation → **higher speed and reliability**

↪ **Key Advantage:**

- Provides a **balance between flexibility and performance**
- Combines **accessibility of street transit with speed and reliability of rapid transit**



46

46

## Clarification — Rapid vs. Semirapid Transit

↪ **Misuse of Term:**

- “Rapid transit” is **often incorrectly used** to describe **semirapid systems**
- **Examples of misuse:** some **BRT and Light Rail (LRT)** systems

↪ **Correct Definition:**

- **True rapid transit** operates with **complete grade separation (ROW Category A)**
- **No interaction with road traffic**

↪ **Key Distinction:**

- **Semirapid (B):** Partial separation → moderate speed and reliability
- **Rapid (A):** Full separation → highest speed, capacity, and reliability



47

47

## D. Specialized Transit

- ↪ **Definition:**  
A group of transit modes that **do not fit into the main street, semirapid, or rapid transit categories**, and are designed for **special operating conditions, technologies, or environments**
- ↪ **Examples (from the table):**
  - *Cable car, Cog railway, Funicular, Aerial tramway (cable lift), Ferryboat, Hydrofoil*
- ↪ **Key Characteristics:**
  - *Operate in **specific environments** (mountains, water, steep slopes, tourist areas)*
  - *Use **special technologies** (cables, water propulsion, inclined tracks)*
  - *Often **limited in network coverage***
  - *Typically serve **specific functions** (tourism, crossing barriers, special routes)*
- ↪ **Key Difference from Other Classes:**
  - *Not classified based on **ROW (A, B, C)** like other transit*
  - *Instead classified by **unique operating method or environment***

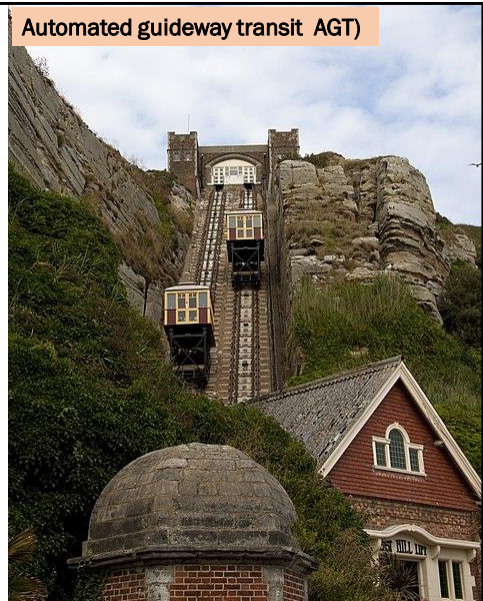
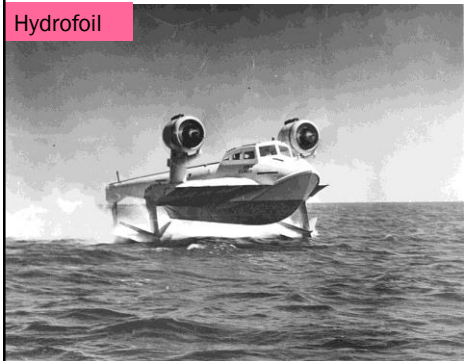
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48



49

49



50

50

Determinant factors	Categories/types	Basic characteristics	Individual modes <sup>a</sup>	Generic classes
Separation from other traffic	C B A	Right-of-way categories	(Paratransit modes)	
			Shuttle bus Regular bus Express bus/street Trolleybus Streetcar/tramway	Street transit
Support Guidance Propulsion -Motor/engine -Traction Control	Highway: driver-steered	Technology	Bus rapid transit Light rail transit AGT shuttle	Semirapid transit
	Rubber-tired: guided, semiguided Rail Special		Automated guided transit Light rail rapid transit Rubber-tired rapid transit Monorails Rail rapid transit/metro Regional rail	Rapid transit
Line length Type of operation Trips served	Short-haul City Regional	Types of service	Cable car Cog railway Funicular Aerial tramway Ferryboat Hydrofoil	Specialized transit
	 Local Accelerated Express			
<sup>a</sup> The list is not exhaustive.				

*Comprehensive classification framework for transit modes,*

51

51

# Transit System Components

52

52

## Transit System Components

*Physical components of the transit systems are generally classified into the following items:*

1. Vehicles or Cars
2. Ways, travel ways, or rights-of-way, which may be
3. Locations and facilities
4. *Bus garages or depots and rail yards*
5. *Control systems*
6. *Intelligent Transportation System (ITS)*
7. *Power supply systems on electrically powered modes*
8. *Transit route or transit line*

53

53

## Transit System Components

### 1. Vehicles (Cars)



#### Definition:

Vehicles used to **transport passengers**, collectively called the **fleet** (or *rolling stock* in rail systems)



#### Key Concepts:

- **Fleet:** *All vehicles operating in the system*
- **Rolling stock:** *Rail vehicles (trains, metro cars)*



#### Transit Unit (TU):

- **A group of vehicles operating together**
- **Can be:**
  - ❖ **Single unit** (one bus or rail car)
  - ❖ **Multiple coupled vehicles** (train set)

54

54

## Transit System Components

### 2. Ways / Travel Ways / Right-of-Way (ROW)



#### Definition:

The **physical paths or corridors** on which transit vehicles operate



#### Types of ROW:

- **Common streets and roads:** *Shared with general traffic*
- **Reserved lanes:** *Dedicated lanes (marked but not physically separated)*
- **Exclusive lanes:** *Fully separated from other traffic*
- **Transit streets:** *Priority given mainly to transit vehicles*
- **Busways:** *Fully separated roadways for buses only*

55

55

# Transit System Components

## 3. Locations and Facilities

↪ **Definition:** Locations where transit vehicles **stop to pick up and drop off passengers**, including supporting passenger facilities

**Includes:**

### ↪ 1. Stops

- Simple points along streets
- Basic facilities such as **signs, shelters, and benches**
- Used mainly for **bus and street transit systems**

### ↪ 2. Stations

- More developed facilities than stops
- Intermediate or regular points along a transit line
- Used for boarding and alighting passengers during the trip
- Located between the origin and destination
- Include platforms, ticketing, and passenger services

### ↪ 3. Terminals

- End points of transit routes or lines
- Handle large passenger volumes and vehicle turnaround
- May include **transfer facilities** for connecting multiple routes



56

## 3. Locations and Facilities (Example ) Haramain Railway – Jeddah

### ↪ Terminals (End Points):

- **Makkah (Haram) Station** → starting/ending point of the line
- **Madinah Station** → starting/ending point of the line

### Stations (Intermediate Stops):

- **Jeddah Station**
- **King Abdulaziz Airport Station (KAIA)**
- **King Abdullah Economic City (KAEC) Station**



57

57

# Transit System Components

## 4. Bus Garages / Depots and Rail Yards

- ↪ **Definition:**  
Facilities used for **vehicle storage, maintenance, and operations support**
- ↪ **Functions:**
  - **Parking and storage** of vehicles when not in service
  - **Maintenance and repair** (workshops/shops)
  - **Inspection and cleaning** before deployment
  - **Dispatching vehicles** into service
- ↪ **Types:**
  - **Bus garages / depots** → for buses and road vehicles
  - **Rail yards** → for trains, metro, and rail vehicles
- ↪ **Key Idea:**  
These facilities ensure the **availability, reliability, and readiness of the fleet**



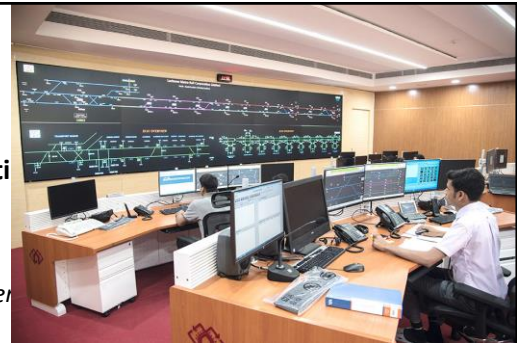
58

58

# Transit System Components

## 5. Control Systems

- ↪ **Definition:**  
Systems that **monitor, manage, and control transit operations**
- ↪ **Main Functions:**
  - **Vehicle detection and tracking**
  - **Communication and signaling** between vehicles and control centers
  - **Traffic management and coordination**
  - **Safety control and incident response**
- ↪ **Components:**
  - **Central control centers**
  - **Communication networks**
  - **Signaling systems (especially for rail)**
- ↪ **Examples:**
  - **Metro control rooms**
  - **Bus fleet monitoring systems (GPS)**



59

59

## Transit System Components

### 7. Power Supply Systems (Electric Modes):

- Provide **energy required for vehicle operation**
- Example: **Catenary systems (overhead wires)**
- Mainly used for **electric transit modes** such as metro, tram, and electric trains



60

60

## Transit System Components

### 8. Transit Route / Transit Line:

- A **designated path or corridor** regularly used by transit vehicles
- Can follow **streets (for buses)** or **exclusive ROW (for rail systems)**

#### ↪ Terminology:

- **Route:** Commonly used for **bus systems**
- **Line:** Commonly used for **rail systems** or shared corridors
- Both terms may sometimes be **used interchangeably**

#### ↪ Additional Concept:

- The combination of all routes/lines in a city forms the **transit network**

61

61

# Transit System Operations, Service , and Characteristics

62

62

## Transit System Characteristics

↩ **Definition:**  
Transit systems are evaluated based on **how effectively they serve passengers and society**, not only by their physical components

### Key Characteristics:

#### ↩ 1. System Performance:

- *Measures how well the system operates overall*
- *Includes **speed, capacity, reliability, and efficiency***
- *Indicates the ability to handle passenger demand*

#### ↩ 2. Level of Service (LOS):

- *Describes the **quality of service experienced by passengers***
- *Includes factors such as: **Comfort***
  - ❖ **Waiting time**
  - ❖ **Accessibility**
  - ❖ **Convenience**

63

63

# Transit System Characteristics

↩ **Definition:** Transit systems are evaluated based on **how effectively they serve passengers and society**, not only by their physical components

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- *Indicates the ability to handle passenger demand*

↩ **2. Level of Service (LOS):**

- *Describes the **quality of service experienced by passengers***
- *Includes factors such as: , Comfort , Waiting time, Accessibility, Convenience*

↩ **3. Impacts:**

- *Effects of the transit system on **society and the environment***
- *Includes: Traffic congestion reduction,, Environmental impact (emissions, noise) , Urban development and land use*

↩ **4. Costs:**

- *Financial aspects of the system*
- *Includes: Capital cost (infrastructure, vehicles), Operating and maintenance cost*
- *Important for evaluating **economic feasibility***

64

64

## 1. System performance

*Main Indicators:*

↩ **A. Service Frequency (f):**

- *Number of **transit units (TU) departures per hour***
- *Higher frequency → **shorter waiting time***
- *Improves passenger convenience and accessibility*
- **Example:**

- ❖ *If **f = 6 buses/hour** → one bus every **10 minutes***
- ❖ *If **f = 12 buses/hour** → one bus every **5 minutes***
- ❖ *Increasing frequency from 6 to 12 → waiting time reduced by **50%***

65

65

## 1. System performance

### Main Indicators:

#### ↪ B. Operating Speed (Vo):

➤ Average speed experienced by passengers along the route

➤ Influenced by:

- ❖ Number of stops
- ❖ Traffic conditions
- ❖ Type of Right-of-Way (ROW)

➤ Higher speed → **shorter travel time**

➤ **Example:**

- ❖ Trip distance = **15 km**
- ❖ Case 1: Speed = **20 km/h** → time =  $15 \div 20 = 45$  minutes
- ❖ Case 2: Speed = **30 km/h** → time =  $15 \div 30 = 30$  minutes
- ❖ Increasing speed saves **15 minutes per trip**

66

66

## 1. System performance

### Main Indicators:

#### ↪ C. Reliability:

➤ Consistency of service relative to the schedule

➤ Measured by **on-time performance**

➤ Higher reliability → **predictable service**

➤ **Example:**

- ❖ 100 scheduled trips
- ❖ 90 arrive within  $\pm 4$  minutes → **90% reliability**
- ❖ Another system: 70/100 on time → **70% reliability**

↪ First system is **more dependable for passengers**

67

67

## 1. System performance

### Main Indicators:

#### ↳ D. Safety:

- Degree of protection for passengers and property
- Measured by **accidents, injuries, and damage per passenger-km**
- Lower accident rate → **higher safety level**
- **Example:**
  - ❖ System A: **2 accidents per 100 million passenger-km**
  - ❖ System B: **0.5 accidents per 100 million passenger-km**
  - ❖ System B is **4× safer** than System A

68

68

## 1. System performance

### Main Indicators:

#### ↳ F. Line Capacity (C):

- Maximum number of **passengers or spaces** that transit units (TUs) can carry past a point per hour
- Depends on **vehicle size + frequency**
- **Example:**
  - ❖ Bus capacity = **80 passengers**
  - ❖ Frequency = **20 buses/hour**
  - ❖ Capacity =  $80 \times 20 = 1,600$  passengers/hour

↳ Increasing frequency or vehicle size increases total capacity

69

69

## 1. System performance

### Main Indicators:

#### ↳ G. Productive Capacity (Pc):

- Combines *speed (Vo)* and *capacity (C)*
- Formula:  $Pc = Vo \times C$
- Reflects overall system effectiveness (how much it moves and how fast)
- Example:
  - ❖ System A:
    - $Vo = 30 \text{ km/h}$ ,  $C = 1,500 \text{ passengers/hour}$
    - $Pc = 30 \times 1,500 = 45,000 \text{ passenger-km/hour}$
  - ❖ System B:
    - $Vo = 20 \text{ km/h}$ ,  $C = 2,000 \text{ passengers/hour}$
    - $Pc = 20 \times 2,000 = 40,000 \text{ passenger-km/hour}$
  - ❖ System A is more effective despite lower capacity

70

70

## 1. System performance

### Main Indicators:

#### ↳ H. Productivity:

- Output produced per unit of resource
- Productivity = Output ÷ Input
  - ❖ Output = service provided (e.g., vehicle-km, trips, passengers carried)
  - ❖ Input = resources used (e.g., cost, fuel, labor)
- Measures system efficiency from the operator perspective
- Example:
  - ❖ System A: **1,000 trip/day at cost \$10,000** → 0.1 trips per \$
  - ❖ System B: **1,500 trip /day at cost \$12,000** → 0.125 trips per \$
  - ❖ System B is more productive (more output per cost)

71

71

## 1. System performance

### Main Indicators:

#### ↳ I. Utilization:

➤ Ratio of **used capacity to offered capacity**

➤ Indicates how efficiently vehicles are filled

#### ➤ Example:

- ❖ Bus capacity = **100 seats**
- ❖ Average passengers = **60 passengers**
- ❖ Utilization =  $60 \div 100 = 60\%$
- ❖ Higher utilization → better use of resources (but too high may reduce comfort)

72

72

## 2. Level of Service (LOS)

### Main Indicators:

#### ↳ Definition:

LOS is the overall measure of service quality experienced by passengers

#### ↳ Meaning:

👉 How good and attractive the transit service is to users

#### ↳ Key Idea:

Higher LOS → more users choose transit

#### ↳ Major factors comprising LOS :

- Performance elements
- Service quality (SQ)
- Price

73

73

## 2. Level of Service (LOS)

### *Performance Elements*

↪ Includes basic system performance:

➤ *Operating speed*

➤ *Reliability*

➤ *Safety*

↪ **Effect:**

Better performance → **shorter travel time & more dependable service**

↪ **Example:**

➤ *Trip time = 30 min vs. 50 min*

➤ *Passengers prefer the faster service*

74

74

## 2. Level of Service (LOS)

### *Service Quality (SQ)*

↪ Focuses on **passenger experience**

↪ Includes:

➤ *Convenience*

➤ *Ease of use*

➤ *Comfort*

↪ **Effect:**

Better experience → **higher satisfaction**

↪ **Example:**

➤ *Direct route + clean, air-conditioned vehicle*

➤ *More comfortable and attractive service*

75

75

## 2. Level of Service (LOS)

### Price

- ↪ Cost paid by passengers (**fare**)
- ↪ **Effect:**  
Lower or reasonable price → **more ridership**
- ↪ **Example:**
  - **Fare = \$1 vs. \$3**  
*Cheaper option attracts more users*

76

76

## 3. Impacts

- ↪ **Definition:** Impacts are the **effects of transit systems on the surrounding area and society**
- ↪ **Key Idea:** Impacts can be **positive or negative**
- ↪ **Types of Impacts:**
  - ↪ **1. Short-Run Impacts (Immediate Effects):**
    - *Reduced traffic congestion*
    - *Changes in air pollution and noise levels*
    - *Changes in visual quality (aesthetics) along the route*
    - **Example:** *New metro line reduces road traffic → less congestion and emissions*
  - ↪ **2. Long-Run Impacts (Long-Term Changes):**
    - *Changes in land values (increase near stations)*
    - *Changes in economic activity (more businesses and jobs)*
    - *Changes in urban form and social environment*
    - **Example:** *Areas near stations become commercial centers with higher land prices*

77

77

# Transit system characteristics

## 4. Costs

↪ **Definition:** Costs represent the **money required to build and operate a transit system**

↪ **Main Categories:**

### ↪ 1. Investment (Capital) Costs

➤ Costs for **building the system or major upgrades**

➤ Includes: *infrastructure, vehicles, stations, tracks*

➤ **One-time or long-term costs**

❖ **Example:** Construction of a metro line = **\$2 billion**

### ↪ 2. Operating Costs

➤ Costs for **daily operation of the system**

➤ Includes: *fuel, salaries, maintenance, electricity*

➤ **Recurring (paid continuously)**

↪ **Example:** Daily operation cost = **\$50,000 per**

78

78

Generic Class		Private Auto on		Street Transit		Semirapid Transit			Rapid Transit			
Characteristics	Unit	Street	Freeway									
Transit unit capacity	sps/TU	1.2–2.0 <sup>a</sup>		40–500		40–750			140–2000			
Max. frequency, $f_{max}$	TU/h	600–800	1500–2000	60–120		40–90			10–40			
Line capacity, C	sps/h	720–1050	1800–2600	2400–15,000		4000–20,000			10,000–70,000			
Operating speed, $V_o$	km/h	20–50	60–90	15–25		20–45			25–80			
Productive capacity, $P_c$	$10^3$ sp-km/h	10–25	50–120	20–150		75–600			700–4000			
Investment cost per pair of lanes	$10^6$ \$/km	1.0–8.0	20.0–100.0	0.5–10.0		5.0–50.0			40.0–120.0			
Typical systems <sup>c</sup>		Auto/street	Auto/fwy	RB-1	RB-2	SCR	BRT	LRT-1	LRT-2	RRT-1	RRT-2	RGR
Transit unit capacity	sps/TU	1.3	1.3	65	75	140	100 <sup>d</sup>	180	430	800	1100	1000
Max. frequency, $f_{max}$	TU/h	700	1800	120	90	90	100	90	40	30	35	28
Line capacity, C	sps/h	910	2340	1800	6750	10,000	10,000	16,200	17,200	24,000	38,500	28,000
Normal operating speed, $V_o$	km/h	35	80	20	18	26	26	30	33	38	36	50
Operating speed at capacity, $V_c$	km/h	20	40	10	12	18	18	23	25	38	34	48
Productive capacity, $P_c$	$10^3$ sp-km/h	18.2	93.6	78	81	180	180	372.6	430	912	1309	1394
Investment cost per pair of lanes	$10^6$ \$/km	3.0	40.0	1.0	1.5	35.0	35.0	40.0	45.0	60.0	100.0	90.0

<sup>a</sup>The systems shown are assumed to be heavily loaded but somewhat below capacity of respective mode.  
<sup>b</sup>Maximum number of spaces that can be utilized.  
<sup>c</sup>Designations used in Figures 2.5, 2.6, and 2.7.  
<sup>d</sup>Articulated buses.

**Performance values for generic classes of modes and for several typical systems**

79

79

# Transportation Engineering and Planning

Module | 6 | Urban Mass transit

## 6.2 | Highway Transit

*Dr. Hamza Mohammad Alkuime*

1

## Major Topics To Be Covered

Topics	No. of Weeks	Contact hours*
1. Introduction to transportation systems	1/3	1
2. Transportation planning	1	3
3. Demand forecasting using 4 steps modeling	4	12
4. Engineering economy in transportation	3	9
5. Evaluation of transportation alternatives	2	6
6. Urban mass transit systems	3 2/3	11
7. Airports	1	3
Total	15	45

2

# Family of Highway Transit Modes

## Definitions

- ↪ Highway transit consists of buses operating mostly on urban streets with general traffic
- ↪ Buses are rubber-tired, steered vehicles that can have a variety of technical and operational characteristics.
- ↪ Buses are used for virtually all types of services,
  - Short-haul to regional
  - Local to express
  - All-day or peak-period only
  - Irregular service
- ↪ Numerous improvements of bus services have been introduced in recent decades
  - *To provide higher performance*
  - *Offer more attractive transit services that can be competitive with autos and reduce street congestion,*

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**Bus, the vehicle**

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## Bus, the vehicle

↪ The bus may be classified based on :

➤ Propulsion Systems

OR

Body Type

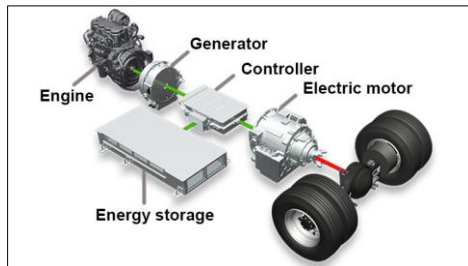


Image source: <https://gettozero.com/series-e.php>

Image Source: <https://info.japanusedbuses.com/content-item/1717-body-types-of-buses>

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## Classification by Propulsion System

### *Diesel Bus*

↪ The majority of buses in are powered by **diesel engines**.



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# Classification by Propulsion System

## Trolleybus

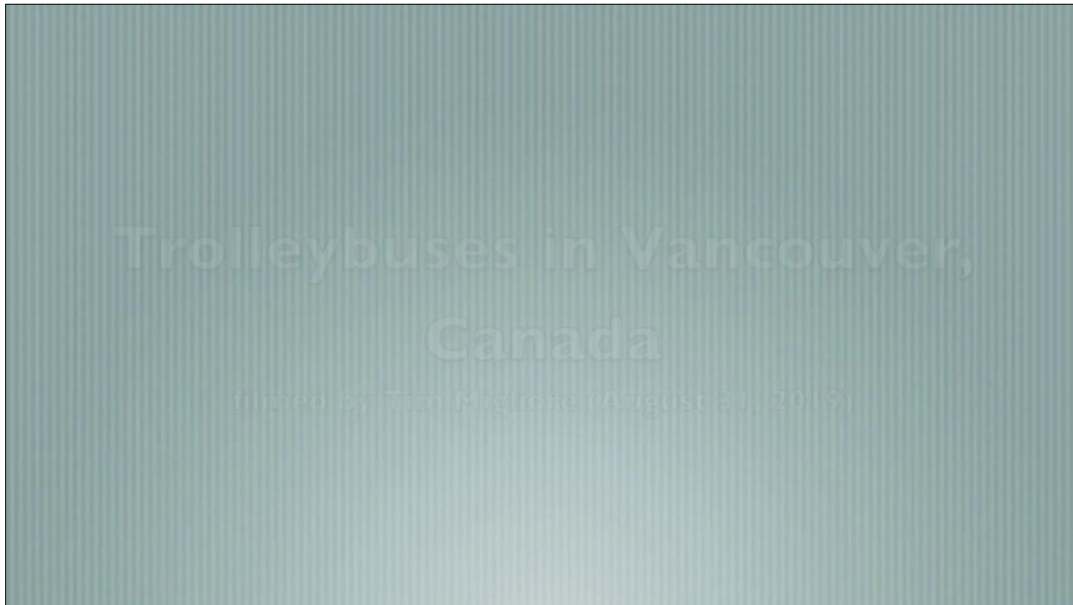
- ↻ An **electrically powered highway vehicle**
- ↻ Receives power through **trolley poles** connected to **two overhead wires (+ and -)**
- ↻ Operates using a continuous external electric power supply
- ↻ The only **rubber-tired highway vehicle without a self-contained power source** for regular operation
- ↻ Runs on standard roads while drawing electricity from overhead lines
- ↻ Produces **zero local emissions** and operates quietly
- ↻ Requires dedicated **overhead wire infrastructure**, which limits route flexibility



7

7

# Trolleybus



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8

## Buses

### Trolleybus Vs Diesel bus

#### Advantages of Trolleybus

- *Faster and smoother **acceleration and deceleration**, especially on gradients*
- *Produces **very low noise and no exhaust emissions***
- ***More durable** and less mechanical wear compared to diesel buses*

#### Disadvantages of Trolleybus

- *Requires **high initial investment and ongoing maintenance** (overhead wires)*
- ***Limited flexibility**, restricted to routes with overhead wiring*

9

9

## Classification by Propulsion System

### Dual-Mode Bus

- ↪ A bus equipped with **both diesel and electric traction systems**
- ↪ Operates as a **trolleybus** in areas with overhead wires (e.g., urban corridors or tunnels)
- ↪ Switches to **diesel mode** on routes without overhead wiring
- ↪ Provides **operational flexibility**, allowing continuous service across both electrified and non-electrified routes
- ↪ Combines the **environmental benefits of electric power** with the **range and independence of diesel operation**



A guided dual-mode

10

10

## Dual-Mode Bus



11

11

## Classification by Propulsion System

### Hybrid Bus

- ↻ A bus powered by a **combination of an internal combustion engine (diesel or gasoline) and electric propulsion**
- ↻ Includes key components such as an **engine, electric motor/generator, energy storage system (battery), and control/switching system**
- ↻ Can operate in **engine mode, electric mode, or combined mode** depending on driving conditions
- ↻ **Reduces fuel consumption and emissions** compared to conventional diesel buses
- ↻ Capable of **electric-only operation** in urban or environmentally sensitive areas
- ↻ Provides **improved acceleration efficiency** through energy recovery (regenerative braking)
- ↻ Has a **higher initial cost** than conventional buses
- ↻ Requires **specialized maintenance** due to hybrid system complexity



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## Volvo's first Electric Hybrid bus in commercial service



<https://www.youtube.com/watch?v=Oxwvq5z0CM>

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13

## Bus, the vehicle


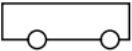


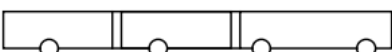
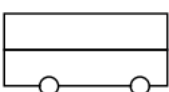
*Classification by Body Type*

14

14

## Classification by Body Type

**Table 5.3** Different bus vehicle types

Type	Sketch	Length (m)	Capacity	
			Min / Max Seats	Total
Minibus		6–7	12/20	30
Midibus		8–10	16/30	50
Standard bus		10–12	35/55	85
Articulated bus		16–18	40/75	130
Double articulated bus		22–24	40/80	140
Double-decker bus		10–12	60/95	125

15

15

## Classification by Body Type – Standard Bus

- ↻ **Length:** 10–12 m
- ↻ **Capacity:** 35–55 seated passengers (up to ~85 total)
- ↻ The **most common bus type** for urban and regional transport
- ↻ Forms the **backbone of public bus fleets worldwide**
- ↻ Used on **high-demand city routes and main corridors**
- ↻ Suitable for a wide range of **urban and suburban operations**
- ↻ **Reliable, cost-effective, and highly versatile** for daily transit service



16

16

## Classification by Body Type

### Minibus

- ↪ **Length:** 6–7 m
- ↪ **Capacity:** 12–20 seated passengers (up to ~30 total)
- ↪ Primarily used to connect local neighborhoods with main transit routes
- ↪ Suitable for **low-demand areas** and **narrow street operations**
- ↪ **Compact size** allows easy maneuverability in congested urban environments
- ↪ Offers **flexibility and cost-effective operation** for small communities



17

17

## Classification by Body Type – Midibus

### Midibus

- ↪ **Length:** 8–10 m
- ↪ **Capacity:** 16–30 seated passengers (up to ~50 total)
- ↪ Used on **medium-demand urban routes**
- ↪ Serves as an **effective alternative to standard buses** in smaller cities
- ↪ Offers a **balanced combination of capacity and maneuverability**
- ↪ Suitable for routes where full-size buses are **not efficient or practical**



18

18

# Classification by Body Type

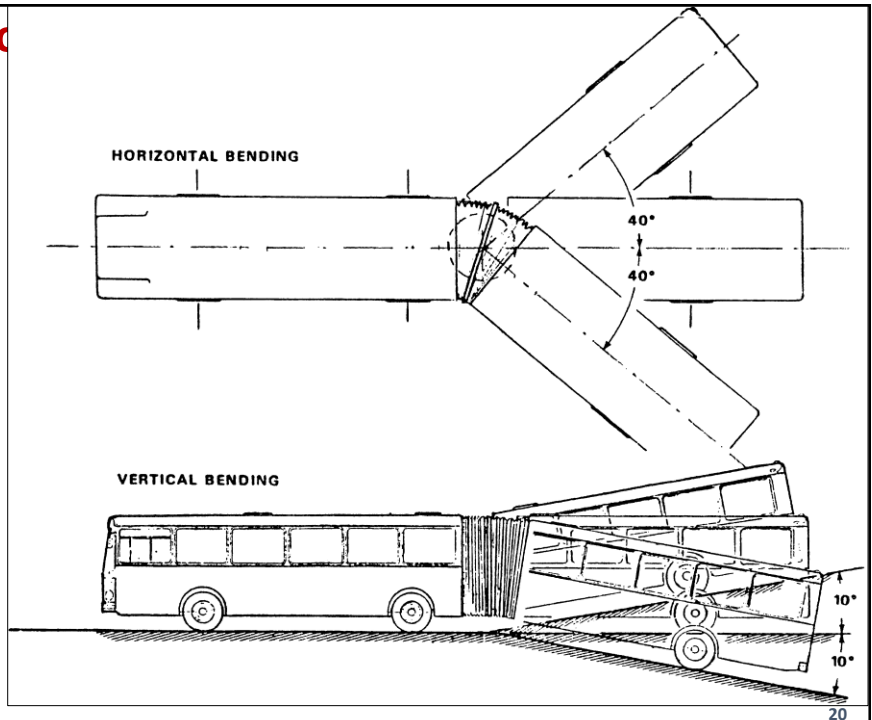
## Articulated Bus

- ↪ **Length:** 16–18 m (with one articulated joint “bendy bus”)
- ↪ **Capacity:** 40–75 seated passengers (up to ~130 total)
- ↪ Commonly used on **high-demand urban corridors**
- ↪ Widely deployed in **Bus Rapid Transit (BRT) systems**
- ↪ Designed with a flexible joint to improve maneuverability on city streets
- ↪ Provides **high passenger capacity while maintaining reasonable turning ability**
- ↪ Suitable for routes where standard buses cannot meet demand



# Classification by Body Type

## Bending ability of articulated bus



## Articulated Bus From California At Mississauga City Hall



<https://www.youtube.com/watch?v=0xwq5z0M>

21

21

## Amman Rapid Bus



[https://www.youtube.com/watch?v=3c\\_88E5d0h4](https://www.youtube.com/watch?v=3c_88E5d0h4)

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## Classification by Body Type

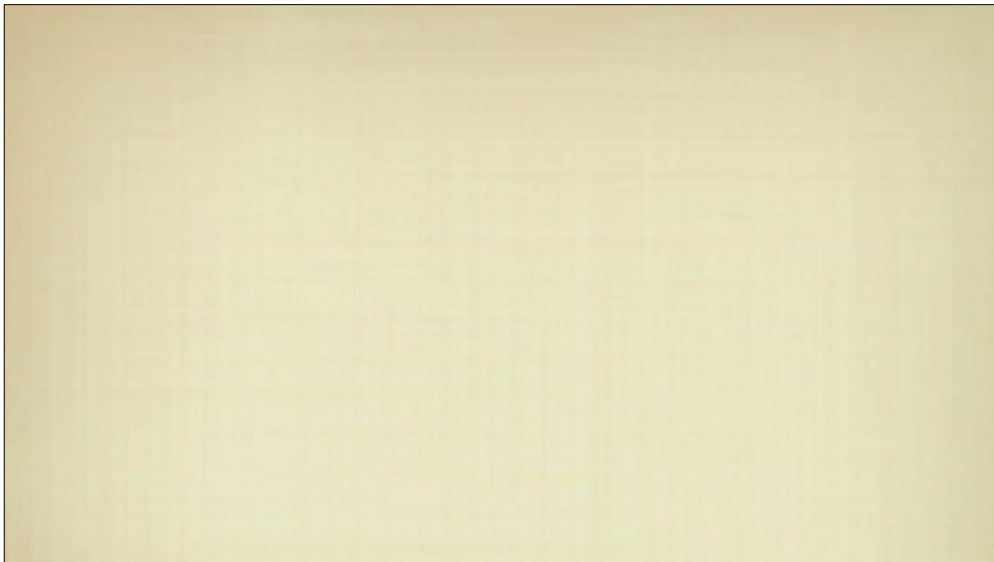
### *Double Articulated Bus*

- ↪ **Length:** 22–24 m (with two articulated joints)
- ↪ **Capacity:** 40–80 seated passengers (up to ~140 total)
- ↪ Designed for **very high-capacity urban transport corridors**
- ↪ Commonly used in **Bus Rapid Transit (BRT) systems and dedicated busways**
- ↪ Ideal for routes with **extremely high passenger demand**
- ↪ Provides **maximum passenger capacity in a single vehicle**
- ↪ Enhances system efficiency by **reducing the number of buses required**



23

## Double Articulated Buses in Hamburg, Germany



<https://www.youtube.com/watch?v=75Qz11X0B8Q&t=50s>

24

24

## Classification by Body Type

### Double-Decker Bus

- ↪ **Length:** 10–12 m
- ↪ **Capacity:** 60–95 seated passengers (up to ~125 total)
- ↪ Used on **high-capacity routes where road space is limited**
- ↪ Commonly operated in **major cities and tourist services** (e.g., London, Hong Kong)
- ↪ Maximizes passenger capacity by utilizing **vertical space (two levels)**
- ↪ Suitable for dense urban areas with **high ridership demand**
- ↪ Provides **high capacity without increasing vehicle length**



25

## Classification by Body Type

### Guided Bus

- ↪ A bus that operates on a **specially designed guideway**, using physical or electronic guidance systems
- ↪ Travels with **higher precision** than conventional buses
- ↪ Operates partly on **dedicated tracks/lanes** and partly on regular roads
- ↪ Can achieve **higher speed, safety, and reliability** in controlled corridors
- ↪ Improves **passenger comfort and ride stability**
- ↪ Enables **efficient use of road space** through accurate lane alignment
- ↪ Commonly integrated into **Bus Rapid Transit (BRT) systems**
- ↪ Requires **high infrastructure investment** due to specialized guideways
- ↪ Less flexible compared to conventional buses



26

26

## Classification by Body Type

*Guided bus*



<https://www.youtube.com/watch?v=16U73WC4rBY>

27

27

## Bus Travel Ways

31

31

## Bus Travel Ways

- ↩ Most buses operate on **urban streets** with basic passenger facilities such as **stops, shelters, and signage**
- ↩ The **level of service** mainly depends on the type of **right-of-way (ROW)** provided
- ↩ This has led to the development of **bus lanes and busways**, especially in systems like **Bus Rapid Transit (BRT)**
- ↩ **Types of Bus Travel Ways**
  - *Shared Travel Way*
  - *Regular Bus Lane (RBL)*
  - *Contraflow Bus Lane (CBL)*
  - *Exclusive Bus Lane (EBL)*

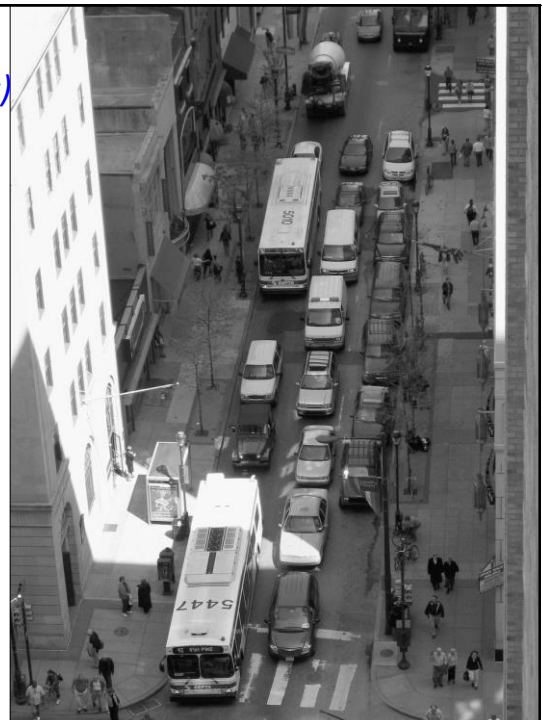
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## Bus Travel Ways

### A. Shared travel-way ( operation mixed traffic)

- ↩ **Definition:**
  - Operates on **regular urban streets and arterial roads** alongside general traffic
  - Requires only **basic facilities** such as bus stops and signage (no dedicated infrastructure)
- ↩ **Advantages:**
  - **High routing flexibility** → buses can serve a wide range of streets and areas
  - **Low capital cost** → no need for special lanes or major construction
  - **Quick and easy implementation** within existing road networks
- ↩ **Disadvantages:**
  - **Highly susceptible to congestion** → frequent delays and unreliable schedules
  - **Lower operating speeds** compared to private vehicles
  - **Frequent stopping** reduces overall travel efficiency
  - **Limited competitiveness** with private cars in terms of travel time
- ↩ **Summary:**
  - Provides **maximum flexibility at minimum cost**, but with **lower performance and reliability**
  - Best suited for **low-demand routes or areas without priority infrastructure**



33

# Bus Lanes on Streets

## Regular Bus Lane (RBL)

### Definition:

- A **curbside lane reserved for buses**, typically located along the edge of the roadway
- Can operate as **exclusive or time-based (e.g., peak-hour only) lanes**

### Key Features:

- Requires strict **control of parking and stopping** to keep the lane clear
- **Turning movements at intersections** must be carefully managed to avoid conflicts
- Provides **convenient passenger access**, enabling easy boarding and alighting
- Improves **bus visibility and priority** within mixed urban traffic

### Limitations:

- Often affected by **"marginal friction"** from nearby curbs, pedestrians, and roadside activity
- May be **slower than central lanes** due to frequent disturbances
- Performance depends heavily on:
  - ❖ **Effective enforcement** of traffic and parking regulations
  - ❖ **Proper management of driveways, deliveries, and access points**
- Can be **ineffective in congested or poorly regulated urban environments**



Downloaded from <https://www.researchgate.net/publication/311111111>

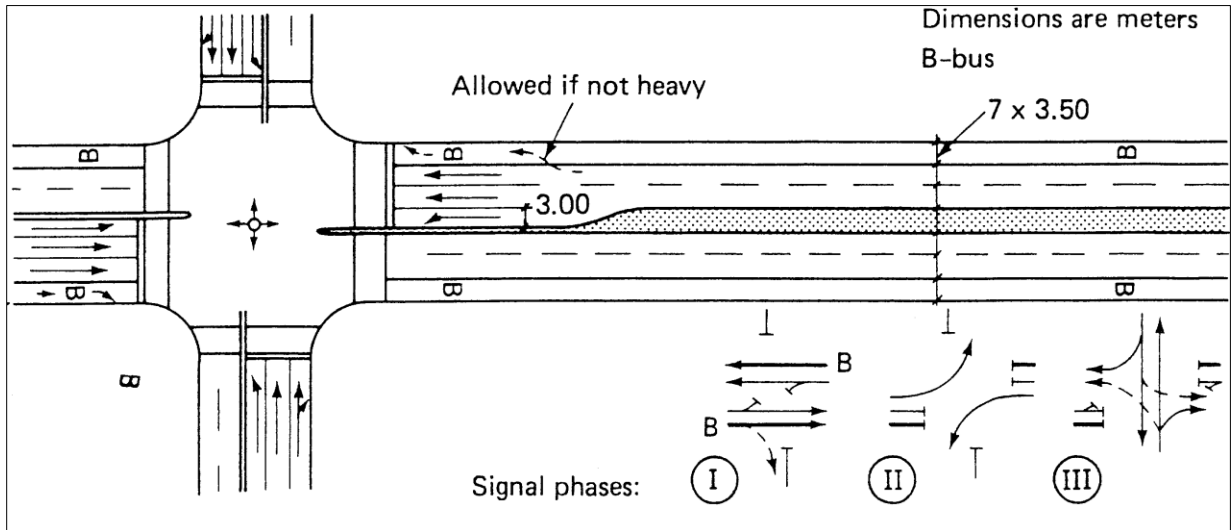
# Regular bus lane on a street

Regular bus lane (RBL) usually curb lanes, are the **most common type of bus lanes on streets**



# Bus Travel Ways

## Curbed Regular Bus Lane



39

39

# Bus travel ways

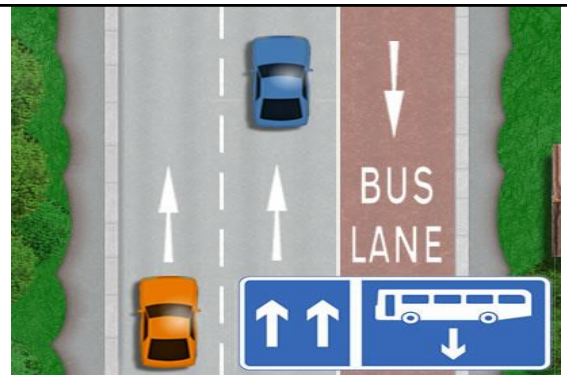
## Contraflow Bus Lane (CBL)

### Definition:

- A bus-only lane operating in the opposite direction of general traffic on the same street
- Typically located along the left side (curbside opposite main flow) to optimize street use

### Key Features:

- Naturally discourages entry of private vehicles, reducing the need for strict enforcement
- Requires clear and highly visible markings (signs, arrows, colored pavement, signals)
- Improves route directness by allowing buses to avoid detours caused by one-way streets
- Enhances operational efficiency in constrained urban layouts



40

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## Bus travel ways

### Contraflow Bus Lane (CBL)

#### Definition:

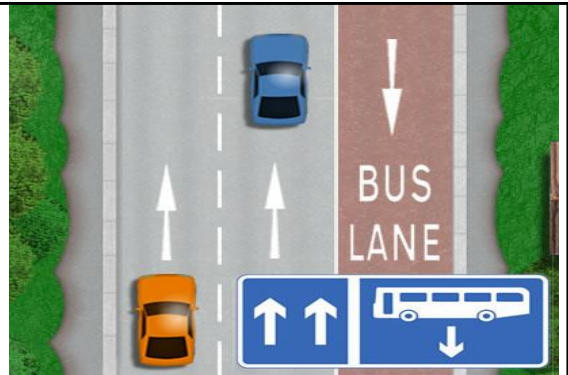
- A **bus-only lane operating in the opposite direction of general traffic on the same street**
- Typically located along the **left side (curbside opposite main flow)** to optimize street use

#### Key Features:

- Naturally **discourages entry of private vehicles**, reducing the need for strict enforcement
- Requires **clear and highly visible markings** (signs, arrows, colored pavement, signals)

#### Safety Considerations:

- **Pedestrians may not expect buses** approaching from the opposite direction
- Risk of **head-on conflicts** if signage and markings are unclear
- Requires **careful design at intersections, crossings, and access points**
- Needs strong **driver awareness and guidance systems**



41

41

## Bus travel ways

### Contraflow bus lane (CBL)



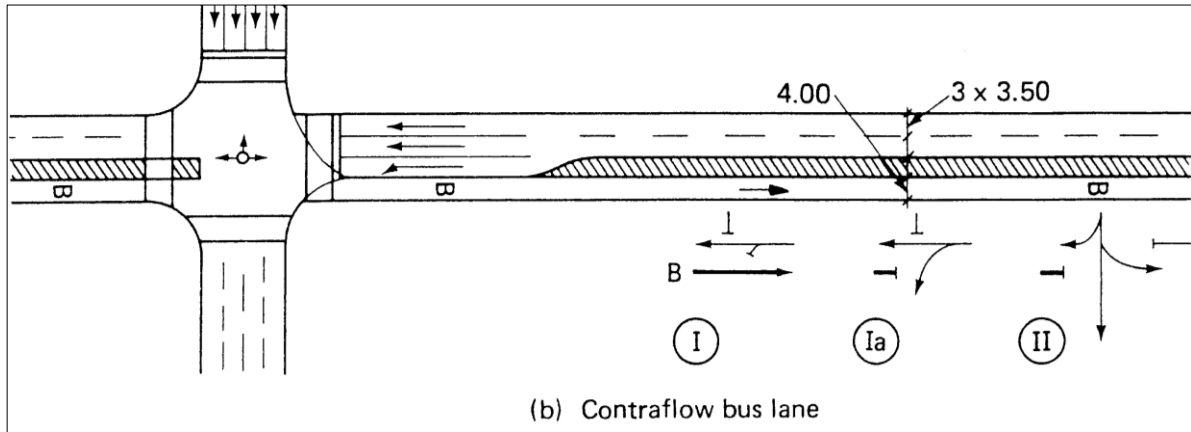
Contraflow bus lane in London

42

42

## Bus travel ways

### Contraflow bus lane (CBL)



43

43

## Bus travel ways

### Contraflow bus lane (CBL)



44

44

## Exclusive bus lanes or busway (EBL)

### Center lanes or curbed medians

#### ↪ Definition:

- A **fully separated facility dedicated to bus operations** in both directions
- Typically located in the **center median**, separated by curbs or physical barriers

#### ↪ Advantages:

- Provides **higher speeds and improved safety** compared to curbside bus lanes
- Ensures **reliable and uninterrupted bus operations**
- Minimizes interference from **general traffic, parking, and roadside activities**
- Ideal for **high-demand corridors and BRT systems**

#### ↪ Requirements:

- **Pedestrian islands** at stops for safe and convenient boarding
- Proper **station design** to support efficient passenger flow
- Traffic management at intersections, including:
  - ❖ Restriction or elimination of left turns, or
  - ❖ **Signalized control (multi-phase signals)** to separate bus and turning movements
- Clear **access control and physical separation** to maintain lane exclusivity

45

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## Bus travel ways

### Center lanes or curbed medians

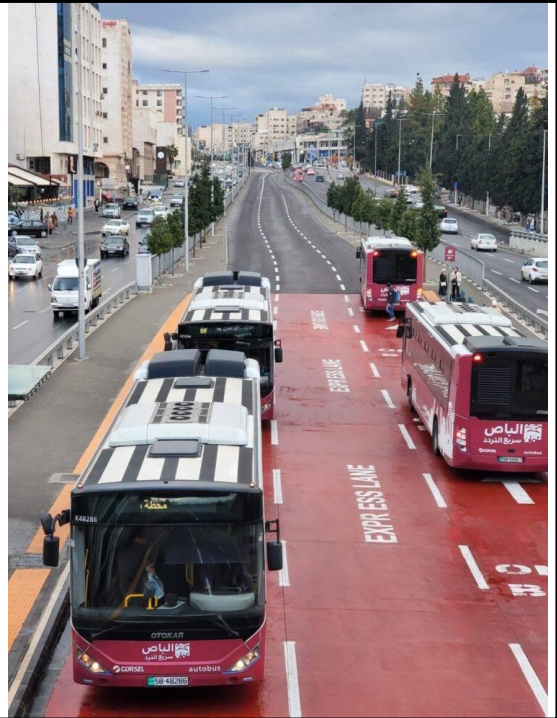


46

46

## Bus travel ways

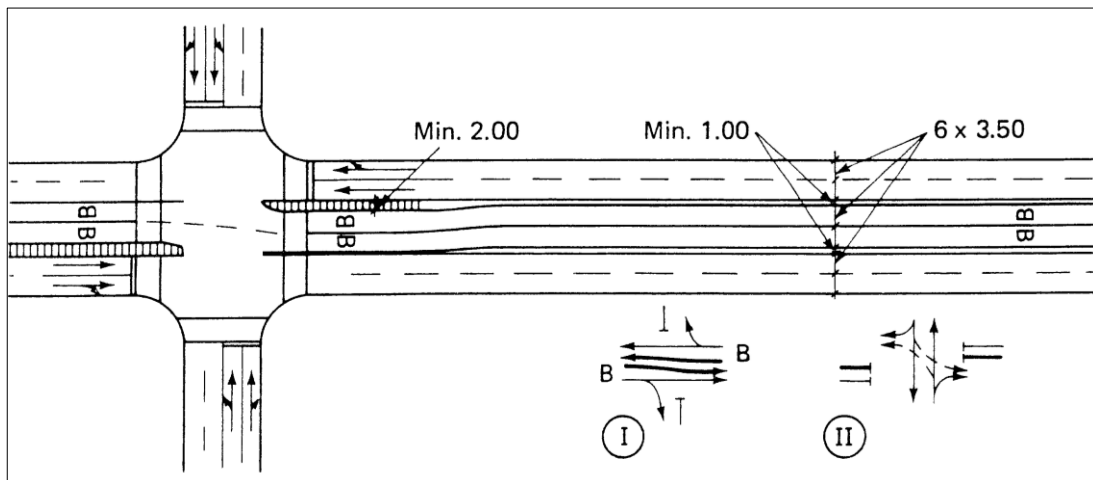
Center lanes or curbed medians



47

## Bus travel ways

Center lanes or curbed medians



48

48

# Bus Transit Modes

51

51

## Family of Highway Transit Modes

### Bus Transit modes

- ↪ Public bus systems can be broadly classified into **three main transit modes**, based on their level of infrastructure, priority, and service quality
  - *Regular / Conventional Bus (RB):*
  - *Bus Transit Systems (BTS):*
  - *Bus Rapid Transit (BRT):*
- ↪ The three modes represent a **progressive improvement in performance**, moving from **flexibility (RB)** to **efficiency and high capacity (BRT)**

52

52

## Bus Transit Modes

### 1. Regular or conventional bus (RB)

#### ↩ Definition:

- A **fixed-route, fixed-schedule system** operating in **mixed traffic (ROW Category C)**
- Shares roadway space with **general traffic**, without priority or dedicated lanes

#### ↩ Basic Features:

- Uses **curbside stops** with simple facilities such as **signs, benches, and occasional shelters**
- Operates with **minimal infrastructure** and integrates easily into existing street networks



53

53

## Bus Transit Modes

### 1. Regular or conventional bus (RB)

#### ↩ Operational Characteristics:

- **Frequent stops** (often at short intervals), reducing travel speed
- **Delays at traffic signals and congestion**, affecting schedule reliability
- Service performance is **highly dependent on road traffic conditions**

#### ↩ Service Limitations:

- **Limited travel speed and reliability** compared to priority-based systems
- Often provides **basic or insufficient passenger** comforts
- Generally **less attractive and less competitive** than private car travel

#### ↩ Cost & Applicability:

- Requires **low capital investment** and is easy to implement
- Suitable for **wide coverage and low-to-moderate demand areas**
- Best used where **cost and flexibility are more important than speed and performance**

54

54

## Bus Transit Modes

### 2. Bus transit system (BTS)

#### ↩ Definition:

- A **coordinated bus system** designed with targeted improvements to achieve **higher speed, reliability, and operational efficiency**
- Represents an **intermediate level** between conventional bus service and full Bus Rapid Transit

#### ↩ Key Features:

- **Dedicated or priority bus lanes** → reduce delays caused by mixed traffic
- **Wider stop spacing** → decreases travel time and improves service speed
- **Off-board / self-service fare collection (SSFC)** → minimizes boarding delays
- **Multi-door buses** → allow faster and simultaneous boarding and alighting

#### ↩ Performance Benefits:

- **Reduced travel time** compared to regular bus systems
- **Improved reliability and schedule adherence**
- **Enhanced passenger convenience and comfort**



HubertVeerkamp

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## Bus Transit Modes

### 3. Bus Rapid Transit (BRT)

#### ↩ Definition:

- An **integrated bus-based system** using **distinct vehicles and fully dedicated infrastructure**
- Operates with **high independence from mixed traffic**, enabling **higher speed, reliability, and safety** than BTS

#### ↩ Key Concept:

- BRT is not defined by a single feature → it is a **combination of coordinated components**
- The exact form can vary between cities depending on **design and operation**



56

56

## BRT Essential Elements

To qualify as a true BRT system, the following must be present:

### 1. Dedicated Right-of-Way (ROW):

- Operates mainly on **exclusive or semi-exclusive lanes (Category A or B)**
- Minimizes interaction with **mixed traffic (very limited Category C use)**
- Ensures **high speed, reliability, and consistent operations**

### 2. Distinctive Bus Services:

- Provides **frequent and reliable service** throughout the day
- Maintains **regular headways** (consistent time gaps between buses)
- Designed for **high passenger demand corridors**

### 3. Modern Stations:

- Equipped with **shelters, passenger information systems, and ticketing facilities**
- Includes **off-board fare collection** to reduce delays
- Typically spaced **300–600 m in urban areas** (longer in suburban zones)
- Designed for **safe, comfortable, and efficient passenger access**

57

57

## BRT Essential Elements

To qualify as a true BRT system, the following must be present:

### ↻ Specially Designed Vehicles:

- **High-capacity buses** (articulated or bi-articulated)
- **Low-floor or level boarding design** for fast and accessible entry
- **Multiple wide doors** for quick boarding and alighting

### ↻ Intersection Priority:

- Uses **signal priority systems** at intersections
- Reduces stopping time and maintains **continuous bus movement**

### ↻ Intelligent Transport Systems (ITS):

- Includes **real-time vehicle tracking and monitoring**
- Provides **passenger information** (arrival times, updates)
- Supports **efficient fare collection and system management**

### ↻ Key Idea:

- A system is considered true BRT only when these elements are **combined together, ensuring high performance similar to rail transit**

58

58

## Bus Transit Modes

### Bus Transit Modes – Vehicles

- ↪ BRT lines are usually served by articulated or double-articulated buses.



59

59

## Bus Transit Modes

### Infrastructure: Lanes

- ↪ **BTS Lanes (Bus Transit System):**
  - Typically located along the *curbside of urban streets*
- ↪ **BRT Lanes (Bus Rapid Transit):**
  - Operate on *exclusive, dedicated lanes, usually positioned in the median (center) of the roadway*
  - Require *specialized station design and signal priority at intersections*



60

60

## Bus Transit Modes

### Operations and Intelligent Transportation Systems (ITS) Applications

- **Automatic Vehicle Location (AVL):**
  - Uses **GPS-based tracking** to monitor bus locations in real time
  - Supports **fleet management, dispatching, and delay control**
- **Real-Time Passenger Information:**
  - Provides **live bus arrival and departure times**
  - Displayed through **station screens, onboard displays, and mobile apps**
  - Improves **passenger convenience and trip planning**
- **Traffic Signal Priority:**
  - Gives buses **priority at signalized intersections**
  - Reduces **stopping time and minimizes delays**
  - Improves **overall travel speed and reliability**
- **Safety and Security Systems:**
  - Includes **on-board surveillance systems and driver alert tools**
  - Enables **emergency communication and monitoring**
  - Enhances **passenger and driver safety**

63

63

## ITS Applications

English من نحن المسارات والترايل تطبيق باص عمان الدعم بنا اتصل



### تمتّع بتجربة تنقل حديثة

باص عمان رؤيا تلامح تحققت في 30 حزيران 2019، من خلال عمل دؤوب وفكر متجدد لإنشاء 27 مساراً لـ135 حافلة، لغاية الآن، بهدف "باص عمان" إلى تحسين النقل العام في العاصمة عمان من خلال توفير تجربة تنقل متميزة ومنتطورة ذات تقنية عالية في نظام، تتبع المعلومات والدعم الإلكتروني، عن طريق استخدام بطاقة مشحونة مم إمكانية إعادة شحن رصيد البطاقة، يتميز باص عمان بالانتظام، كما تتميز جميع حاملاتنا بالنظافة والأمان وسهولة الاستخدام حيث أنها تخضع لنظام مراقبة أمني وتهيئة للاستخدام من قبل الأشخاص ذوي الإعاقة وكبار السن. تغطي المرحلة الأولى 11 منطقة تابعة للأمانة من أصل 22 هي ( المدينة - العبداني - بسمان، طارق، أبو نعيم، شفا بدران، صويلح، الجبيهة، تلح العلي، النهر، ماركا ) من خلال 135 حافلة، 52 منها كبيرة بسعة 59 راكب و 83 حافلة متوسطة بسعة 42 راكب، وسيتم وفقاً لخططنا التوسيع إضافة وتجهيز باصات جديدة من خلال إعطاءات دولية لتأمين 150 حافلة جديدة و ستبدأ العمل بنهاية العام 2020 بحد أقصى لتغطية 34 مساراً جديداً لاستخدام باص عمان؛ يتوجب شراء بطاقة راكب وشحنها بالرمز المرغوب من إحدى نقاط البيع في محطات الحافلات الرئيسية ومراكز التوزيع أو من خلال إحدى آلات البيع المتوفرة في عدة مواقع استراتيجية، يمكن إعادة شحن بطاقة الراكب واستخدامها لعدة عامين.

### مميزات الخدمة

 <p>سهولة الاستخدام</p> <p>الباص مزود بنظام دعم إلكتروني عبر بطاقة مشحونة وبنون كاشن، يوجد كذلك إنترنت مجاني داخل الباص.</p>	 <p>الانتظام</p> <p>وصول وانطلاق الباص من المحطات المحددة بتردد منتظم ومحدد.</p>	 <p>الأمان</p> <p>الباصات آمنة ومراقبة بأحدث الأنظمة الأمنية المتطورة عن طريق غرفة التحكم المركزية.</p>	 <p>الانتظامة</p> <p>يتم الإشراف على نظافة الباصات بشكل دوري، إضافة إلى أن التدخين ممنوع نهائياً داخل الباص.</p>
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64

64

## ITS Applications

### كيفية استخدام تطبيق باص عمان:

- سجل اسمك ورقم بطاقتك المدفوعة مسبقاً لتتمكن من استخدام مميزات التطبيق.
- يمكنك التحقق من رصيد بطاقتك و إعادة شحن البطاقة من خلال التطبيق والدفع بواسطة بطاقة الائتمان.
- سيتعرف التطبيق على موقعك الحالي كنقطة البداية. في حال اختلاف نقطة البداية، يمكنك إعادة ادخالها.
- ثم ادخل نقطة وجهتك.
- سوف يظهر على الخريطة المسار الأسرع مع معلومات عن المواقف و الأوقات و الاسعار.
- ان لم يكن بجوزتك بطاقة مدفوعة مسبقاً، يمكنك تنزيل البطاقة الافتراضية مجاناً وشحنها عن طريق التطبيق.
- سوف يظهر التطبيق المواقف الأقرب لك بالإضافة الى اعلامك بتحديث الخدمات ونقاط البيع.

لتحميل التطبيق على الأجهزة:



## Bus signal preemption



Global Traffic Technologies

- Conditional Basis
- Continuous Operation
- Driver Discretion

## *Exclusive bus lanes or busway (EBL)*

### *Center lanes or curbed medians*



67

67

## **Bus Transit Modes**

### *Costs for U.S. Bus Rapid Transit Projects*

<b>BRT System</b>	<b>Miles</b>	<b>Capital Costs (\$ million)</b>	<b>Cost per Mile (\$ million)</b>	<b>Federal Funding</b>	<b>State and Local Funding</b>
Boston Silver Line, Washington St., Phase 1	2.4	\$46.5	\$19.4	0%	100%
Cleveland HealthLine	7.1	\$197.1	\$7.0	50%	50%
Boston Silver Line-Waterfront/Phase 2	8.8	\$624.2	\$89.1	77%	23%
Pittsburgh, MLK Jr. East Busway	9.1	\$68.0	\$20.0	50%	50%
Eugene EmX	4.0	\$65.9	\$16.4	80%	20%
Oakland San Pablo Rapid	14.0	\$3.2	\$0.23	N/A	N/A
Los Angeles Orange Line	14.2	\$377.6	\$25.0	7%	93%
Las Vegas, MAX and SDX	19.0	\$51.6	\$2.7	82%	18%
Kansas City MAX	12.0	\$65.9	\$5.5	63%	37%
Los Angeles Metro Rapid	400.0	\$94.0	\$0.24	77%	23%

68

68

*Case study*

## **Amman BRT**

69

69

## **Amman BRT**

 <https://www.youtube.com/watch?v=DT0IUoptqVw&t=33s>

70

70