Transportation Engineering and Planning (110 401367)

Fall 2021-2022

Module No. 1

1.1_ Introduction of Transportation Systems

Dr. Hamza Alkuime

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Introduction of Transportation Systems

2

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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

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Introduction of Transportation Systems

Roles of Transportation in Society:

- Economically
  - *Availability of goods and services*
  - *Expansion of trade*
- Socially
  - *Affects employment opportunities*
- Environmentally
  - *Its pollution affects the air, water & land qualities which are dangerous to human, animal & plant lives.*
- Politically
  - *Increase the ability of the country to defend itself*

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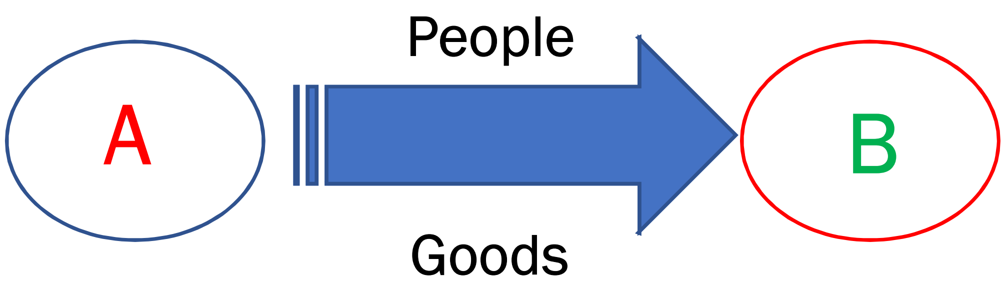
Introduction of Transportation Systems

Definition of Transportation

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



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Introduction of Transportation Systems

Transportation Engineering

- 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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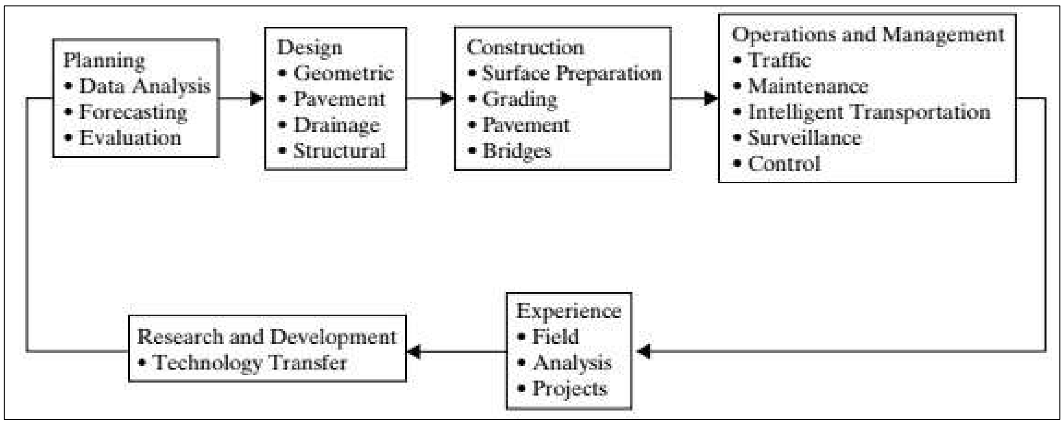
Introduction of Transportation Systems

Transportation Engineer

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



Introduction of Transportation Systems

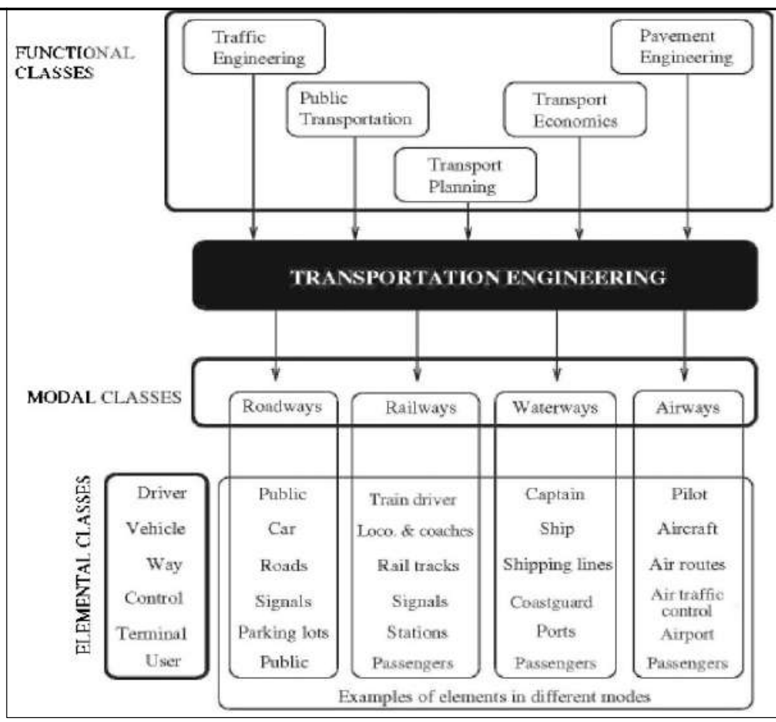
Transportation System

- A facility consisting of the means and equipment necessary for the movement of passengers or/and goods

Introduction of Transportation Systems

Classification of transportation studies

- Transportation engineering can be classified according to :
  - *Modal (mode of travel) classification*
  - *Element classification*
  - *Functional classification*



Introduction of Transportation Systems

Modal classification

- Classification of transportation system based on mode of travel including
  - *Walking, Car, Bus, Train, Ship, and Aircraft .etc*
- Or it can be grouped to classes of modes which use a particular "surface" including
  - *Land*
  - *Water*
  - *Air*
  - *Pipeline*
  - *Telecommunication*

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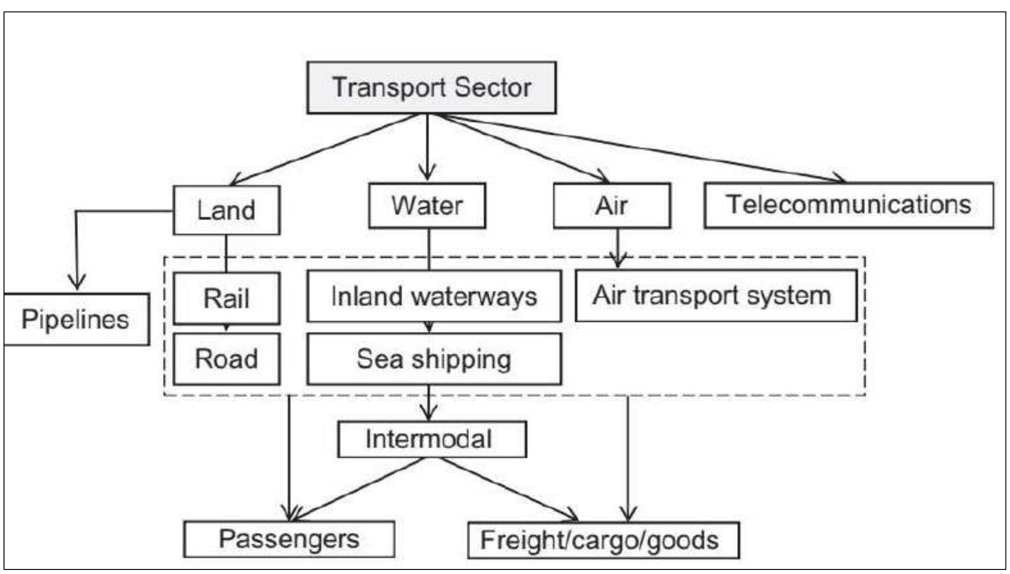
Introduction of Transportation Systems

Modal classification



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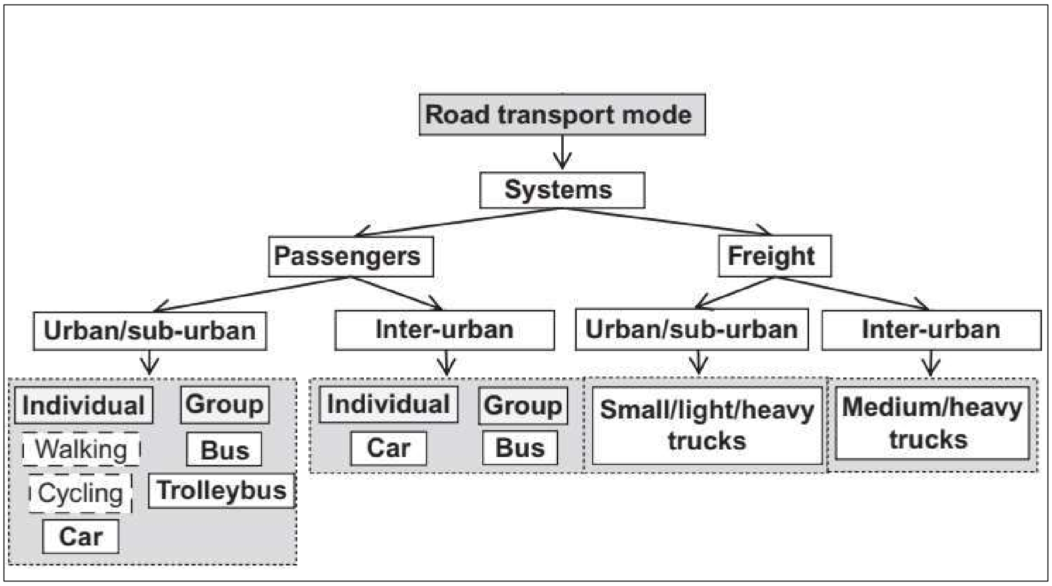
Introduction of Transportation Systems

Modal classification



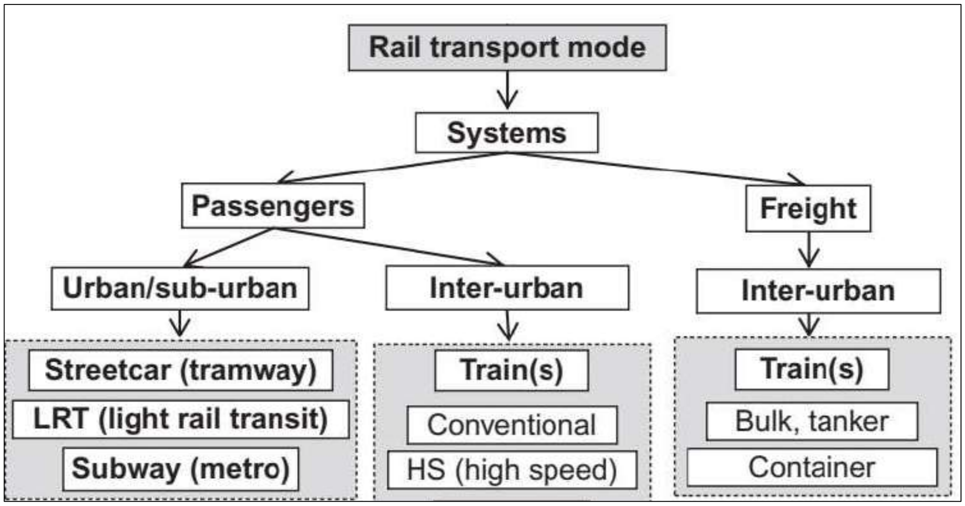
Introduction of Transportation Systems

Trolleybus

- Trolley is an electric bus that draws power from dual overhead wires

Introduction of Transportation Systems

Modal classification



Introduction of Transportation Systems

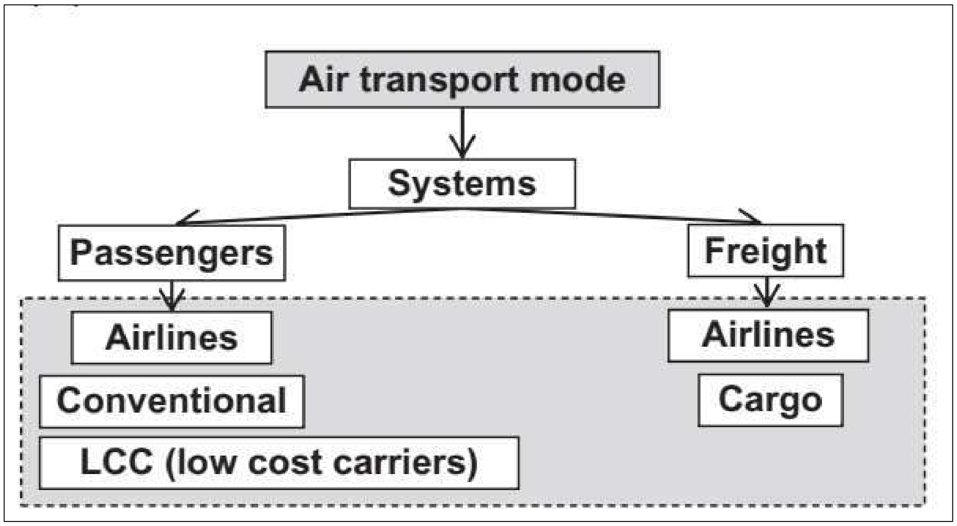
Tramway

High speed train

Bulk train

Introduction of Transportation Systems

Modal classification



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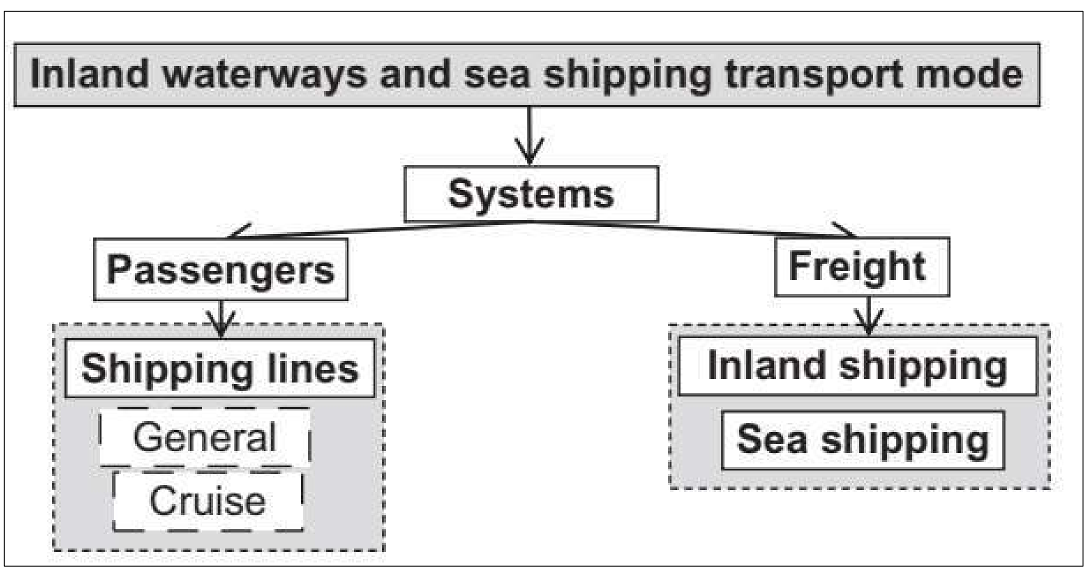
Introduction of Transportation Systems

Modal classification



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Introduction of Transportation Systems

Inland shipping

Sea shipping

Cruise

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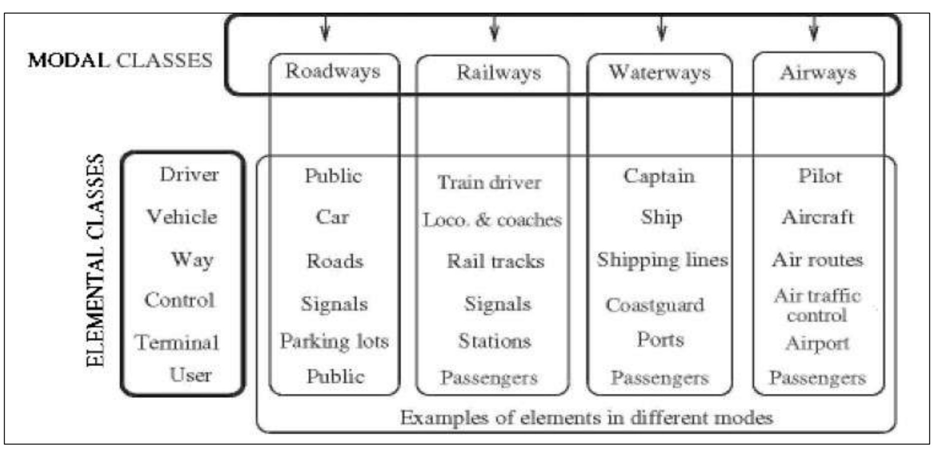
Introduction of Transportation Systems

Element classification

- Classification in terms of the basic elements which constitute any mode of transport



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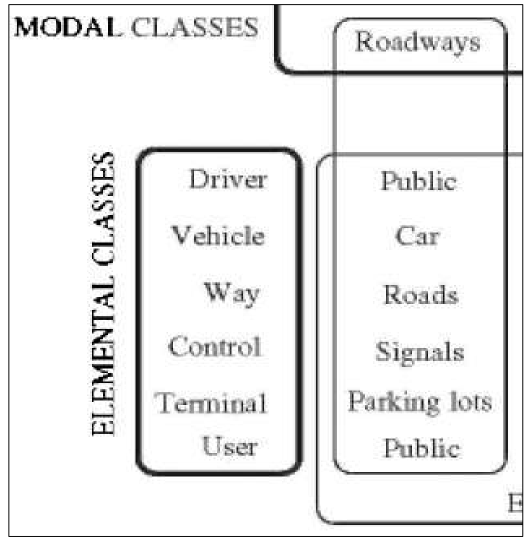
Element classification

Elemental classes

- Driver
  - *The person control the vehicle used in the selected mode of transportation*
- Vehicle
  - *The vehicle which are used in transportation*
- 3. Travel way
  - *A specified path which is either constructed or charted*
- 4. Control
  - *System levels controls which are imposed on the movement of the vehicles*



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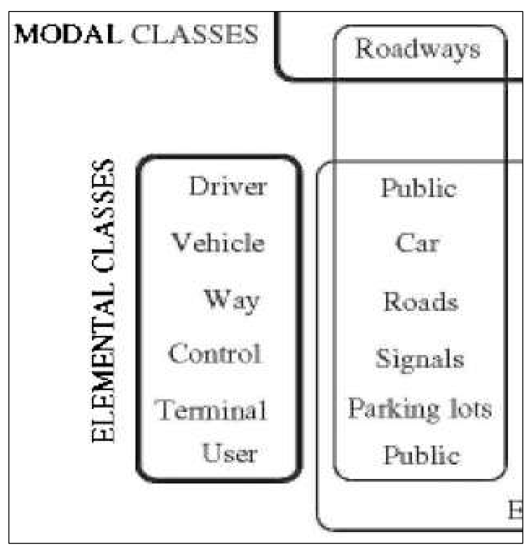
Element classification

Elemental classes

- 5. Terminal
  - *A location where a vehicle of a mode stope for various reasons*
- 6. User
  - *Public at large for passenger transport*
  - *Organization for goods transport*



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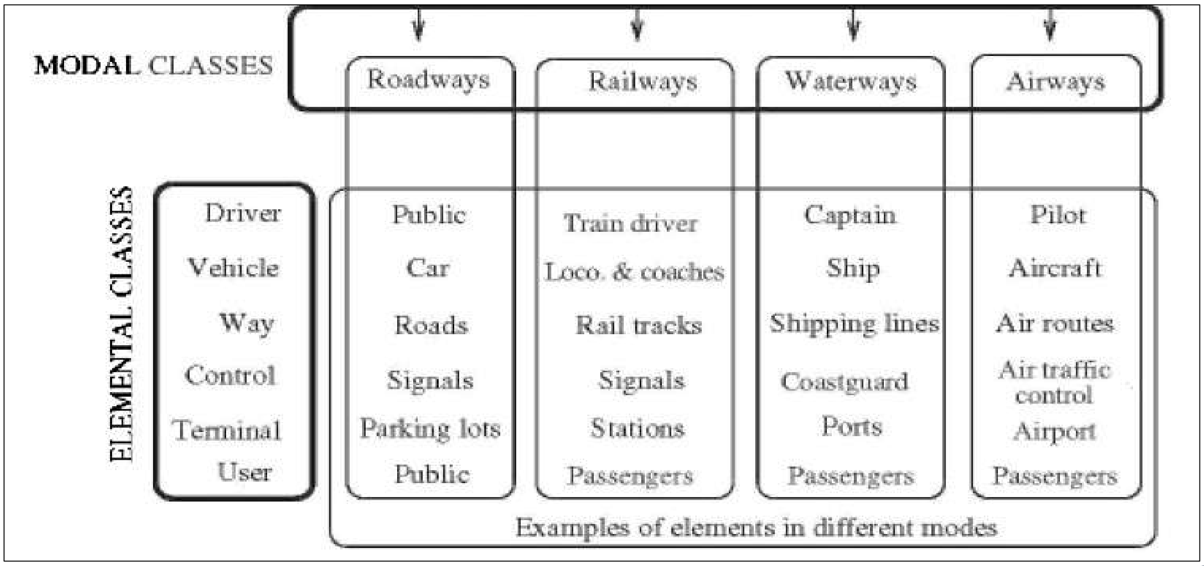
Introduction of Transportation Systems

Element classification



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Introduction of Transportation Systems

Functional classification

- Functionally, the transportation engineering can be divided into :
  - *Traffic engineering*
    - Deals with analysis, design, and operation of transportation facilities used by different modes of transportation
  - *Pavement engineering*
    - Deals with structural analysis and design of the way used by different modes of transportation
  - *Public transportation*
    - Deals with analysis, design, and operation of public transportation facilities
  - *Transport planning*
    - Deals with planning transportation facilities with will be able to meet the present and the future needs in a sustainable manner
  - *Transport economics*
    - Deals with various economic costs and benefits of building and operating different transportation facilities

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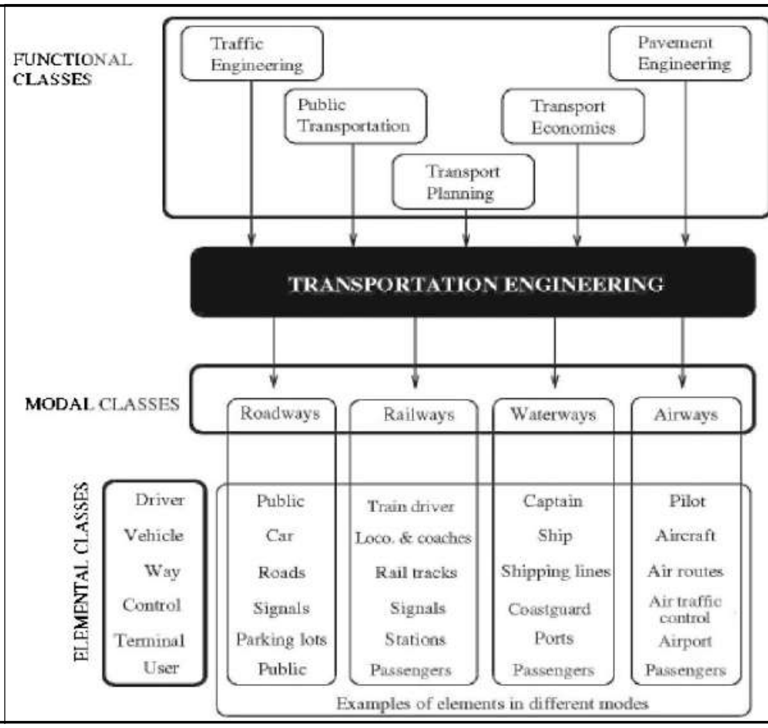

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Transportation Engineering and Planning (110 401367)

Fall 2021-2022

Module No. 1

1.2_ Highway Classification

Dr. Hamza Alkuime

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Highway Classification

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Highway Classification

Highways are classified according to :

- Their location.
- Their respective functions in terms of the character of the service they are providing.

Highway Classification

Location classification

- Highways and streets are classified **depending on the area in which they are located** to :
  - *Urban roads :*
    - All highway facilities within urban areas.
  - *Rural roads*
    - The highway facilities outside urban areas

Definition of Urban and Rural Areas

Urban areas

Urban

- Small urban areas
  5,000<pop<50,000
- Urbanized areas
  ≥ 50,000

Definition of Urban and Rural Areas

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:Ginza_area_at_dusk_from_Tokyo_Tower.jpg

Definition of Urban and Rural Areas

Rural Areas:

- Those areas outside the boundaries of urban areas

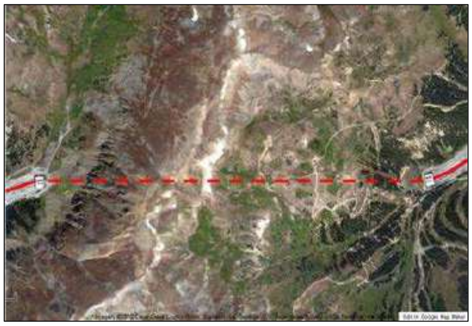
Image source: https://enacademic.com/dic.nsf/enwiki/11583337

Highway Function Classification

- The concept of functional classification defines the role that a particular roadway segment plays in serving this flow of traffic through the network.
- Roadways are assigned to one of several possible functional classifications within a hierarchy according to the character of travel service each roadway provides.
- Planners and engineers use this hierarchy of roadways to properly channel transportation movements through a highway network efficiently and cost effectively
- Roadways serve two primary travel needs:
  - *Access to/egress from specific locations*
  - *Travel mobility*
  - *While these two functions lie at opposite ends of the continuum of roadway function, most roads provide some combination of each*

Highway Functional Classification

Road mobility and accessibility



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

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Highway Functional Classification

Road mobility and accessibility

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

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Highway Functional Classification

Road mobility and accessibility

This roadway serves both mobility needs (the residents that live along the side streets that intersect and land access needs (there are both residential and commercial properties located along the roadway)

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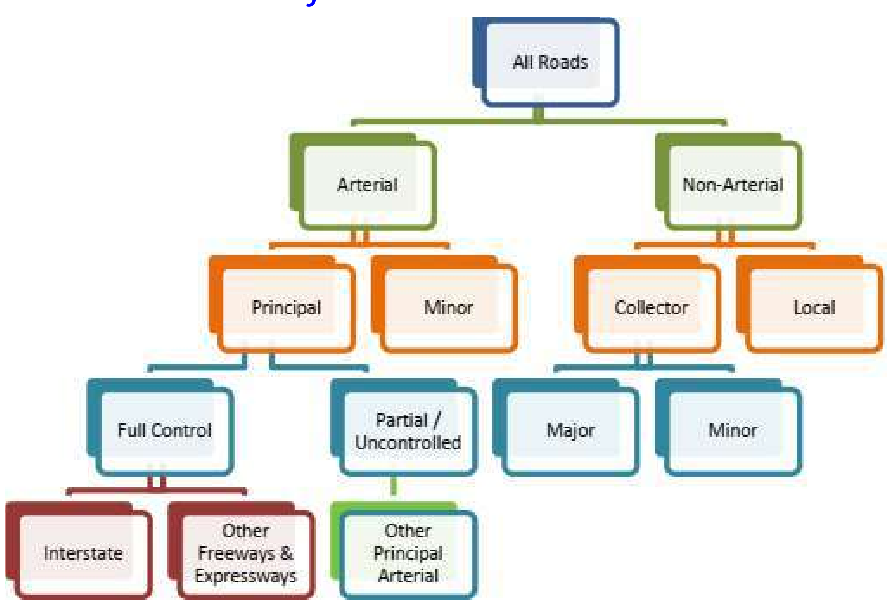
Highway Functional Classification

Federal Functional Classification Decision Tree



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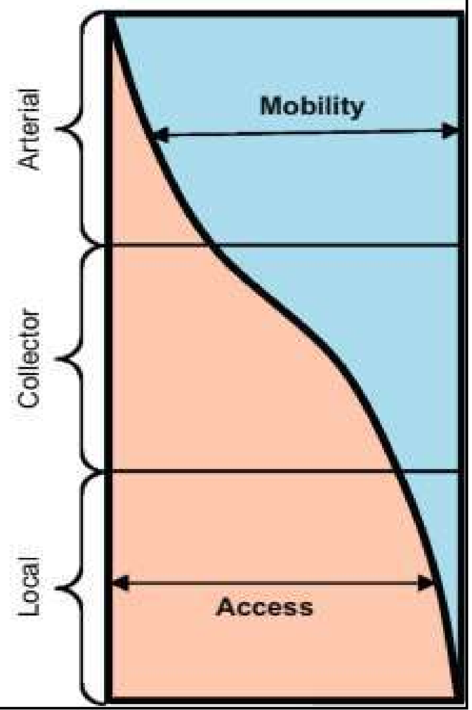
Highway Functional Classification

Arterials

- Roadways that provide a high level of mobility
  - *Emphasis on providing high-speed, uninterrupted flow*
  - *Long-distance trips are most practical on arterials*



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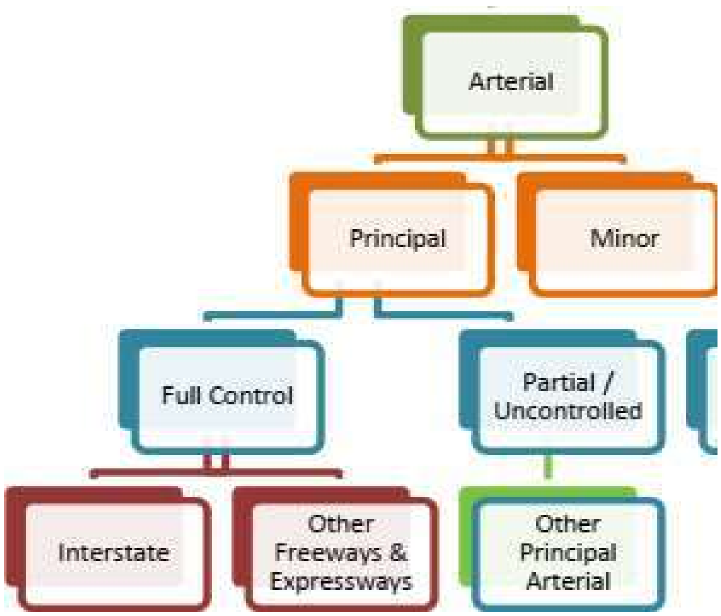
Highway Functional Classification

Arterials



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Highway Functional Classification

Arterials

Interstate

- The highest classification of Arterials
- Designed and constructed with mobility and long-distance travel in mind
- Provided a superior network of limited access, divided highways offering high levels of mobility while linking the major urban areas of the United States

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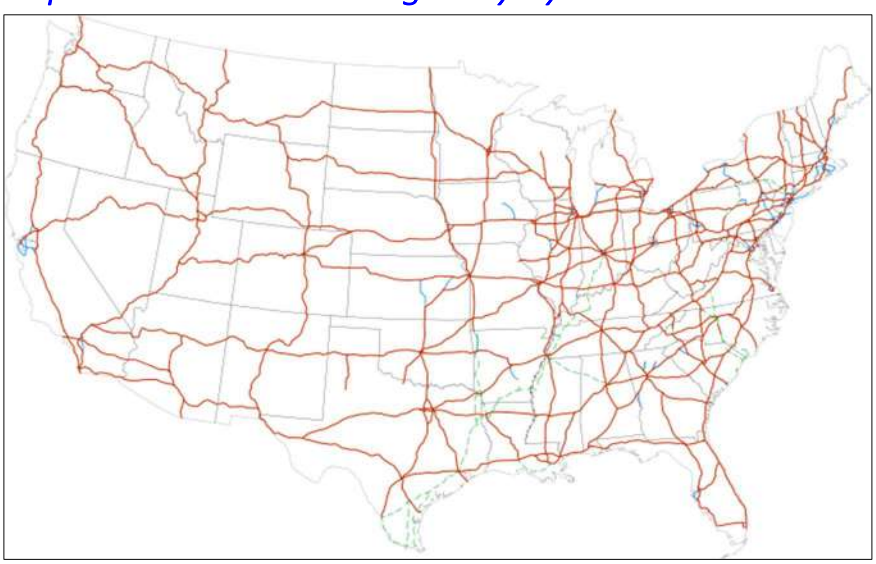
Highway Functional Classification

Map of the present Interstate Highway System in the United States



https://en.wikipedia.org/wiki/Interstate_Highway_System

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Highway Functional Classification

Arterials

Other Freeways & Expressways

- Roadways have directional travel lanes are usually separated by some type of physical barrier,
- Their access and egress points are limited to on- and off-ramp locations or a very limited number of at-grade intersections
- Like Interstates, these roadways are designed and constructed to maximize their mobility function, and abutting land uses are not directly served by them

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Highway Functional Classification

Arterials

Other Freeways & Expressways

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Highway Functional Classification

Arterials

Other Principal Arterials

- These roadways serve major centers o metropolitan areas, provide a high degree of mobility and can also provic mobility through rural areas

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Highway Functional Classification

Arterials

Minor

- Provide service for trips of moderate length
- Serve geographic areas that are smaller than their higher arterial counterparts
- Offer connectivity to the higher arterial system.

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Highway Functional Classification

Arterials

Urban arterial

Suburban interstate (Freeway)

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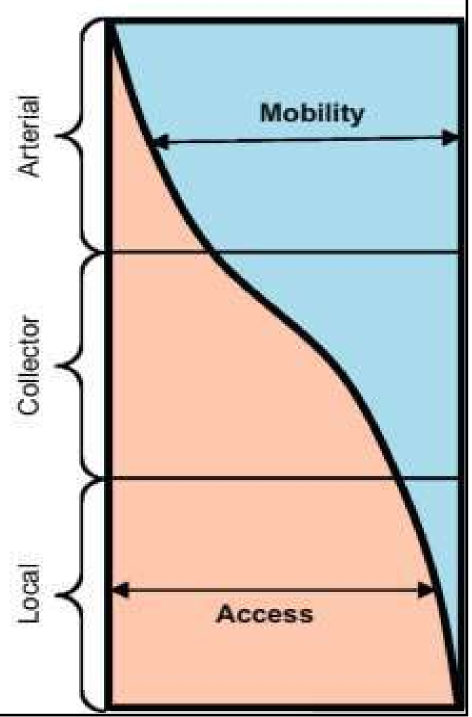
Highway Functional Classification

Road mobility and accessibility

- Locals
  - Roadways *provide* *a high level of accessibility*
  - *Provide direct connectivity to businesses, residences, and other land uses*



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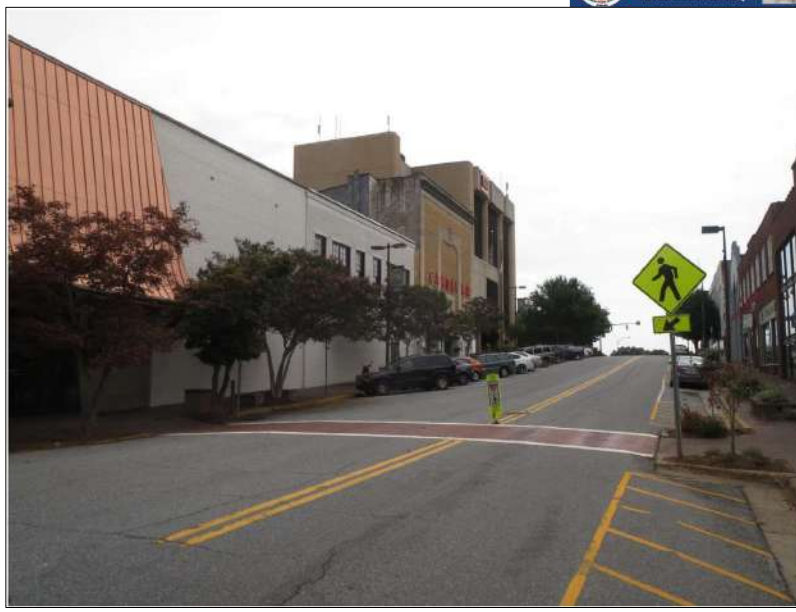
Highway Functional Classification

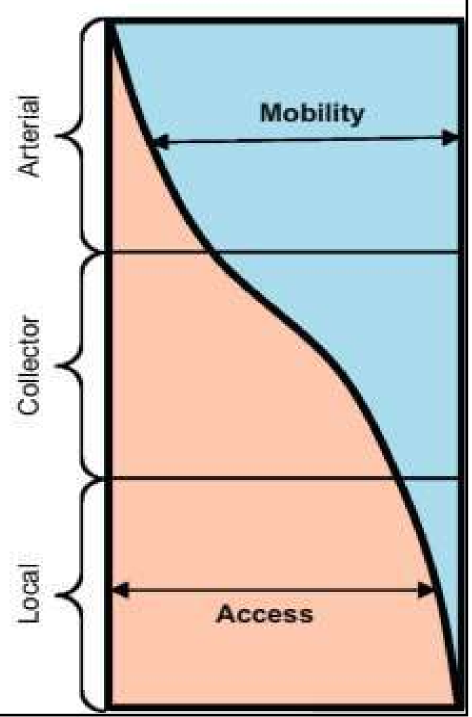
Local Streets



Highway Functional Classification

Road mobility and accessibility

- Collector
  - Roadways *a more balanced blend of mobility and access*
  - *Collectors facilitate travel between local roads and arterials by collecting traffic and distributing it to local roads or to higher mobility arterials*



Highway Classification

Collector roadway

Highway Functional Classification

Collectors

- Collectors are broken down into two categories:
  - *Major Collectors*
  - *Minor Collectors*
- The determination of whether a given Collector is a Major or a Minor collector is frequently one of the biggest challenges in functionally classifying a roadway network

Highway Functional Classification

Collectors

- Generally, Major Collector routes are :
  - *Longer in length*
  - *Have lower connecting*
  - *Have lower driveway densities*
  - *Have higher speed limits*
  - *Spaced at greater intervals*
  - *Have higher annual average traffic volumes*
  - *May have more travel lanes*

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Highway Functional Classification

Relationship between Functional Classification and Travel Characteristics

National Classification	Distance Served (and Length of Route)	Access Points	Speed Limit	Distance between Routes	Usage (AADT and DVMT)	Significance	Number of Travel Lanes
Arterial	Longest	Few	Highest	Longest	Highest	Statewide	More
Collector	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Local	Shortest	Many	Lowest	Shortest	Lowest	Local	Few

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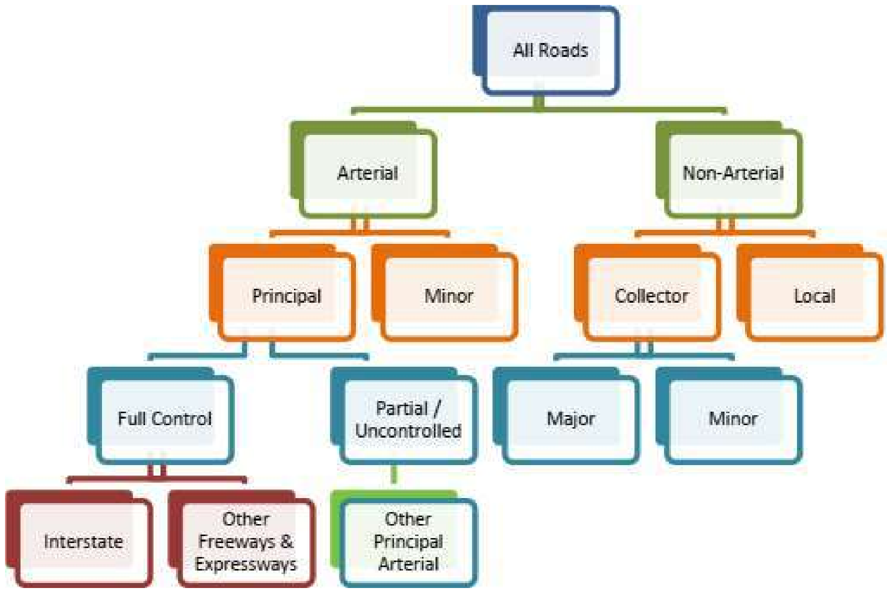
Highway Functional Classification

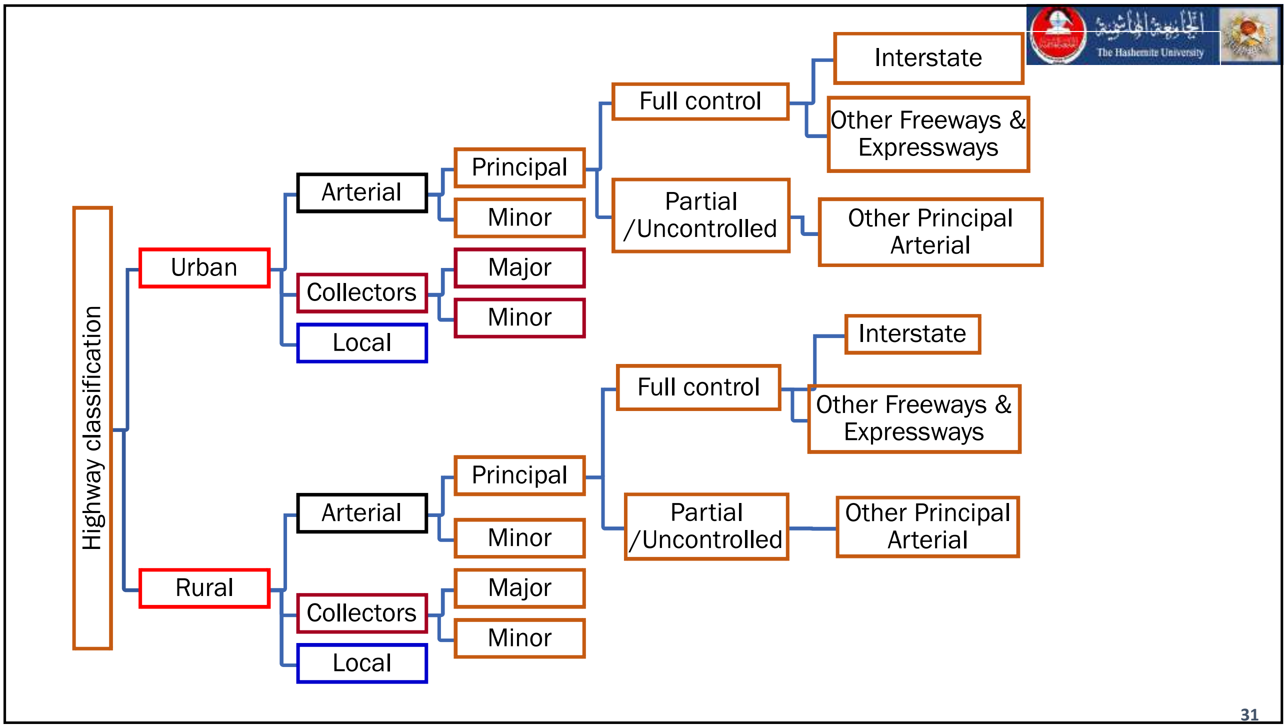
Federal Functional Classification Decision Tree



Highway Location Classification

Urban and Rural

- Urban and rural functional systems are classified **separately** since they have different characteristics with regards to:
  - *Density and types of land use*
  - *Density of street and highway networks*
  - *Nature and travel patterns*
- In general,
  - *In urban areas*
    - There are relatively more arterials
  - *In rural areas*
    - There are more collectors


Highway classification
Urban
Rural
Arterial
Collectors
Local
Arterial
Collectors
Local
Principal
Minor
Major
Minor
Principal
Minor
Major
Minor
Full control
Partial /Uncontrolled
Full control
Partial /Uncontrolled
Interstate
Other Freeways & Expressways
Other Principal Arterial
Interstate
Other Freeways & Expressways
Other Principal Arterial
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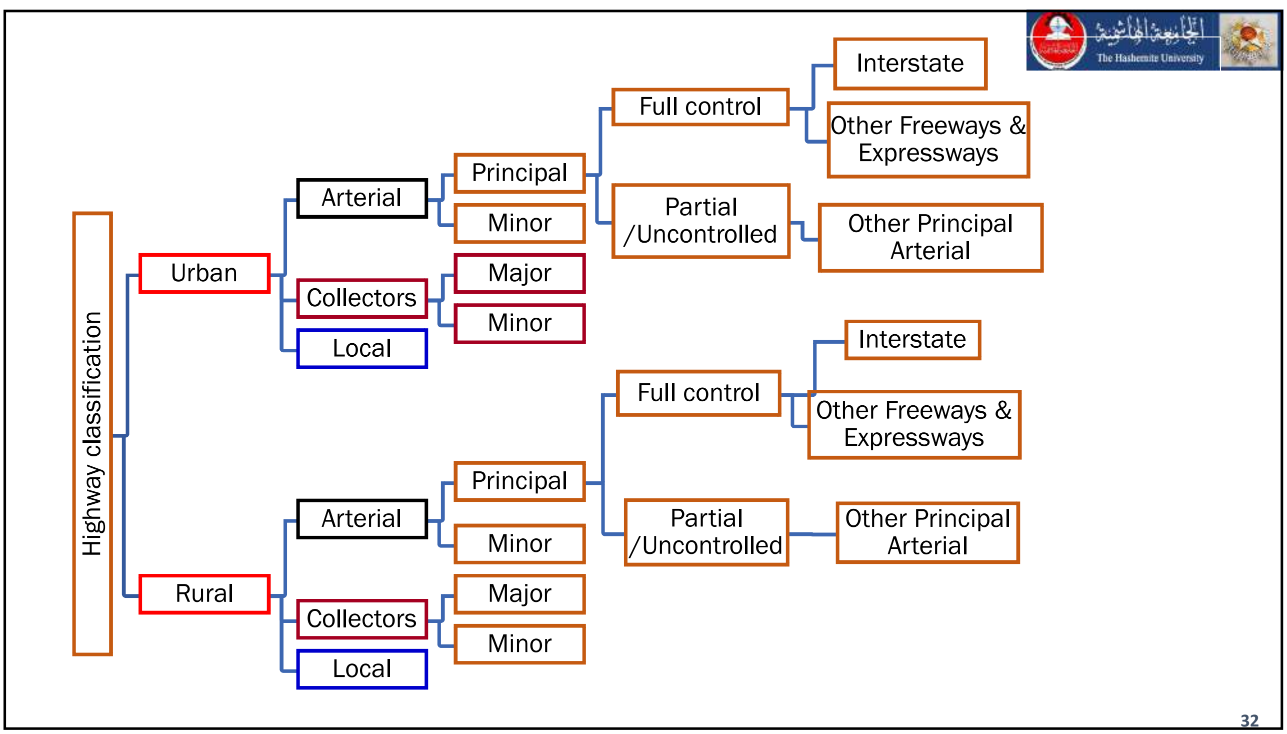
Highway classification
Urban
Rural
Arterial
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Principal
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Major
Minor
Full control
Partial /Uncontrolled
Full control
Partial /Uncontrolled
Interstate
Other Freeways & Expressways
Other Principal Arterial
Interstate
Other Freeways & Expressways
Other Principal Arterial
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Highway Location Classification

Urban interstate

Rural two-lane highway

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Highway Classification

Characteristics of Urban and Rural Principle Arterials

Urban	Rural
• Serve major activity centers, highest traffic volume corridors and longest trip demands • Carry high proportion of total urban travel on minimum of mileage • Interconnect and provide continuity for major rural corridors to accommodate trips entering and leaving urban area and movements through the urban area • Serve demand for intra-area travel between the central business district and outlying residential areas	• Serve corridor movements having trip length and travel density characteristics indicative of substantial statewide or interstate travel • Connect all or nearly all Urbanized Areas and a large majority of Urban Clusters with 25,000 and over population • Provide an integrated network of continuous routes without stub connections (dead ends)

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Highway Classification

Characteristics of Urban and Rural Minor Arterials

Urban	Rural
• Interconnect and augment the higher-level Arterials • Serve trips of moderate length at a somewhat lower level of travel mobility than Principal Arterials • Distribute traffic to smaller geographic areas than those served by higher-level Arterials • Provide more land access than Principal Arterials without penetrating identifiable neighborhoods • Provide urban connections for Rural Collectors	• Link cities and larger towns (and other major destinations such as resorts capable of attracting travel over long distances) and form an integrated network providing interstate and inter-county service • Be spaced at intervals, consistent with population density, so that all developed areas within the State are within a reasonable distance of an Arterial roadway • Provide service to corridors with trip lengths and travel density greater than those served by Rural Collectors and Local Roads and with relatively high travel speeds and minimum interference to through movement

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Highway Classification

Characteristics of Major Collectors (Urban and Rural)

MAJOR COLLECTORS	
Urban	**Rural**
• Serve both land access and traffic circulation in higher density residential, and commercial/industrial areas • Penetrate residential neighborhoods, often for significant distances • Distribute and channel trips between Local Roads and Arterials, usually over a distance of greater than three-quarters of a mile • Operating characteristics include higher speeds and more signalized intersections	• Provide service to any county seat not on an Arterial route, to the larger towns not directly served by the higher systems and to other traffic generators of equivalent intra-county importance such as consolidated schools, shipping points, county parks and important mining and agricultural areas • Link these places with nearby larger towns and cities or with Arterial routes • Serve the most important intra-county travel corridors

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Highway Classification

Characteristics of Minor Collectors (Urban and Rural)

MINOR COLLECTORS	
Urban	**Rural**
• Serve both land access and traffic circulation in lower density residential and commercial/industrial areas • Penetrate residential neighborhoods, often only for a short distance • Distribute and channel trips between Local Roads and Arterials, usually over a distance of less than three-quarters of a mile • Operating characteristics include lower speeds and fewer signalized intersections	• Be spaced at intervals, consistent with population density, to collect traffic from Local Roads and bring all developed areas within reasonable distance of a Collector • Provide service to smaller communities not served by a higher class facility • Link locally important traffic generators with their rural hinterlands

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Highway Classification

Characteristics of Urban and Rural Local Roads

Urban	Rural
• Provide direct access to adjacent land • Provide access to higher systems • Carry no through traffic movement • Constitute the mileage not classified as part of the Arterial and Collector systems	• Serve primarily to provide access to adjacent land • Provide service to travel over short distances as compared to higher classification categories • Constitute the mileage not classified as part of the Arterial and Collector systems

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Final Considerations

- In many instances, assigning a functional classification to a roadway **is straightforward**, especially for Interstates and Locals
- However, there is flexibility when deciding between adjacent classifications
- For example
  - *Deciding whether a given roadway acts as a Minor Arterial or Major Collector can be subject to debate.*
  - *Deciding between a Major Collector and Minor Collector assignment can be even more challenging*
- To assist transportation planners responsible for determining the functional classification of roadways
  - *Table 3-5 illustrates the range of lane width, shoulder width, AADTs, divided/undivided status, access control and access points per mile by functional classification categories.*

Final Considerations

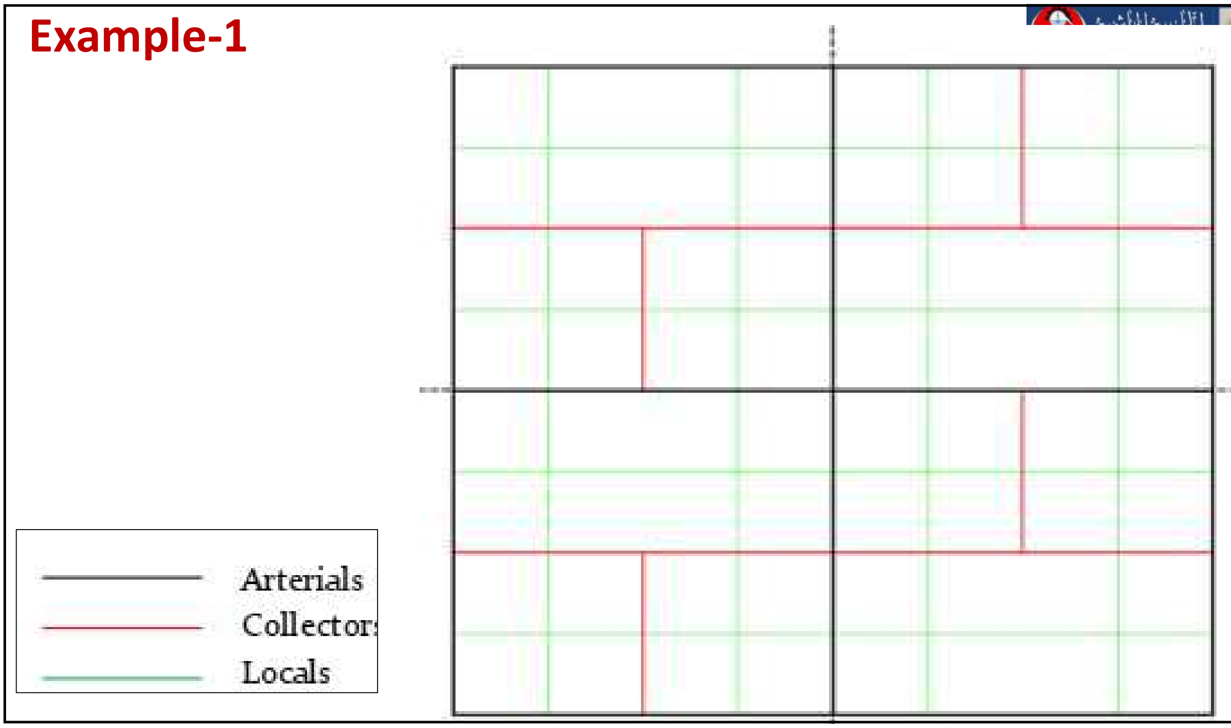
- To assist transportation planners responsible for determining the functional classification of roadways
  - *Table 3-5 illustrates the range of lane width, shoulder width, AADTs, divided/undivided status, access control and access points per mile by functional classification categories.*

	Arterials		
	Interstate	Other Freeways & Expressway	Other Principal Arterial
Typical Characteristics			
Lane Width	12 feet	11 - 12 feet	11 - 12 feet
Inside Shoulder Width	4 feet - 12 feet	0 feet - 6 feet	0 feet
Outside Shoulder Width	10 feet - 12 feet	8 feet - 12 feet	8 feet - 12 feet
AADT[1] (Rural)	12,000 - 34,000	4,000 - 18,500[2]	2,000 - 8,500[2]
AADT[1] (Urban)	35,000 - 129,000	13,000 - 55,000[2]	7,000 – 27,000[2]
Divided/Undivided	Divided	Undivided/Divided	Undivided/Divided
Access	Fully Controlled	Partially/Fully Controlled	Partially/Uncontrolled

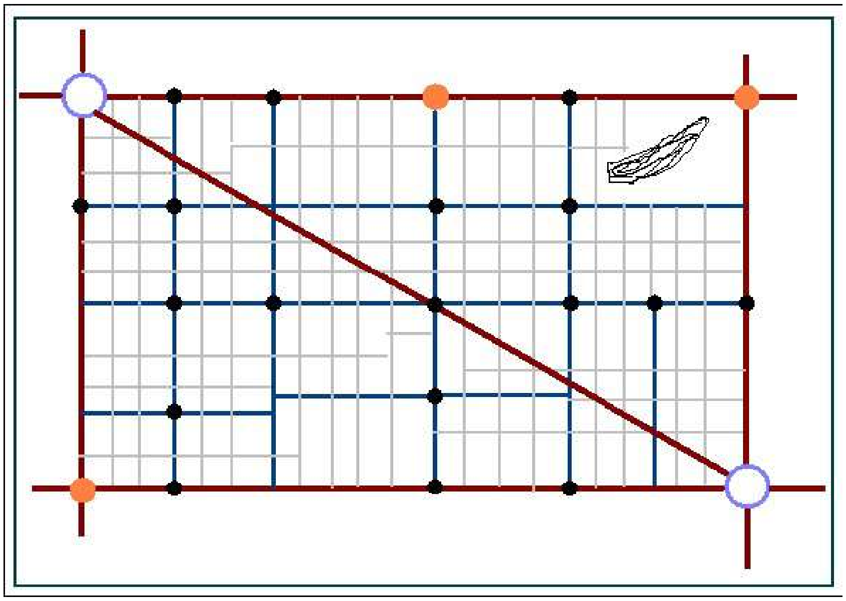
Highway Classification

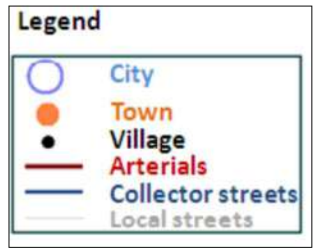
Examples No. 1 to 4 :

Example-1



Example-2





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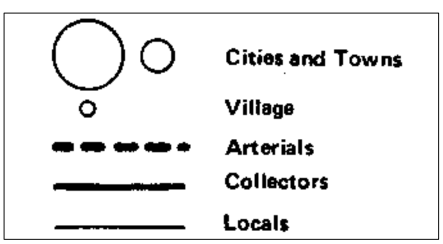
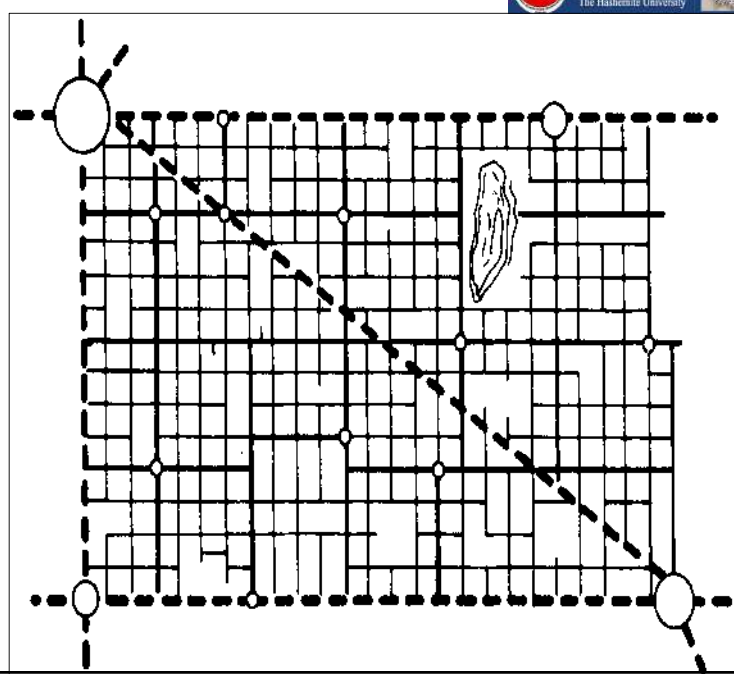
Example-3

Schematic Illustration of a Functionally Classified Rural Highway Network





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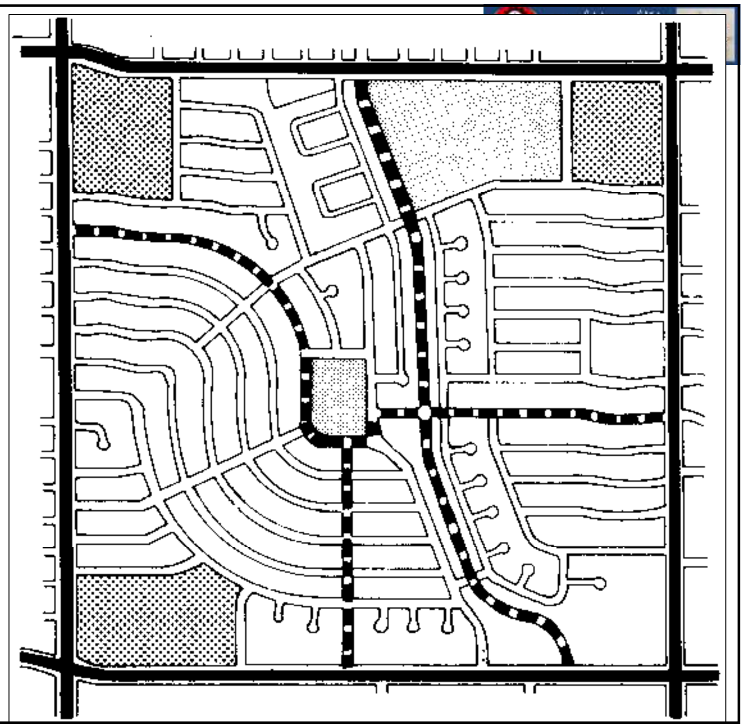
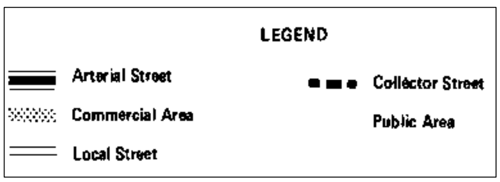
Example-4

Schematic Illustration of the Functional Classes for a Suburban Road Network





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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. **2**

2.1 _ Transport Systems Definitions And Classification

Dr. Hamza Alkuime

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Transport Systems and Classification

- Urban transportation modes and operational concepts can be classified according to several different bases include
  1. *Classification by type of Usage*
  2. *Classification by transit Modes*
  3. *Classification by types of Service*
  4. *Classification by Generic Classes of Transit Modes (<u>Most important</u>)*

2

2

Transport Systems and Classification

Classification by type of Usage

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Transport Systems and Classification

Classification by Type of Usage

- There are three basic categories of transportation by type of operation and usage (Primary classification):

A. *Private transportation*

- Consists of privately owned vehicles operated by owners for their own use, usually on publicly provided and operated streets.
- Private auto is the most common mode, but motorcycle, bicycle, and walking

B. *Public transport, mass transportation,* or *transit*

- These are transport systems with fixed routes and schedules, available for use by all persons who pay the established fare.
- Is the *common carrier* type of urban passenger transport.
- The most common representatives are bus, light rail transit, and rapid transit or metro,

C. *For-hire urban passenger transportation*

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Transport Systems and Classification

Classification by Type of Usage

C. For-hire urban passenger transportation

- *commonly designated as paratransit*
- *Is transportation service provided by an operator and available to all parties who meet the conditions of a contract for carriage (i.e., pay prescribed fares or rates), __but__ which is adjustable in various degrees to the individual user's desires.*

- Paratransit modes classified into:
  - *Demand-responsive*
    - Paratransit modes with routes and schedules that change with the requests of individual users
  - *Fixed-route, fixed schedule service*
    - Paratransit modes with fixed-route
  - *Most paratransit modes do not have fixed routes and schedules.*
  - *Taxi, dial-a-ride, and jitney are major mode*

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Transport Systems and Classification

Classification by Type of Usage

- **__Urban Public Transportation__**, strictly defined,
  - *Includes both transit and paratransit categories, since both are available for public use.*
  - *However, the term public transport is commonly identified with transit only, and inclusion of paratransit is specifically emphasizing*
- A secondary classification of travel categorizes transport as individual or group.
  - *Individual transport*
    - Refers to systems in which each vehicle serves a separate party (person or organized group);
  - *Group transport*
    - Usually carries __unrelated persons__ in the same vehicles

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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

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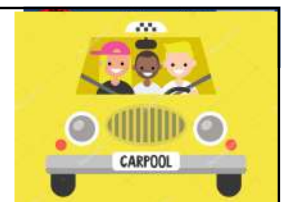
Transport Systems and Classification

Classification by Type of Usage



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Transport Systems and Classification

Classification by transit Modes

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 types of Service*
  - *Classification by generic Classes of Transit Modes (Most important)*

Transport Systems and Classification

Classification by Transit Modes

A transit mode is defined by its three basic characteristics

- A. Right-of-way (ROW) category
  - The travel way or strip of land on which the transit vehicles operate
- B. System technology
  - Refers to the mechanical features of their vehicles and ways.
- C. Type of service

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Transport Systems and Classification

Classification by transit Modes

A. Right-of-way (ROW) category

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Transit Mode Classification

A. Right-of-way (ROW) category

- Right-of-way (ROW) or (transit way) is
  - *The travel way or strip of land on which the transit vehicles operate*
- There are three basic ROW categories distinguished by the degree of their separation from other traffic :
  - *Category C*
  - *Category B*
  - *Category A*
- As moving from category C to category A
  - *The degree of separation between travel modes increases*
  - *The performance (speed, capacity, and reliability) of the transit system improves*
  - *The investment costs increase.*

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A. Right-of-way (ROW) category

Category C

- Represents surface streets with mixed traffic.
- It is the lowest cost and least impacting alternative
- It has the lowest service performance
  - *because transit vehicle movement is dependent on the flow of general traffic*
- Transit may have preferential treatment
  - Such as reserved lanes separated by lines
  - Special signals or travel mixed with other traffic

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A. Right-of-way (ROW) category

Category B

- Includes ROW types that are longitudinally physically separated from other traffic
- Separated from other traffic by
  - *Curbs*
  - *Barriers*
  - *Grade separation*
- This ROW category is most frequently used for
  - *light rail transit (LRT) systems*
  - *High occupancy vehicle (HOV) lanes*
- They provide better traffic flow than general lanes but do not separate public from private vehicles

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A. Right-of-way (ROW) category

Category B

Tram in Rotterdam, Netherlands

Tram in Portland, Oregon

Bus in transit mall, Denver, Colorado

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A. Right-of-way (ROW) category

High occupancy vehicle (HOV) lanes

- Known as
  - HOV lane, carpool lane, diamond lane, 2+ lane, and transit lane or T2 or T3 lanes
- Defined as
  - *Is a restricted traffic lane reserved for the exclusive use of vehicles with a driver and one or more passengers,*
- It includes
  - *Carpools*
  - *Vanpools*
  - *Transit buses*

https://en.wikipedia.org/wiki/High-occupancy_vehicle_lane

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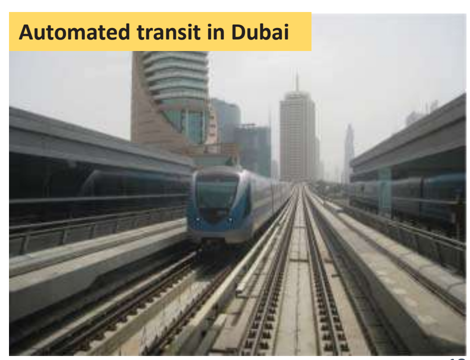
A. Right-of-way (ROW) category

Category A

- Defined as
  - *A physically separated and fully access-controlled ROW **without** intersections or legal access by other vehicles or persons.*
- It is also referred to
  - *"grade separated,"*
  - *"private,"*
  - *"exclusive" ROW*
- It can be
  - *A tunnel*
  - *Aerial structure*
  - *At-grade level.*

Transit tunnel in Seattle

Automated transit in Dubai



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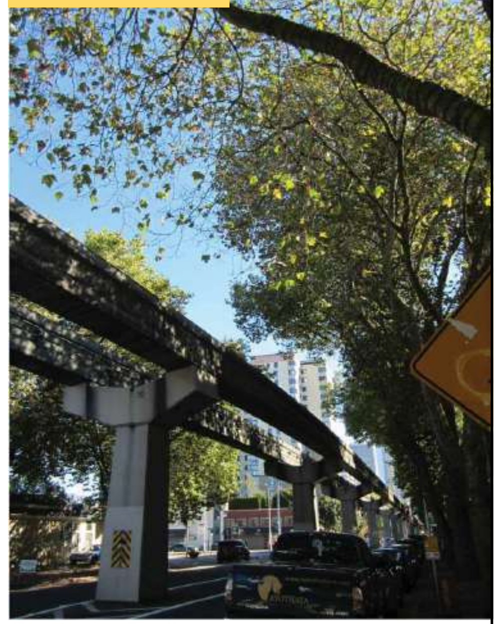
A. Right-of-way (ROW) category

Category A

Light rail transit in Los Angeles

Monorail in Seattle



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A. Right-of-way (ROW) category

What do you think ?

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Transport Systems and Classification

Classification by transit Modes

B. System technology

Transport Systems and Classification

Classification by Transit Modes

- A transit mode is defined by its three basic characteristics
  - A. Right-of-way (ROW) category
    - The travel way or strip of land on which the transit vehicles operate
  - **B. System technology**
    - Refers to the mechanical features of their vehicles and ways.
  - C. Type of service

Transit Mode Classification

B. System technology

- System technology of transit modes refers to
  - *The mechanical features of their vehicles and ways.*
- The four most important features are :
  1. *Support*
  2. *Guidance*
  3. *Propulsion*
     - Refer to the type of propulsion unit and Method of traction (transferring acceleration/deceleration forces)
  4. *Control*
     - The means of regulating the travel of one or all vehicles in a system

B. System technology

Support

- *Support* is
  - *the vertical contact between vehicle and riding surface, which transfers the vehicle weight and traction force*
- Support types
  - *Most common*
    - Rubber tire on concrete, asphalt, or other surface
    - Steel wheel on steel rail
  - *Others*
    - Vehicle body on water (boats and hydrofoils)
    - Air cushion (hovercraft)
    - Magnetic levitation

Transport Systems and Classification

Classification by transit Modes

C. Classification by types of Service

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 types of Service*
  - *Classification by generic Classes of Transit Modes (Most important)*

Transit Mode Classification

C. Types of Service

- There are many different types of transit services.
- They can be classified into groups by three characteristics
  1. The *types of routes and trips served*
  2. *Stopping schedule or type of operation*
  3. *Time of operation*

C. Types of Service Classification

1. Types of routes and trips served

- Classified into :
  - *Short-haul transit*
    - is defined as low- to medium speed services within small areas of high travel density
    - Such as central business districts (CBDs), campuses, airports, and exhibition grounds.
  - *City transit* (most common type)
    - Includes transit lines serving an entire city.
    - They may operate on any ROW category (C, B, or A).
  - *Regional transit*
    - Consists of long high-speed lines with few stops
    - Serving long trips within the metropolitan region.
    - Regional rail and some express bus lines exemplify this category

C. Types of Service Classification

2. Stopping schedule or type of operation

- Classified into:
  - *Local service*
    - is with all transit units stopping
      - At all stops
      - As required by passengers
  - *Accelerated service*
    - is operation when successive skip different sets of stations on a predetermined schedule (e.g., skip-stop).
  - *Express service*
    - is provided when all transit units (TUs) on a line stop only at widely spaced stops.
    - These lines often parallel local service but serve fewer stops /stations, comprising express/local service

C. Types of Service Classification

3. by *time of operation*

- Classified into:
  - *Regular* or *all-day service*
    - is transit operated during most daily hours.
    - This is the basic transit service, and it includes the great majority of transit lines.
  - *Commuter transit* or *peak-hour service*
    - refers to routes operated during peak hours only.
    - They are usually radial from suburbs, focusing on the CBD, and designed for work trips only.
    - Commuter transit is a supplement to an all-day, regular transit but not a substitute for it.
  - *Special* or *irregular service*
    - is transit operated only during special events
    - For example : sporting events, conventions, exhibitions, or public celebrations) and emergency conditions (snowstorms, floods)

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 types of Service*
  - <u>*Classification by generic Classes of Transit Modes (Most important)*</u>

Transport Systems and Classification

Classification by transit Modes

D. Classification by generic Classes of Transit Modes

Transport Systems and Classification

4. Generic Classes of Transit Modes

- The most important classification of transit modes is into three generic classes
- It is based mostly but not entirely on ROW type.
- These generic classes include :
  - *A. Street transit* (or *surface transit*)
  - *B. Semirapid transit*
  - *C. Rapid transit*

4. Generic Classes of Transit Modes

A. Street transit (surface transit)

- *Street transit* designates
  - *modes operated on streets with mixed traffic (ROW category C).*
- Its <u>reliability</u> depends on traffic conditions
  - *primarily traffic congestion and various interferences*
- Its speed is lower than the speed of traffic flow due to the time lost at passenger stops
- Examples
  - *Buses, trolleybuses, and streetcars/tramways are in this class*

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4. Generic Classes of Transit Modes

B. Semirapid transit

- Consists of modes utilizing mostly ROW category B,
  - *but C or A may also be used on some sections.*
- This class includes a wide range of modes from those with B and C categories, such as
  - *buses and light rail transit (LRT) operating on separated ROW and streets on the low side,*
  - *Largely grade-separated LRT with tunnels or aerial structures (B and A) on the high side.*
- Performance of these modes depends
  - *The <u>degree and locations</u> of ROW separations:*
    - It is particularly important that transit be separated from other vehicular traffic in central, congested urban areas.
  - *Technology:*
    - Rail modes can operate in short trains and have higher safety through automatic signalization than buses.
    - Higher types of Semirapid transit (with little or no category C ROW) can match or exceed the speed and reliability of auto travel.

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4. Generic Classes of Transit Modes

Rapid transit

- *Rapid transit* modes operate **exclusively on category A ROW**
- It have high speed, capacity, reliability, and safety.
- All existing rapid transit systems utilize *guided technologies* (rail or rubber tire),
  - *which permit the operation of trains (high capacity and low operating costs) and automatic signal control (high safety).*
- Because the term ''rapid transit'' is very popular, some cities use it for their transit systems, although they consist of buses or LRT only.
  - *Technically speaking, the Bus Rapid Transit (BRT) mode is semirapid, rather than rapid transit.*

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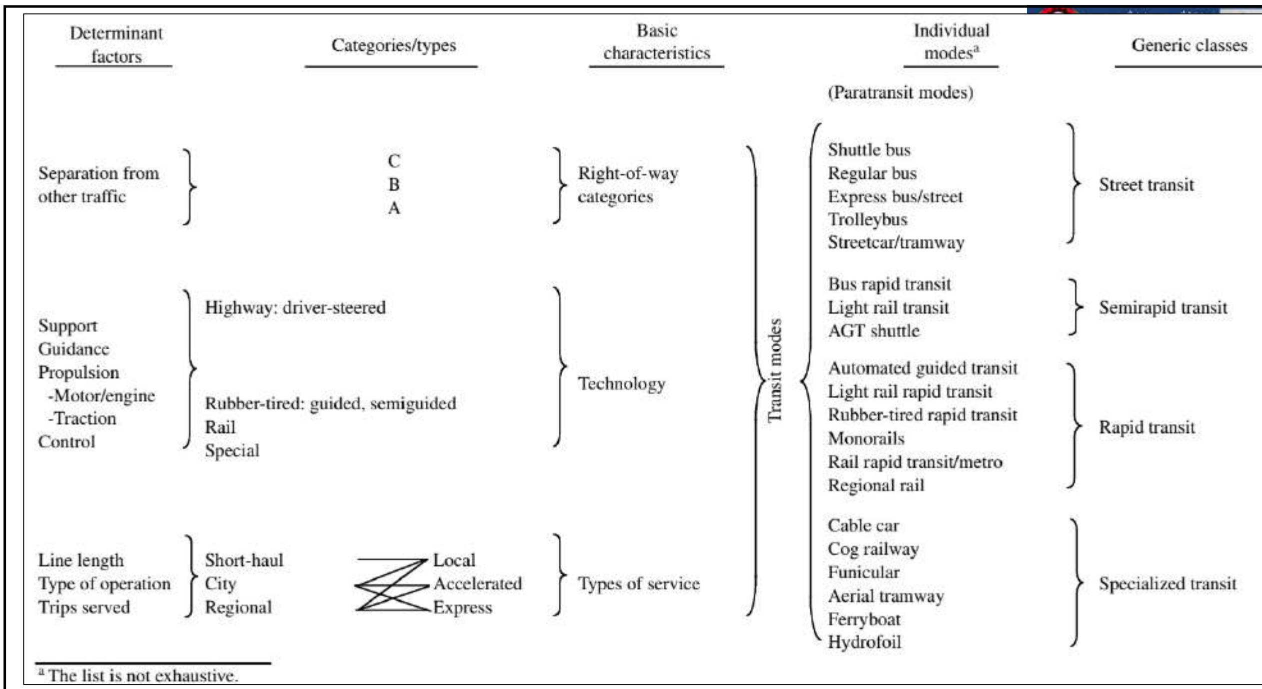

An overview of transit mode definition, classification, and characteristics

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Trolleybus


Automated guideway transit (AGT)


Cable Car


Cog railway

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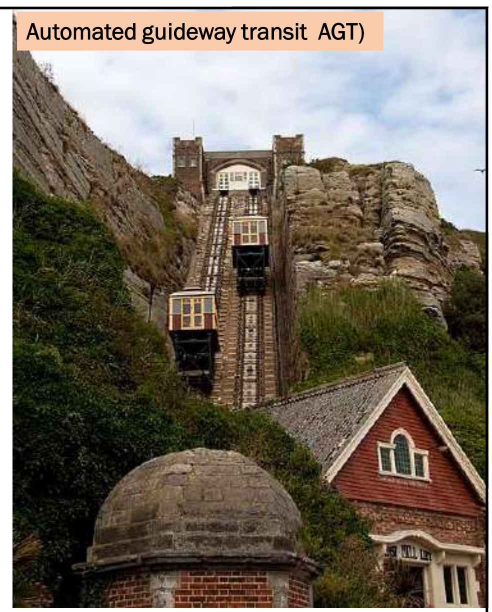
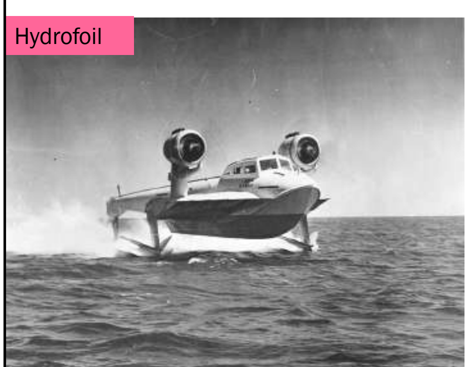
Ferry


Automated guideway transit AGT)


Hydrofoil

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Transit System Components

Transit System Components

Physical components of the transit systems are generally classified into the following items:

1. Vehicles or Cars
   - *Referred to collectively as the fleet for any mode and rolling stock for rail vehicles.*
   - *A transit unit (TU) is a set of vehicles traveling together; it may be a single vehicle unit or a train with several coupled vehicles.*
2. Ways, travel ways, or rights-of-way, which may be
   - *Common streets and roads*
   - *Reserved lanes (designated only)*
   - *Exclusive lanes (physically separated)*
   - *Transit streets*
   - *Busways (grade-separated roadways for buses only)*

Transit System Components

Physical components of the transit systems are generally classified into the following items:

3. Locations and facilities

- *Refer to Locations and facilities at which vehicles stop to pick up and drop off passengers can be of several types.*

Includes

- *Stops*
  - locations along streets with simple facilities (signs, shelters, etc.).

- *Stations*
  - Usually facilities below, on, or above ground for passengers and system operation.
- *Terminals*
  - End stations of major transit lines
  - Transfer stations serve more than one line and provide for passenger interchange among them

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Transit System Components

Physical components of the transit systems are generally classified into the following items:

4. Bus garages or depots and rail yards

- *Buildings or areas for vehicle storage.*
- *Shops are facilities for vehicle maintenance and repair*

5. Control systems

- *include electric, computer and other electronic equipment for*
  - Vehicle detection
  - Communication and signals,
  - *Central control facilities*

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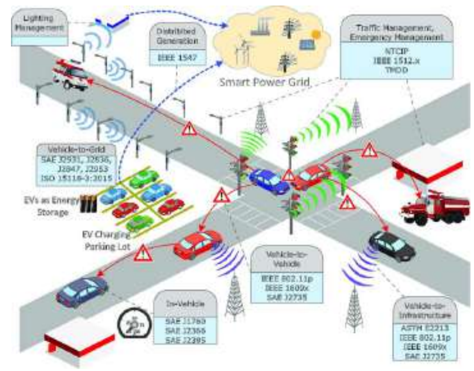
Transit System Components

Physical components of the transit systems are generally classified into the following items:

6. *Intelligent Transportation System* (*ITS*)

   - *is a broad set of devices, facilities, and processes that utilizes computer and other electronic technology devices for control and efficient operation of transportation systems.*
   - *In transit systems, ITS is used mostly in*
     - The monitoring and control of TU operations
     - Fare collection and control
     - Collection of statistical data
     - Passenger information systems



Transit System Components

Physical components of the transit systems are generally classified into the following items:

8. *Power supply systems* on electrically powered modes

   - *Consist of substations, distribution cables, catenary or third-rail structures, and related equipment.*

9. *Transit route* or *transit line*

   - *is a designated set of streets or separated rights-of-way that transit TUs regularly serve*
   - *The term ''route'' is commonly used for buses*
   - *The term ''line'' for rail modes and for sections on which several routes overlap;*
     - but the two terms are sometimes used interchangeably.
   - *The collection of all routes/lines in a city is its transit network.*

Transit System Operations, Service , and Characteristics

Transit System Operations and Service

- Transit operations
  - *produce transportation that is offered to potential users.*
- Transit operations include such activities as
  - *Scheduling*
  - *Crew rostering*
  - *Running and supervision of TUs*
  - *Fare collection*
  - *System maintenance*
- Transit service
  - *is the system as seen by its actual and potential users*

Transit System Characteristics

- *Transit system characteristics*
  1. *System performance*
  2. *Level of service* (*LOS*)
  3. *Impacts*
  4. *Costs*

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Transit system characteristics

1. System performance

- *Defined as*
  - *refers to the entire set of performance elements*
- The most important being:
  - A. *Service frequency* (f)
    - Number of TU departures per hour
  - B. *Operating speed* (V_o)
    - Speed of travel on the line which passengers experience.
  - C. *Reliability*
    - Expressed as a percentage of TU arrivals with less than a fixed time deviation from schedule (e.g., 4 min).
  - D. *Safety*
    - Measured by the number of fatalities, injuries, and property damage per 100 million passenger-km, or a similar unit.

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Transit system characteristics

System performance

F. *Line capacity* (C)

- ❖ The maximum number of spaces (offered capacity) or persons (utilized capacity) TUs can carry past a point along the line for one hour.

G. *Productive capacity* (P_c)

- ❖ Composite indicator incorporating one basic element affecting passengers (speed) and one affecting the operator (capacity)
  - The product of operating speed and capacity of the line, (V_o x C).
- ❖ Productive capacity is a very convenient performance indicator for mode evaluation

H. *Productivity*

- ❖ The quantity of output per unit of resource
- ❖ (e.g., vehicle-km per operating cost, or space-km per unit of labor, fuel, ROW width, and so on).

I. *Utilization*

- ❖ The ratio of output to input, but of the same or a similar unit; for example, person-km/space-km offered.

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Transit system characteristics

2. Level of service (LOS)

- Defined as
  - *the overall measure of all service characteristics that affect users.*
- LOS is a basic element in attracting potential users to the system.
- Major factors comprising LOS can be divided into three groups:

A. *Performance elements that affect users*

- ❖ Such as operating speed, reliability, and safety

B. *Service quality (SQ)* consisting of qualitative elements of service

- ❖ Such as convenience and simplicity of using the system, riding comfort, aesthetics, cleanliness, and behavior of passengers

C. *Price*

- ❖ The amount a user must pay for service (i.e., its fare or rate)

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Transit system characteristics

3. Impacts

- *Defined as*
  - *The effects transit service has on its surroundings and the entire area it serves*
  - *The impact may be positive or negative.*
- *Impact types*
  - *Short-run impacts*
    - Reduced street congestion
    - Changes in air pollution, noise, and aesthetics along a new line.
  - *Long-run impacts*
    - Changes in land values
    - Changes in economic activity
    - Changes in physical form, and the social environment of the city

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Transit system characteristics

4. Costs

- *Costs* are usually divided into **two** major categories:
  - *Investment (or capital) costs*
    - Those required to construct or later make permanent changes in the physical plant of the transit system.
  - *Operating costs*
    - Costs incurred by regular operation of the system

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Generic Class		Private Auto on		Street Transit			Semirapid Transit			Rapid Transit		
Characteristics	Unit	Street	Freeway									
Transit unit capacity	sps/TU	1.2–2.0[b]		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[c]		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[d]	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_o^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

[a]The systems shown are assumed to be heavily loaded but somewhat below capacity of respective mode.
[b]Maximum number of spaces that can be utilized.
[c]Designations used in Figures 2.5, 2.6, and 2.7.
[d]Articulated buses.

Performance values for generic classes of modes and for several typical systems

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Technical, operational, and system characteristics of urban transport modes

Generic Class / Characteristics	Mode / Unit	Private: Auto on Street	Private: Auto on Freeway	Street Transit: RB	Street Transit: SCR	Semirapid Transit: BRT	Semirapid Transit: LRT	Rapid Transit: RRT	Rapid Transit: RGR
Vehicle capacity, C_v	sps/veh	4–6, total	1.2–2.0 usable	40–120	100–250	40–150	110–250	140–280	140–210
Vehicles/TU	veh/TU	1	1	1	1–3	1	1–4	1–10	1–10
TU capacity	sps/TU	4–6, total	1.2–2.0 usable	40–120	100–500	40–150	100–750	140–2400	140–2000
Max. technical speed, V	km/h	40–80	80–120	40–80	60–70	70–90	60–100	80–100	80–130
Max. frequency,[b] f_{max}	TU/h	600–800	1500–2000	60–180	60–120	60–300[d]	40–60	20–40	10–30
Line capacity,[c] C	sps/h	720–1050[d]	1800–2600[d]	2400–8000	4000–15,000	4000–8000 –20,000[d]	6000–20,000	10,000–70,000	8000–60,000
Normal operating speed, V_o	km/h	20–50	60–90	15–25	12–20	20–40	20–45	25–60	40–80
Operating speed at capacity, V_o^c	km/h	10–30	20–60	8–15	8–13	15–40	15–40	24–55	38–75
Productive capacity,[c] P_c	10^3 sp-km/h	10–25[e]	50–120[e]	25–90	35–150	75–200 –600	120–600	700–1800	800–4000
Lane width (one-way)	m	3.00–3.65	3.65–3.75	3.00–3.65	3.00–3.35	3.65–3.75	3.40–3.60	3.70–4.30	4.00–4.75
Vehicle control[f]	—	Man./vis.	Man./vis.	Man./vis.	Man./vis.	Man./vis.	Man./vis.-sig.	Man.-auto./sig.	Man.-auto./sig.
Reliability	—	Low–med.	Low–high	Low–med	Low–med	High	High	Very high	Very high
Safety	—	Low	Low–med	Med	Med	High	High	Very high	Very high
Station spacing	m	—	—	200–500	300–500	500–800	500–1000	500–2000	1200–4500
Investment cost per pairs of lanes	10^6 \$/km	1.0–8.0	20.0–100.0	0.5–6.0	5.0–10.0	5.0–40.0	10.0–50.0	40.0–100.0	50.0–120.0

[a]Abbreviations: sps = spaces; veh = vehicles; TU = transit unit; RB = regular bus; SCR = streetcar; BRT = bus rapid transit; LRT = light rail transit; RRT = rail rapid transit; RGR = regional rail.
[b]For auto, lane capacity; for transit, line (station) capacity in TU/h.
[c]Values for C and P_c are not necessarily products for the extreme values of their components because these seldom coincide.
[d]With multiple parallel lanes and overtaking at stations.
[e]For private auto, capacity is product of average occupancy (1.2–1.3) and f_{max}, since all spaces cannot be utilized.
[f]Abbreviations are for manual, visual, signal, and automatic.

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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 2

2.2 _ Highway Transit

Dr. Hamza Alkuime

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

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*
  - *To provide be more attractive transit services that can be competitive with autos and reduce street congestion,*

3

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Bus, the vehicle

4

4

Bus, the vehicle

- The bus may be classified based on :

➢ Propulsion Systems OR Body Type

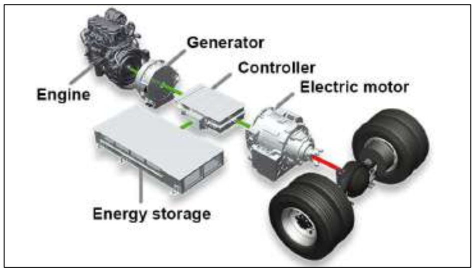


Image source: https://gettozero.com/series-e.php

Image Source: https://info.japanusedbuses.com/content-item/1717-body-types-of-buses

Classification by Propulsion System

Diesel Bus

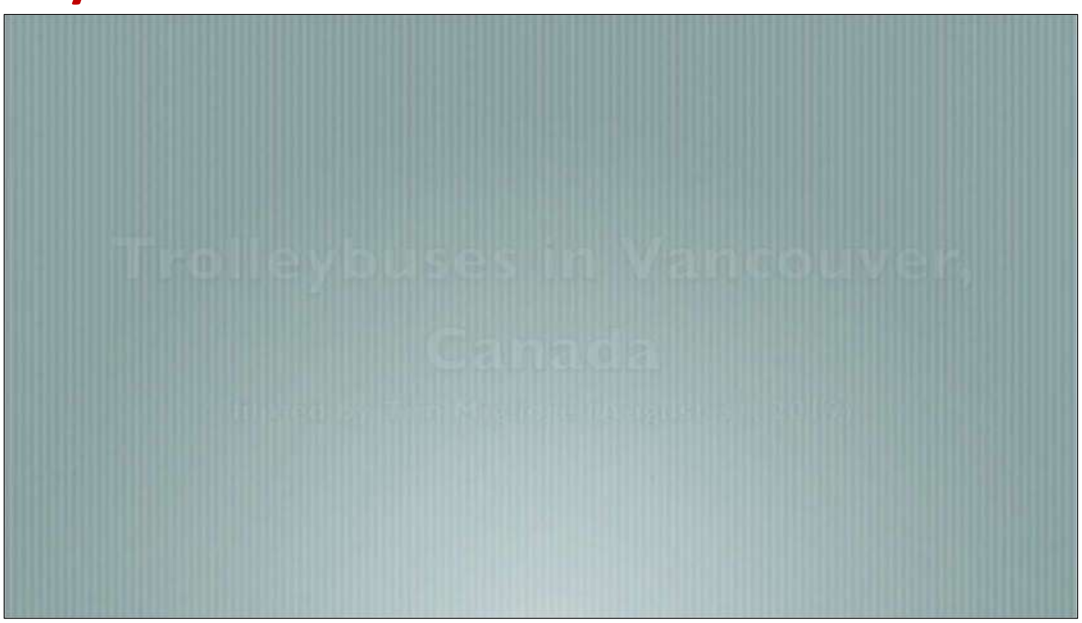
- The vast majority of buses in the United States are powered by the six- or eight cylinder four-stroke water-cooled straight in-line or V type diesel motor.

Classification by Propulsion System

Trolleybus

- As electrically powered highway vehicles that obtain power via trolley poles from two overhead wires (+ and -)
- Trolleybuses are the only rubber-tired highway vehicles without a self-contained power source for regular operation

Trolleybus



https://www.youtube.com/watch?v=___JBMR3wT4

Buses

Trolleybus Vs Diesel bus

- Advantages
  - *The trolleybus due to electric traction, they are more*
    - Rapid
    - Smooth acceleration and deceleration, particularly on gradients
  - *The trolleybus produce extremely low noise and no exhaust fumes.*
  - *The trolleybus vehicles are more durable than diesel buses*
- Disadvantages
  - *The trolleybus* require a higher investment and line maintenance costs (for overhead wires)
  - *The* travel using *trolleybus* is limited to the network of overhead wires except for short distances or maneuvers

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Classification by Propulsion System

Dual-Mode Bus

- A bus that has both diesel and electric traction
  - It can operate on a trunk section of a line in the center city, or in a short tunnel section as a trolleybus and then proceed on streets as a diesel bus

A guided dual-mode

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Dual-Mode Bus

https://www.youtube.com/watch?v=D4mc1WfVf-o

Classification by Propulsion System

Hybrid Bus

- This bus model has
  - A diesel (sometimes gasoline)
  - An electric motor/generator
  - An electric battery or other energy storage device.
  - *A special switching mechanism allows*
    - the use of either of the motors or their combination during different regimes of travel

Volvo's first Electric Hybrid bus in commercial service

https://www.youtube.com/watch?v=Oxwxql5zzOM

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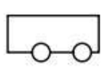
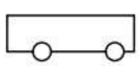
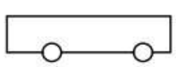
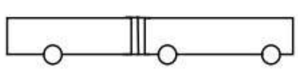
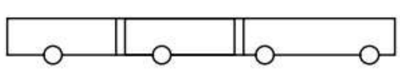
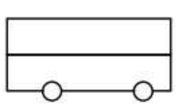
Classification by Body Type

Table 5.3 Different bus vehicle types

Type	*Sketch*	*Length (m)*	*Capacity* Min/Max Seats	*Capacity* 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

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Classification by Body Type

A contemporary minibus

Midibus in Budapest

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Classification by Body Type

Standard U.S. urban low-floor bus

Three-axle bus in Hamburg

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Classification by Body Type

Low-floor articulated bus with wheelchair ramp lowered

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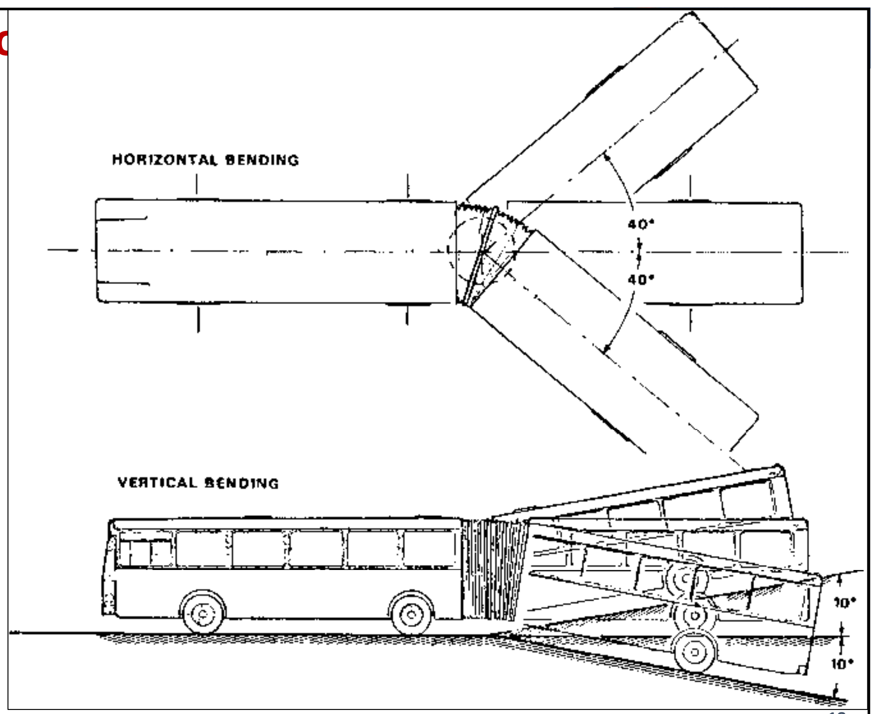
Classification by Bo

Bending ability of articulated bus



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Articulated Bus From California At Mississauga City Hall

الجامعة الهاشمية
The Hashemite University

https://www.youtube.com/watch?v=0xwxql5zz0M

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Amman Rapid Bus

الجامعة الهاشمية
The Hashemite University

https://www.youtube.com/watch?v=3q_66Ec5db4

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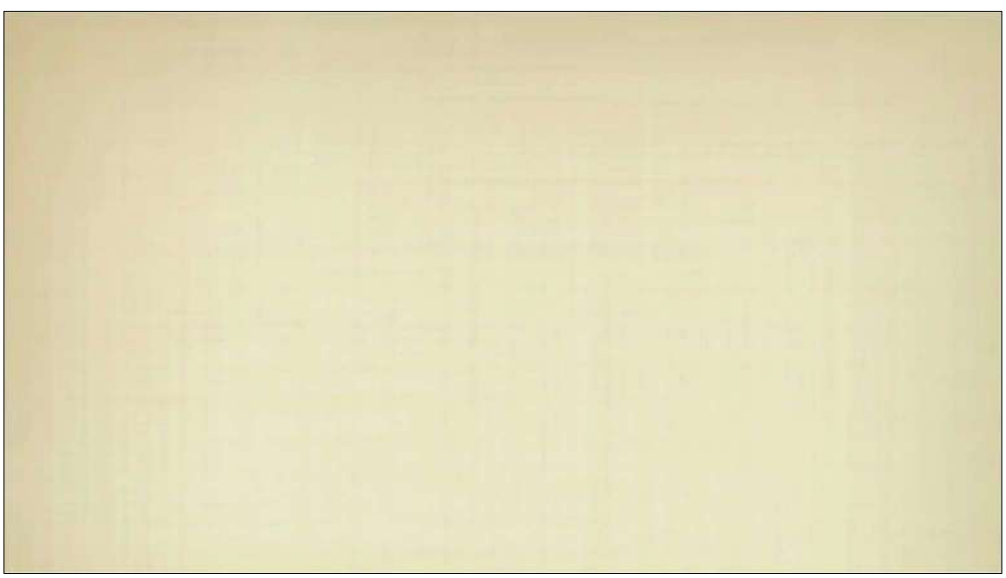
Classification by Body Type

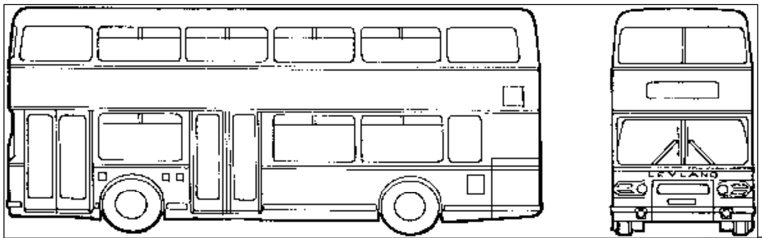
Double-articulated bus

Double Articulated Buses in Hamburg, Germany



https://www.youtube.com/watch?v=7SQs15X0BVQ&t=50s

Classification by Body Type



Double-decker bus

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Classification by Body Type

Guided bus

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Classification by Body Type

Guided bus

https://www.youtube.com/watch?v=1OUY3WC4nDY

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Optimal Bus Size

Optimal Bus Size

- The selection of bus size is usually **a complex task** because the relative importance of several factors include:
  1. *Line capacity* required to meet passenger volume
     - increases nearly linearly with vehicle size.
  2. *Service frequency*
     - is desirable for passengers, but above 20 to 30 departures per hour it is fully satisfactory
  3. *Vehicle maneuverability*
     - Decreases with vehicle size.
     - Large vehicles are less convenient and slower on routes with many turns, narrow lanes, and so on.
  4. *Riding comfort*
     - Increases with the vehicle size on single-body buses, but may be lower with articulated and double-decker buses
  5. *Operating costs* per unit of offered capacity (space-km)
     - Increases with the vehicle size on single-body buses, but may be lower with articulated and double-decker buses

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Bus Travel Ways

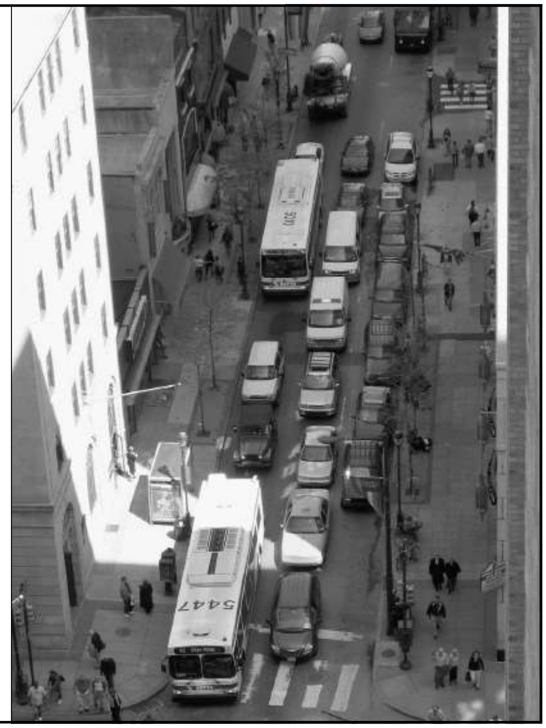
Bus Travel Ways

- A vast majority of buses operate on urban streets with no special fixed facilities except bus-stop signs and benches or shelters
- In recent years in many cities
  - *there has been a growing recognition of the fact that the level of bus service **depends mostly on the type of ROW facilities**, leading to the introduction of bus lanes and busways, i.e., elements of BTS and BRT*
- Bus Travel Ways includes
  - A. *Shared travel-way*
  - B. *Bus Lanes on Streets*
    1. Regular Bus Lane (RBL)
    2. Contraflow Bus Lane (CBL)
    3. Exclusive Bus Lane (EBL)

Bus Travel Ways

A. Shared travel-way (operation mixed traffic)

- *Bus operation on urban streets and arterials* requires virtually no investment
  - *Allows nearly any bus routing, but has adequate reliability only if auto and other traffic on the same streets does not have frequent delays*
- Since buses are vulnerable to traffic congestion and must make passenger stops along their way,
  - *Bus operating speed is always lower than the travel speed of private automobiles on the same facility.*
    - Thus, buses in mixed traffic ***cannot*** be competitive with autos with respect to travel speed



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Bus Travel Ways

B. Bus Lanes on Streets

- The most important preferential measure for buses is
  - *the longitudinal separation of travel ways*
- The numerous reasons for preferential treatment of buses can be divided into two categories:
  - *Greater importance of public transport due to its basic role in the city, its greater efficiency, and fewer negative side effects*
  - *Much higher occupancy of public than of private vehicle*
- It can be provided in different forms with respect to
  - *Types of lanes*
  - *Alignment*
  - *Degree of separation from other vehicle categories includes*

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Bus Travel Ways

B. Bus Lanes on Streets

- Bus Lanes on Streets includes

1. **Regular Bus Lane (RBL)**
   - One per direction or one reversible lane for both peak hours,
   - used for <u>commuter bus lines</u>
2. **Contraflow Bus Lane (CBL)**
   - One or two lanes **<u>opposite</u>** to the flow on one roadway separated by lines, curbs, rubber cones, or overhead signs serving buses in the prevailing direction
3. **Exclusive Bus Lane (EBL)**
   - Physically separated facility for two-way bus travel at all times.

Regular bus lane on a street

Regular bus lane (RBL) usually curb lanes, are the most common type of bus lanes on streets

Bus Lanes on Streets

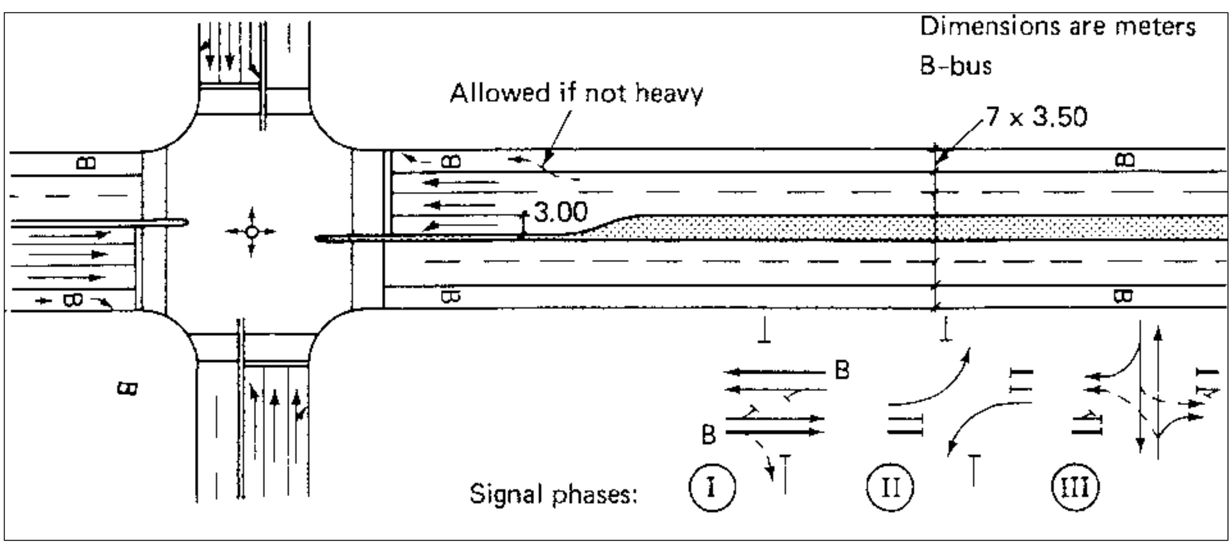
Regular Bus Lane (RBL)

- Curb RBLs
  - *Their introduction, naturally, requires prohibition of parking and stopping*
  - *Turning traffic at intersections requires special solutions*
  - *Convenient*
    - since they allow easy stopping of buses for passenger boarding/alighting,
  - *usually slower than other lanes because of "marginal friction": closeness to curb, trees, poles, and pedestrians.*
  - *Most important,* ***their effectiveness is greatly dependent*** *on*
    - The enforcement of driving, stopping, and parking prohibitions
    - Adequate provision for deliveries outside that lane, accesses to driveways and parking areas,
      - For this reason RBLs cannot be effectively used in cities with inadequate enforcement of traffic controls and chaotic street conditions

Downtown DC's dedicated bus-only lanes will be made permanent next week - Curbed DC

Bus Travel Ways

Curbed Regular Bus Lane



Bus travel ways

Contraflow Bus Lane (CBL)

- *CBLs,* having the opposite direction from other lanes on the same street
  - must be located along the curb to the left from the main travel direction
- The opposite direction of CBL operation strongly discourages any encroachment of other traffic
  - So that **less enforcement is needed** than with RBL
- Yet, to prevent potentially dangerous head-on situations,
  - *CBLs must* ***be marked more conspicuously than*** *RBLs: double yellow lines, signs, and sometimes overhead lane signals are used.*
- Another potential safety hazard is to pedestrians who may step into the lane, not expecting vehicles traveling the ''wrong way'' on a street perceived to be one-way.
- To further ensure safety,
  - *It is desirable that CBLs be used only where bus frequency is high (20 to 40 buses/h), so that a bus is in view of other drivers at most times.*

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Bus travel ways

Contraflow bus lane (CBL)

Contraflow bus lane in London

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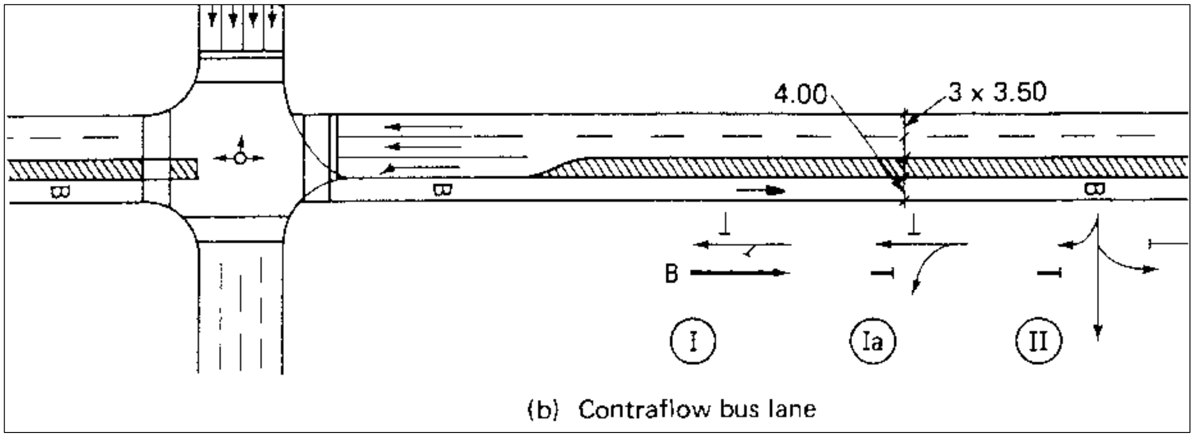
Bus travel ways

Contraflow bus lane (CBL)



Bus travel ways

Contraflow bus lane (CBL)

Bus Priority Measures: Contraflow bus lanes in London - YouTube

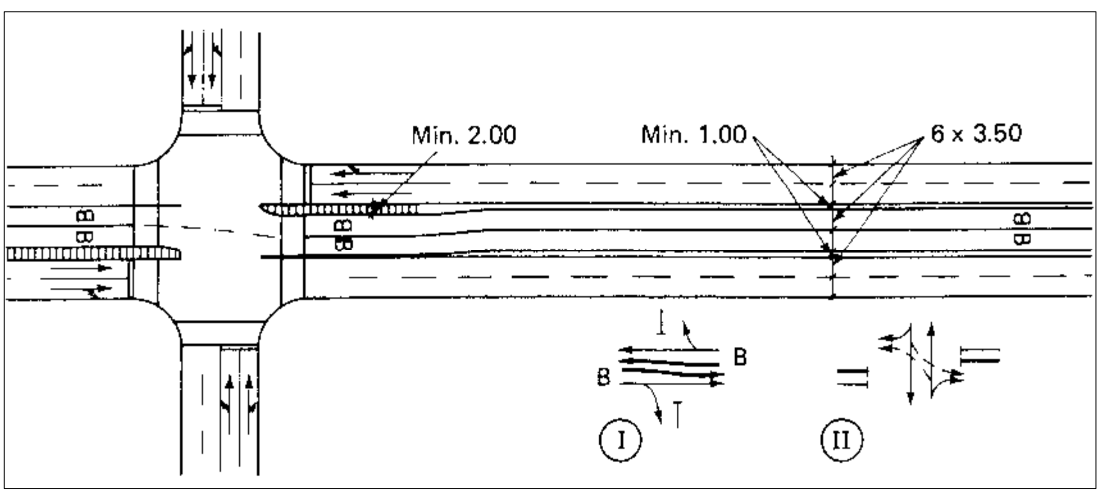
Exclusive bus lanes or busway (EBL)

Center lanes or *curbed medians*

- Physically separated facility for two-way bus travel at all times.
  - *It is desirable wherever possible to separate lanes on their entire length by curbs*
- Such lanes are faster and safer than curb RBLs,
  - *but pedestrian islands must be provided at all stops for safety and convenience*
- This type of facility requires either
  - *Elimination of left turns for other traffic*
  - *A three-phase signal control that separates left turns from bus movements.*

Bus travel ways

Center lanes or *curbed medians*



Bus travel ways

Center lanes or *curbed medians*

MBTA, city of Boston cut ribbon on New England's first center-running bus lane on Columbus Avenue | Mass Transit (masstransitmag.com)

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Bus travel ways

Center lanes or *curbed medians*

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Bus Transit Modes

Family of Highway Transit Modes

Bus Transit modes

- Three general types of Bus Transit Modes:
  1. *Regular or conventional bus* (*RB*)
  2. *Bus Transit Systems* (*BTS*)
  3. *Bus Rapid Transit (BRT)*

Bus Transit Modes

1. Regular or conventional bus (RB)

- *Regular or conventional bus (RB):*
  - *A bus transit system consisting of buses operating with fixed schedules on streets in mixed traffic (ROW category C) and curbside stop locations equipped with signs and sometimes with passenger protection and information facilities.*

Bus Transit Modes

Regular or conventional bus (RB)

- Characteristics
  - *Bus stops are at every corner*
  - *Considerable time is lost due to traffic signals.*
  - *The stops often have inadequate information for passengers*
  - *It has limited speed and reliability*
  - *It requires little investment but offers services with weak image and reputation*
  - *It is usually not competitive with auto travel*

Bus Transit Modes

2. Bus transit system (BTS)

- *Bus transit system* (*BTS*)
  - *A bus mode developed as a coordinated system with significant improvements in its components for higher operating speed, reliability, and efficiency.*
- Upgraded components may include
  - *Provision of bus lanes, stops with greater spacings designed for fast boarding due to self-service fare collection (SSFC)*
  - *Multichannel doors*
  - *Low-floor buses*

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Bus Transit Modes

3. Bus Rapid Transit (BRT)

- *Bus Rapid Transit* (*BRT*)
  - *Bus transit designed as an integrated system of distinct buses and a separate infrastructure with considerable independence from other traffic, allowing higher speed, reliability, and safety than BTS*
- Although it is not possible to precisely define the distinction among the three bus modes, which may differ in many physical components and operating practices
  - *The six components listed in the box next slide are used as the basic elements that a system must have to be considered a BRT.*

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Bus Transit Modes

BRT must have the following elements

1. Predominantly ROW category B or A not shared by other modes such as taxis or HOVs, and only limited line sections, if any, with ROW C (MOST Important)
2. Distinctive lines with frequent, reliable service and regular headways during all daily hours
3. Distinct stops or stations with good passenger protection, information, and fare-collection equipment, allowing fast passenger exchange, **which are spaced at least 300 to 600 m apart** in the central city and at greater distances in suburban areas
   - *Amman BRT has length of 32 Km and 21 Stop stations*
4. Bus vehicles of distinctive design, with a large door channel-to-capacity ratio, low floor, or high platform for fast passenger exchange at stops and stations.
5. Bus preferential treatment at all major intersections.
6. Use of intelligent transportation system (ITS) technology for monitoring vehicle locations ands movements, passenger information, and fare collection.

Bus Transit Modes

Vehicles

- BRT lines are usually served by articulated buses because they serve heavily traveled lines and require high passenger comfort

Two all-electric articulated bus prototypes tested in Gothenburg, Sweden (automotivetestingtechnologyinternational.com)

Bus Transit Modes

Infrastructure: Lines and Stations

- BTS lanes are usually placed along street curbs.
- With the goal of making BRT lines a distinct transit system with priority over general traffic,
  - *their exclusive lanes are placed in most cases in a central position*
  - This position provides for faster travel of buses, although it requires special design of stations and regulation of turning movements at intersections
- Bus station designs depend on
  - *The passenger volumes, their access to stations on islands in the middle of the street, and the method of fare collection*
- Pedestrian access must be channeled via one or two pathways from intersections or overpasses to a set of fare gates

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Bus Transit Modes

Operations and ITS Applications

- The most common ITS elements include
  1. *The automatic vehicle location (AVL) system, based on GPS or other technologies,*
     - is often used by control centers for bus dispatching, coordination of transfers among bus lines, interventions when delays occur, and other events
  2. *Priority or preemption at signalized intersections*
  3. *Silent alarm for the driver and other security device*
  4. *Passenger information systems for*
     - pre trip and onboard information for forthcoming stops, transfers, etc., automated or transmitted from the driver or from the control center
  5. *Announcements of next bus arrivals at stations*

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Bus signal preemption

https://www.youtube.com/watch?v=oT80Y18oAH8

Exclusive bus lanes or busway (*EBL*)

Center lanes or *curbed medians*

https://www.youtube.com/watch?v=gasAoFqlkxg

Bus Transit Modes

Costs for U.S. Bus Rapid Transit Projects

BRT System	Miles	Capital Costs ($ million)	Cost per Mile ($ million)	Federal Funding	State and Local Funding
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%

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Case study

Amman BRT

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Amman BRT

- https://www.youtube.com/watch?v=DT0lUoptqVw&t=33s

Bus Stops on Streets

- The planning of stops along a bus route involves three major aspects:
  - *Spacings*
  - *Locations*
  - *Stop designs*

Bus Stops Spacings

Spacings

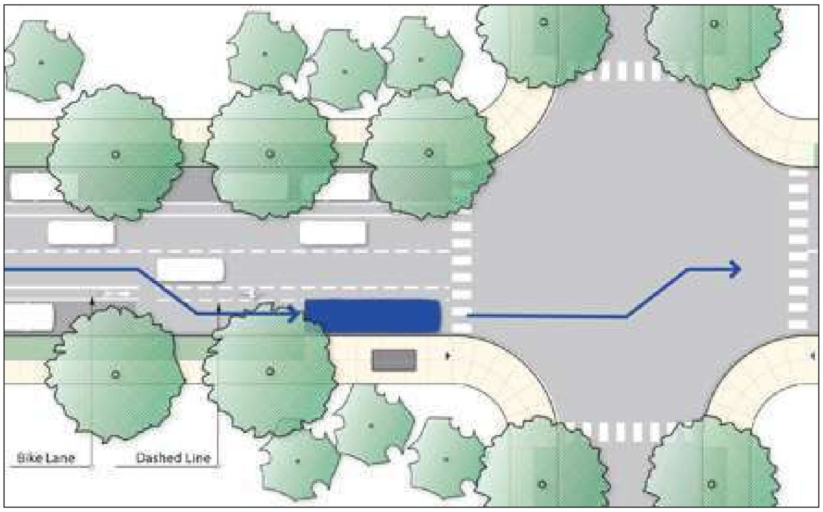
- he spacings of bus stops should be **inversely** related to
  - *The ratio of passenger origins and destinations*
  - *The volume of passengers traveling through an area*
- Stop spacings should be such that,
  - *On the average, buses stop at distances of 400 to 600 m*
  - *In exceptional cases somewhat closer, but in no case below 300 m*
  - *Average spacings shorter than 300 m, common for many U.S. cities, are acceptable only as demand stops*
- The use of average spacings shorter than 300 m on regular bus routes will result in
  - *heavily degrades service quality (speed, comfort)*
  - *Negatively affects ridership*
  - *Moreover, frequent stops make it economically and physically difficult to provide adequate facilities*
    - such as shelters, benches, and information signs

Bus Stops Locations

- There are three types of locations for transit stops along streets:
  - *Near-Side (NS)*
    - At an intersection before crossing the cross street
  - *Far-Side (FS)*
    - At an intersection **passed** the cross street
  - *Midblock (MB)*
    - Away from intersections

Bus Stops Locations

Near-Side (NS)



http://www.pacebus.com/guidelines/04c_stop_location_roadway_design.asp

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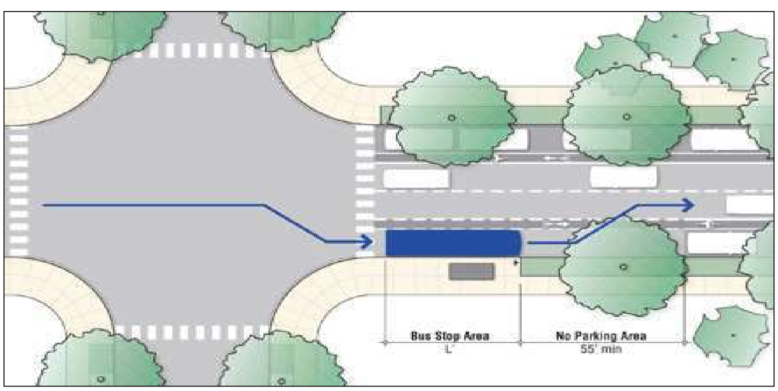
Bus Stops Locations

Far-Side (FS)



http://www.pacebus.com/guidelines/04c_stop_location_roadway_design.asp

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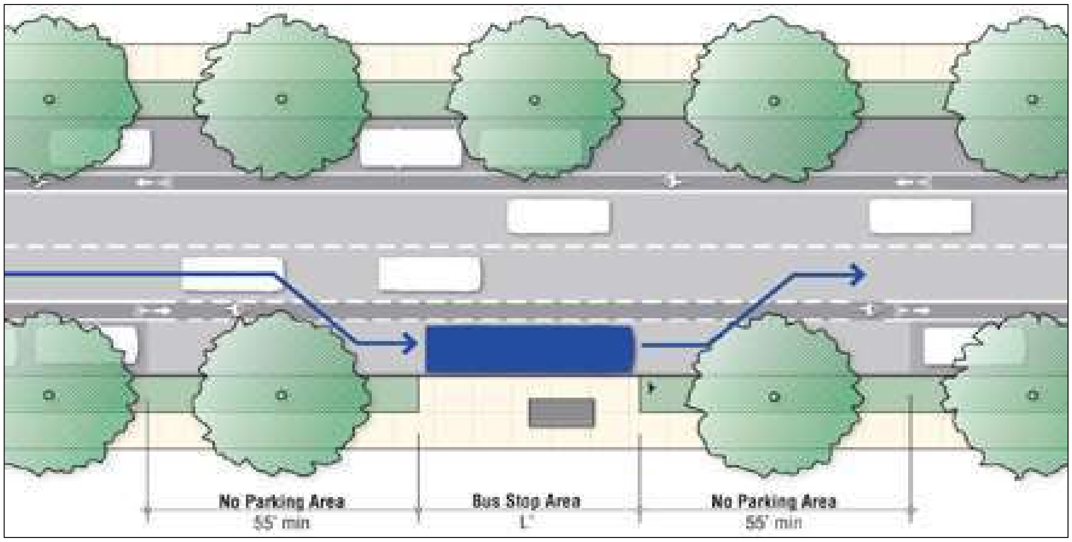
Bus Stops Locations

Midblock (MB)



http://www.pacebus.com/guidelines/04c_stop_location_roadway_design.asp

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Bus Stops Locations

Locations

- It is common in many cities to
  - *adopt one type of stop location (usually NS) and use it throughout the city.*
    - However, such uniformity of stop locations is <u>seldom justified</u>
- Major factors <u>influencing</u> the choice of stop locations are
  1. *land uses*
     - Buildings generating transit trips
  2. *Traffic signal coordination*
  3. *Passenger access*
  4. *Geometry of bus turning and stopping*

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Bus Stops Locations

Traffic signal coordination

- Signal coordination is often a major factor,
  - *since it can strongly influence bus speeds.*
- A simple rule, known as ''Von Stein's law of transit stop locations
  - *on a street with coordinated signals, alternate stops (NS-FS-NS, etc.) result in the shortest delays*
    - Signal coordination
      - means that vehicles traveling along the main road tend to progress or move through downstream signalized intersections without having to stop.

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Signal coordination

Source: https://www.youtube.com/watch?v=74JS2zv1N5Q

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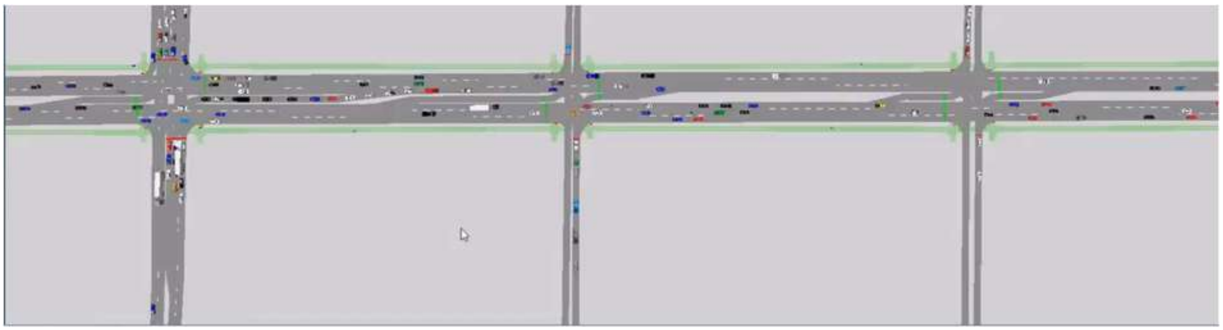
Signal coordination



Source: https://www.youtube.com/watch?v=74JS2zv1N5Q

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Bus Stops Locations

Von Stein's law of transit stop locations

- A bus (or any other transit vehicle) can leave an NS stop at intersection 1 only
  - *during a green phase (i.e., within a "through band" on the signal timing diagram)*
- It therefore arrives at intersection 2 during its green phase.
  - *With an NS stop there,*
    - The bus would have to stop and risk being "caught" by the next red phase
  - *With an FS stop,*
    - The bus passes intersection 2 within the band (i.e., with the platoon of vehicles). Thus at intersection 2, FS is clearly better than NS. Since stopping at the FS may delay the vehicle, so that it falls out of the band
  - *it is better that the following stop,*
    - at intersection 3, be NS, so that the bus may utilize its waiting at the red signal for passenger exchange at the stop.

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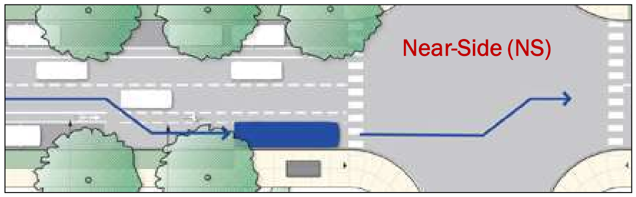
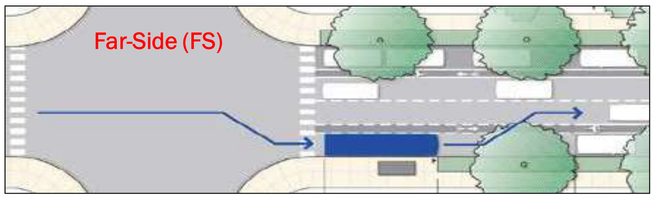
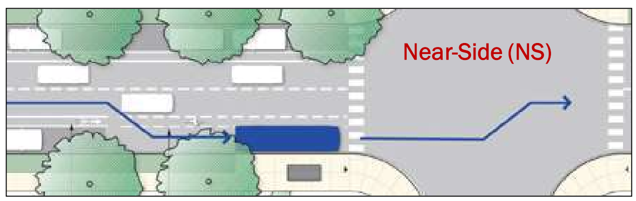
Intersection No.1



Intersection No.2



Intersection No.3



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Bus Stops on Streets

Locations

- Passenger access and convenience are maximized when stops are located where waiting passengers are
  - *Well protected from traffic*
  - *Have sufficient space for circulation*
  - *Do not impede the pedestrian flow on the sidewalk.*

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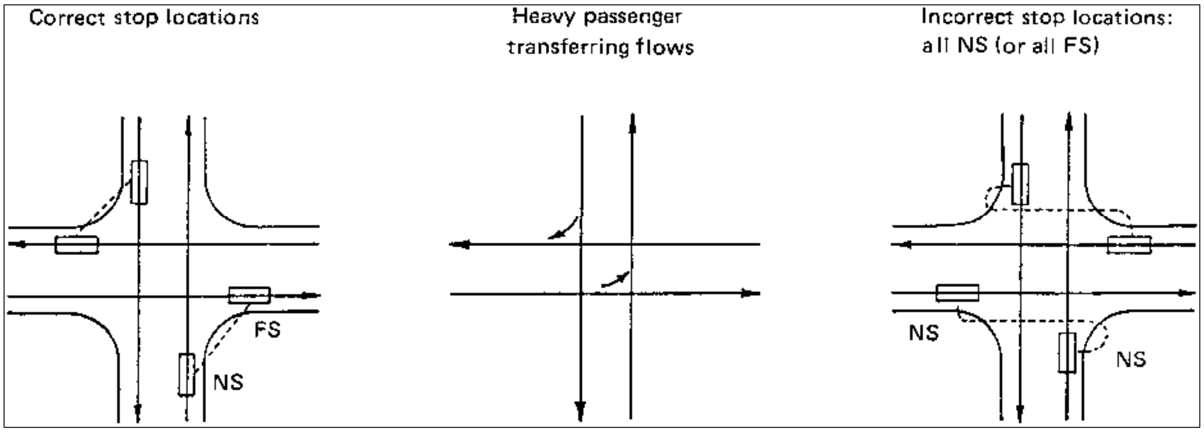
Bus Stops on Streets

Locations

Impact of bus stop locations on convenience of passenger transfers between intersecting routes



- The stops should be located at intersecting points of two or more bus routes so as
  - to minimize the walking distance required for transfer between buses

Bus Stops Locations

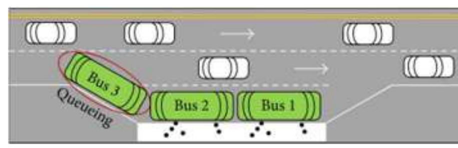
Locations

- Most of these factors favor either NS or FS stops over MB stops
- MB
  - *require the greatest curb length*
  - *cause longer walking to cross streets and transfer points,*
  - *nd may encourage jaywalking*
- In conclusion,
  - *The blanket use of only one type of stop is usually not the best solution.*
  - *Selection among the three types should be made for each individual route based on the factors discussed*

Bus Stops Design

- The simplest type of bus stop is
  - *where buses travel and stop in the curb lane.*
  - *Although such stops are convenient for passengers and require the least maneuvering,*
    - But they block a traffic lane for other traffic

- A better location for bus stops is outside driving lanes
  - *this provides greater safety and less interference with other traffic*
  - *The most common such stops are located in parking lanes and in special bus bays*



Zicla Blog | Bike lanes and bus stops: a marriage of convenience.

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Bus Stops Design

The Hashemite University

Zicla Blog | Bike lanes and bus stops: a marriage of convenience.

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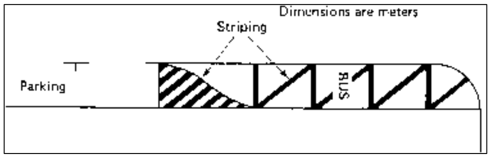
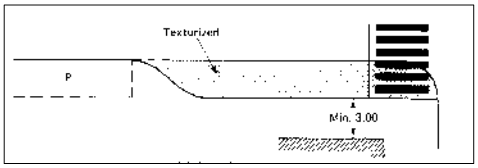
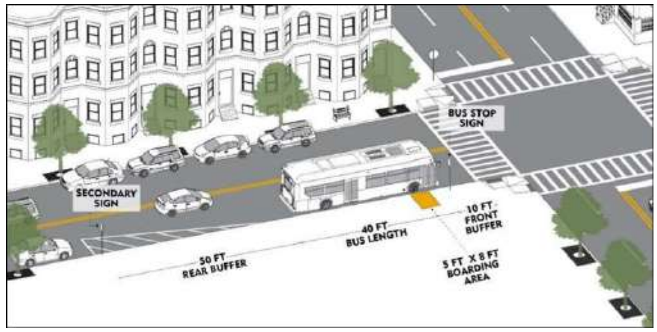
Bus Stops Design

Near-side stop in parking lane







Bus Stop Design Guide | Maryland Transit Administration

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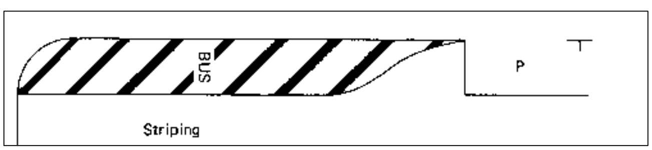
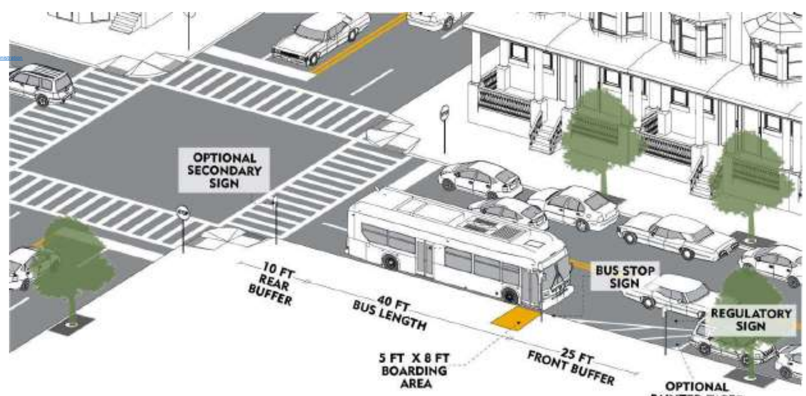
Bus Stops Design

Far-side stop in parking lane



Bus Stop Design Guide | Maryland Transit Administration



Bus Stop Design Guide | Maryland Transit Administration

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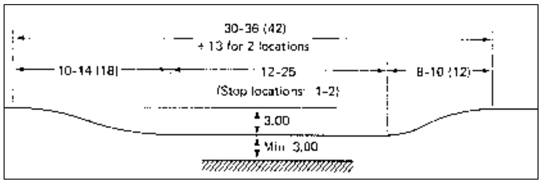
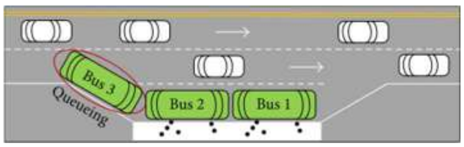
Bus Stops Design

Midblock bus bay





(7) (PDF) Quantifying the economic and other benefits of enabling priority bus egress from bus stops (researchgate.net)

Bus Stops Design

Desirable curb lengths for different types of bus stops (m)

of bus stops (m)[a]

Approximate Bus Length	One-Bus Stop NS	One-Bus Stop FS	One-Bus Stop MB	Two-Bus Stop NS	Two-Bus Stop FS	Two-Bus Stop MB
7.50	27.5	19.5	38.0	36.0	28.0	46.5
9.00	29.0	21.0	39.5	39.0	31.0	49.5
10.50	30.5	22.5	41.0	42.0	34.0	52.5
12.00	32.0	24.0	42.5	45.0	37.0	55.5

[a]Note: The values given here are recommended in the U.S. literature. Tests performed by MARTA (Atlanta) show that considerably shorter dimensions can also provide satisfactory operation (see Figures 5.21 and 5.24).

Bus Stations and Terminals

Bus Stations and Terminals

- Bus stations
  - *are off-street areas or buildings with stops for several bus routes.*
  - *Usually built at*
    - Transfer points among several bus routes (e.g., in a timed transfer network in low-density areas)
    - Between bus feeders and rail lines
- Terminals
  - *Strictly speaking, end stations of one or more bus routes*
  - *However, the term is sometimes used for any large station with passenger facilities,*
    - such as waiting rooms, ticket offices, and so on
- Bus stations and terminals must be on sites with
  - *Good accessibility from major highways and arterials*
  - *Naturally, extensive service by intracity transit routes*

Bus Stations and Terminals

Bus berths (bus loading points)

- The number of berths in a bus station **depends** on
  1. *The number of routes*
  2. *The peak-hour headways on each line*
  3. *Schedule coordination*
  4. *Reliability of operation*
  5. *Dwell times of buses*
- Routes with
  - *Headways below 3 to 5 min*
    - Usually require at least two berths
      - since bus delays often cause the dwell times of two buses to overlap.
  - *Headways between 5 and 10 min*
    - Allow use of one berth if dwell times are short compared to the headways and delays.

Berth assignment planning for multi-berth bus stops | Semantic Scholar

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Bus Stations and Terminals

Multiple bus stops

- Multiple bus stops along a curb (on a street or in a station) can be designed for three different cases with respect to bus arrivals/departures:
  - *1. Not allowing any overtaking*
  - *2. Allowing independent departures but **dependent** arrivals*
  - *3. Allowing independent arrivals and departures*

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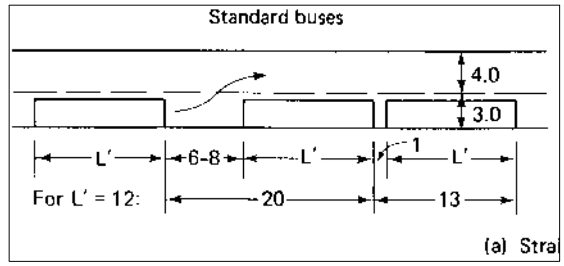
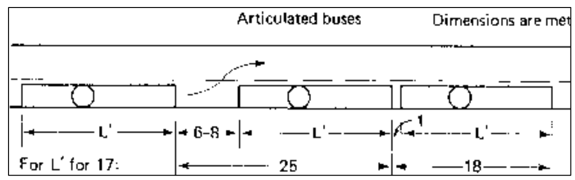
Bus Stations and Terminals

Multiple bus stops

Straight curve, Independent departures

- Stops occupy a curb length equivalent to
  - a bus length (L) plus 1 m for distance between stopped buses.



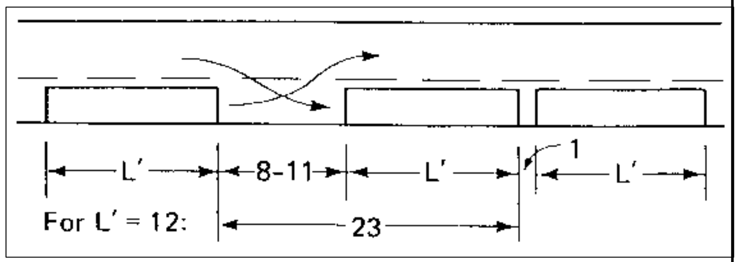


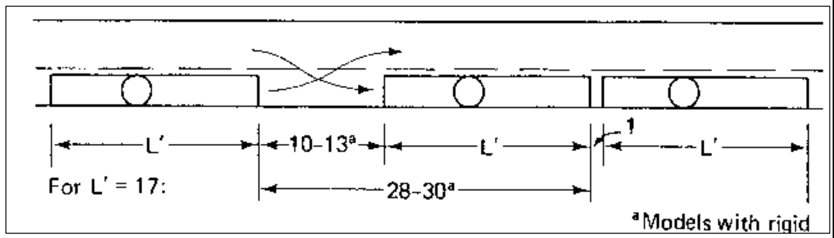
Bus Stations and Terminals

Multiple bus stops

Straight curve, Independent arrivals and departures

A distance of 6 to 8 m between vehicles is required for both regular and articulated buses



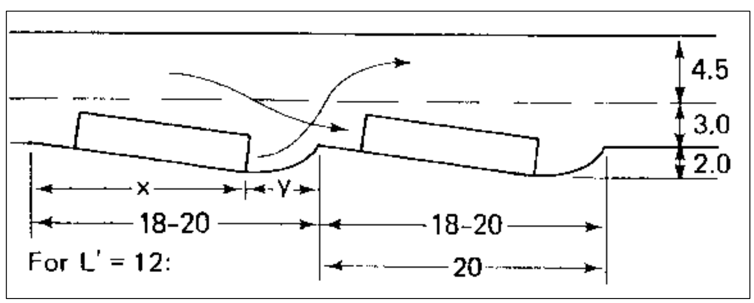


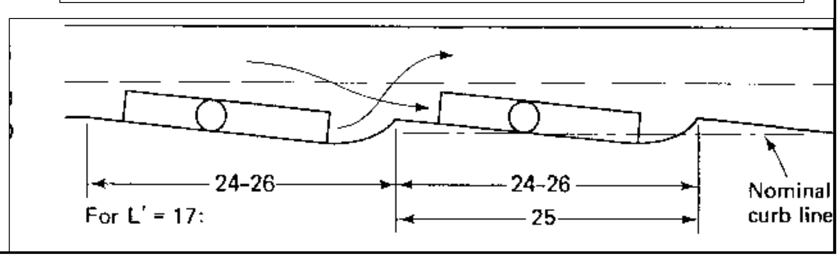
Bus Stations and Terminals

Multiple bus stops

Sawtooth curb design, Independent arrivals and departures

The arrivals are the more critical maneuvers and require distances of 8 to 11 m for standard and 10 to 13 m for articulated buses





Bus Stations and Terminals

Sawtooth curb

- This design geometry allows
  - *faster and easier bus maneuvers*
  - *Bus takes a shorter distance per stop location than does straight curb for the same vehicle.*
- The sawtooth design has become common for bus feeder locations in recently built rail transit stations in U.S. cities

Motorcoaches - Arrival Drop-Off & Departure Pick-Up | The Constitutional Walking Tour of Philadelphia

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Bus Stations and Terminals

Parallel islands

- Another layout of bus stops a series of parallel islands separated by single-lane roadways
- This layout is efficient for major terminals with many lines

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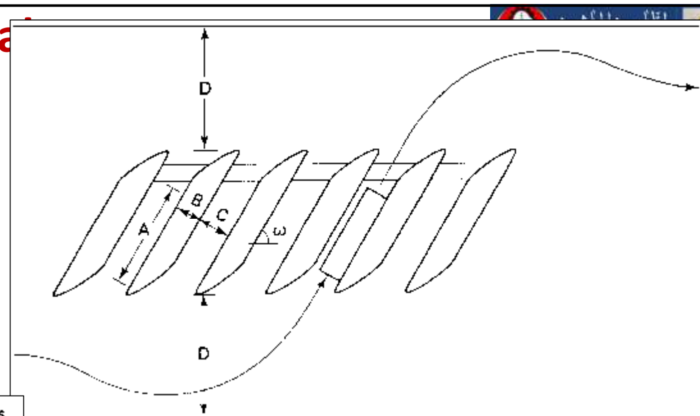
Bus Stations and Terminals

Parallel islands



Meters

ω	A	B*	C	D
45°	L′ or 2L′ + 1.00	1.50–3.00	3.25	8.00–10.00
60°	L′ or 2L′ + 1.00	1.50–3.00	3.50	10.00–12.00
90°	L′ or 2L′ + 1.00	1.50–3.00	3.75	12.00–14.00

*For stairs or escalators leading to a pedestrian mezzanine 1.50–2.50 m should be added.

The most common are the designs of islands at angles of 45, 60, and 90 degrees to the access roadways.

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Bus Stations and Terminals

Bus stops around a major rectangular or oval island

- The bus stops around a major rectangular or oval island is the best layout for
  - *Pedestrian safety*
  - *Pedestrian comfort*
  - *Pedestrian convenience*
- This arrangement allows passengers to
  - *transfer among all bus routes (e.g., at timed transfer points)*
  - *or between buses and trains at rail transit stations (via stairways from the island)* ***without crossing a roadway***

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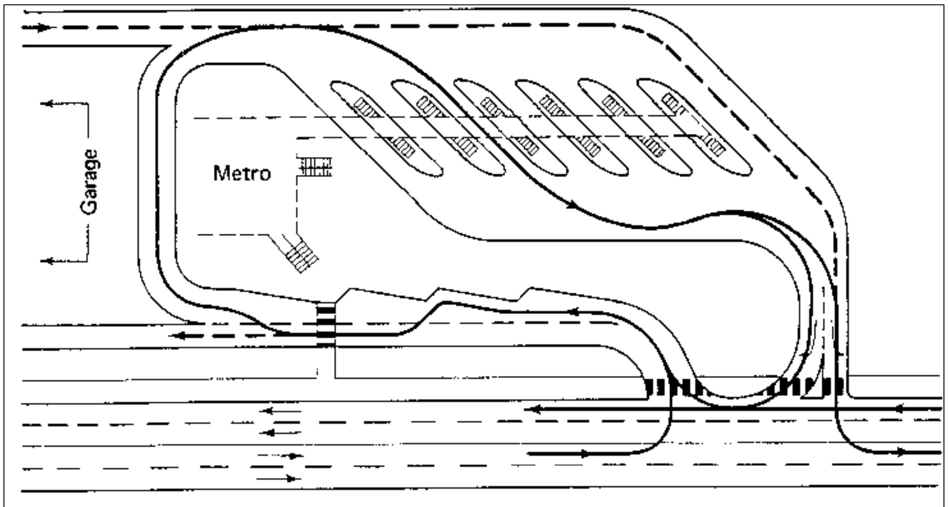
Bus Stations and Terminals

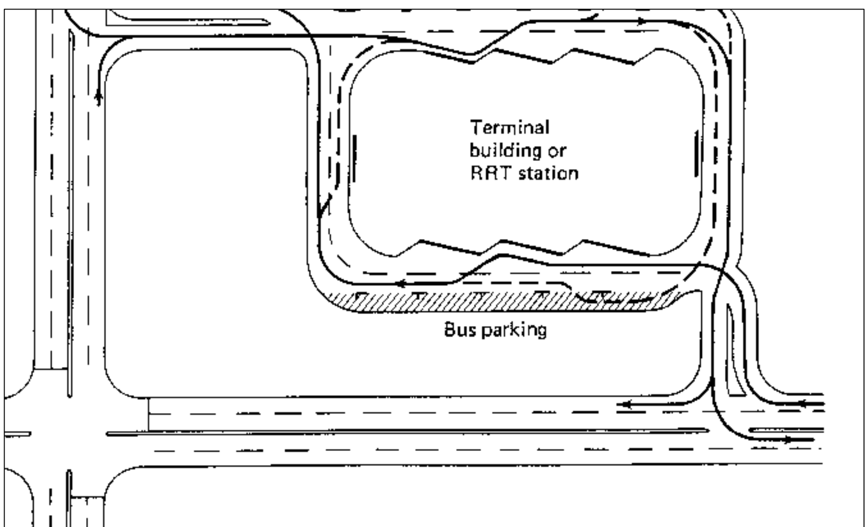
Bus stops around a major rectangular or oval island



(a) Bus-rail transfer station with island stops

Bus Stations and Terminals

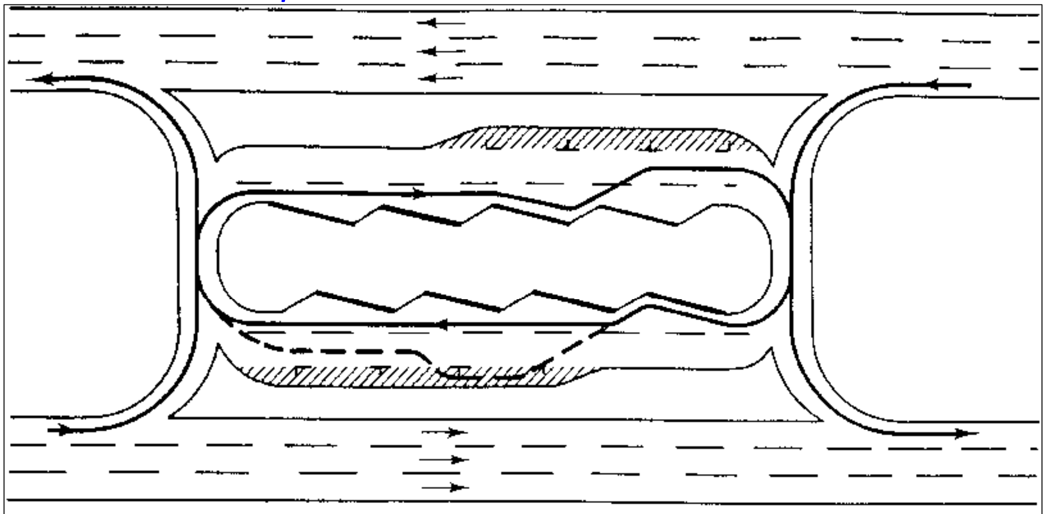
Bus stops around a major rectangular or oval island



(b) Central island station in quadrant of an intersection

Bus Stations and Terminals

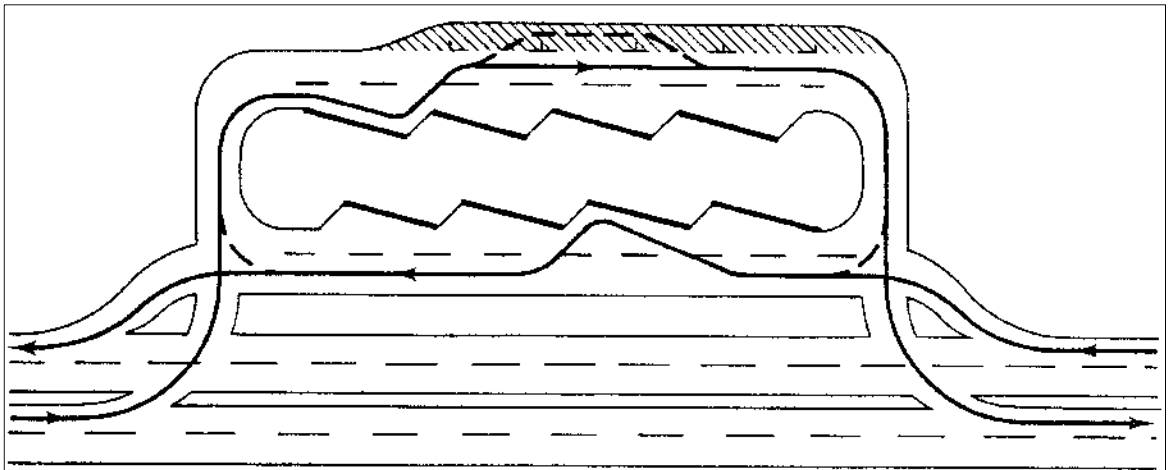
Oval island stations parallel with streets



(a) Parallel station between a pair of one-way streets

Bus Stations and Terminals

Oval island stations parallel with streets



(b) Parallel station on the side of a two-way street

Mafraq Bus Stations and Terminals

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Mafraq Bus Stations and Terminals

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Mafraq Bus Stations and Terminals

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North Bus station

103

103

South Bus station

104

South Bus station

105

105

South Bus station

106

Al Mahtta Bus station

107

Zarqa Bus station

108

108

Irbid Bus station

109

109

Irbid Bus station

110

110

HU Bus station

111

HU Bus station

112

HU Bus station

113

HU Bus station

114

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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 2

2.3 _ Amman BRT

Dr. Hamza 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

TRANSPORTATION ENGINEERING AND PLANNING (110401367)
SPRING 2019-2020

Amman BRT

Dr. Hamza Alkuime

3

References

- https://www.youtube.com/watch?v=DT0lUoptqVw&t=33s

4

4

Amman BRT

Problem definition

5

Amman BRT

Problem definition

6

Amman BRT

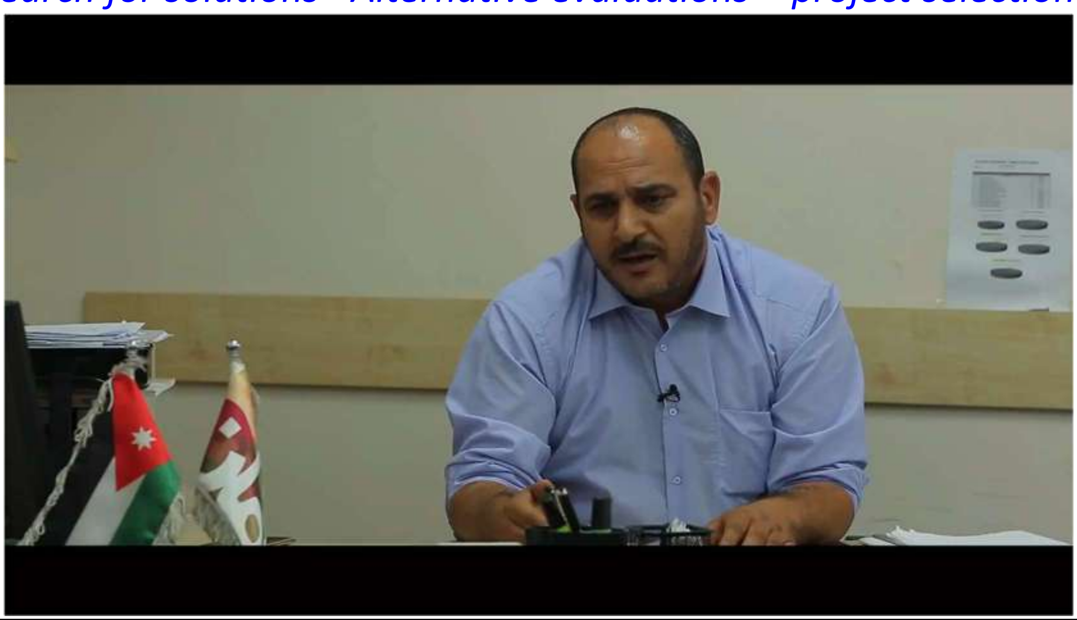
Search for solutions+ Alternative evaluations+ project selection

7

7

Amman BRT

Search for solutions+ Alternative evaluations+ project selection



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Amman BRT

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Amman BRT

https://www.youtube.com/watch?v=oT80Y18oAH8

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Amman Rapid Bus

Bus type

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Amman BRT

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Amman BRT

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Amman BRT

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Amman BRT

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Amman BRT

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Amman BRT

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Amman BRT

كاميرا حسنى تأخذكم بجولة كاملة في إحدى رحلات الباص السريع. - YouTube

18

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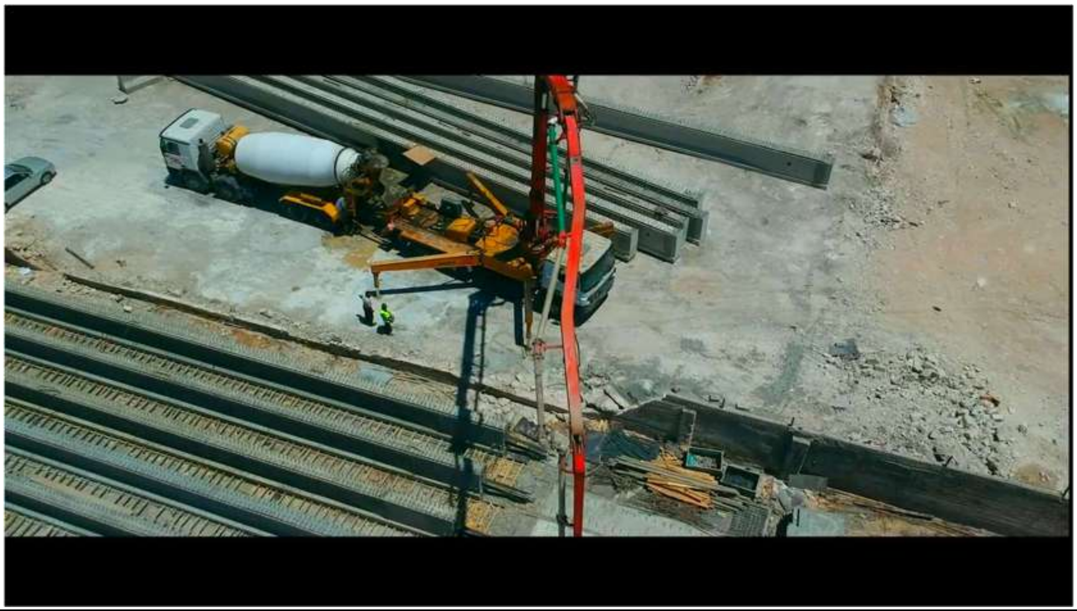
You are the Future



Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 2

2.4_Rail Transit

Dr. Hamza 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

2

Family of Rail Transit Modes

Definitions and Characteristics of Individual Rail Modes

- On the basis of the main features that define transit modes
  - *ROW type*
  - *Technology*
  - *operational/service characteristics*
- Rail systems can be classified into four modes:
  - *Streetcars/tramways (SCR/TW)*
  - *Light rail transit (LRT)*
  - *Rail Rapid Transit (RRT)*
  - *Regional rail (RGR)*

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Streetcars/Tramways

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Streetcars/Tramways

- Streetcar (SCR) systems consist of
  - *one, two, and occasionally three rail vehicle trains operated mostly on streets in mixed traffic but sometimes also with limited separation from street traffic by preferential treatment or separate ROW*

Tram in Rotterdam, Netherlands

Streetcars/Tramways

- A typical SCR/tramway vehicle has
  - *Four to six axles*
  - *Length of 14 to 21 m*
  - *Seating about 20% to 40% of*
    - its 100 to 180 total passenger-space capacity.

https://www.masstransitmag.com/rail/vehicles/press-release/21119575/toronto-transit-commission-ttc-legacy-ttc-streetcars-to-make-final-trip-down-queen-street

Streetcars/Tramways

https://www.youtube.com/watch?v=kI-SLL-Cd2k

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Streetcars/Tramways

- In recent years many tramway systems have introduced a modern streetcar
  - *35 to 53 m long multiarticulate*
  - *low-floor vehicles with five to seven body sections,*
  - *Capacities up to 350 space*

A modern streetcar (*Siemens Ultra-low-floor model in Vienna*)

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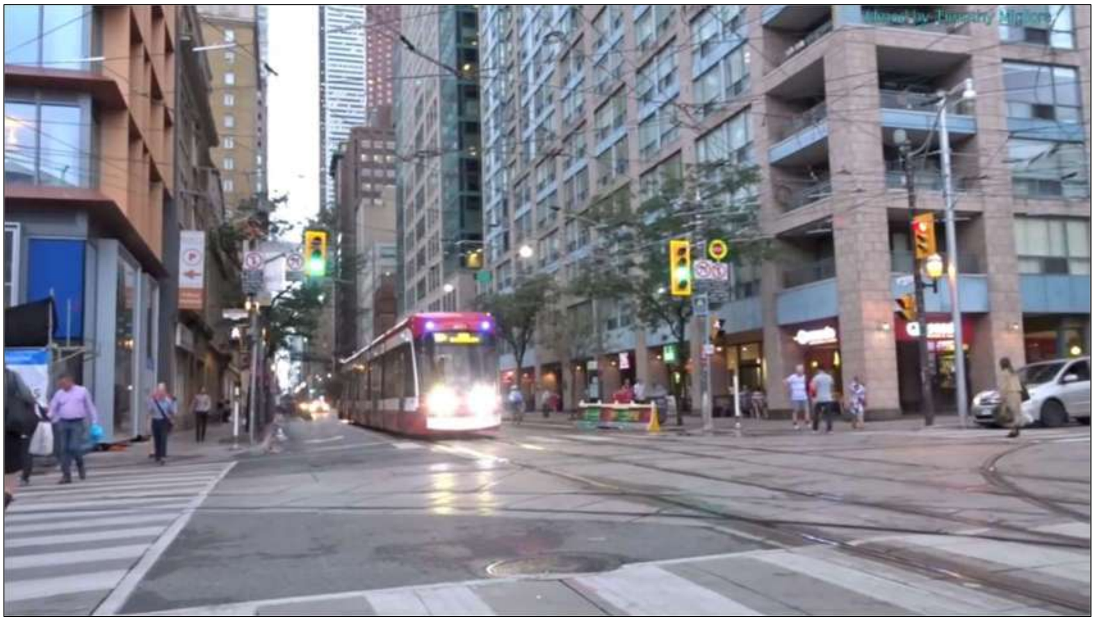
Streetcars/Tramways



https://www.youtube.com/watch?v=kI-SLL-Cd2k

Streetcars/Tramways

- Streetcars have
  - *Excellent dynamic characteristics*
  - *Excellent riding comfort*
- However, their reliability and operating speed depend greatly on the conditions along their lines:
  - *if they run on narrow streets with congested traffic*
    - their performance can be unsatisfactory,
  - *while on wide streets with little traffic interference or with various preferential treatments,*
    - SCR service can be very good

Streetcars/Tramways

- SCRs offers
  1. Operating speeds of 15 to 30 km/h
     - Because of the predominantly shared ROW
  2. Superior riding comfort and a more distinct image than highway transit modes
- SCRs disadvantages
  1. Involve considerably higher costs on lightly traveled lines
  2. They may have operational problems in congested mixed traffic
  3. The need for route extensions in expanding cities
  4. The delays SCRs encountered in congested streets have led to their extensive replacement by buses,
     - particularly at times when transit was given no priority treatment.

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Streetcars/Tramways

- They were the main transit mode until the 1950s, but then they were eliminated from many cities in several countries
- However,
  - *The mainly replaced by buses and trolleybuses*
  - *Their role has also diminished*
    - because of conversion of this mode into higher-quality LRT or substitution by RRT systems
- However, there has been a rebirth of streetcars in a number of U.S. cities in **different functions**, which can be classified into three groups, following general sequence of their development: (next slide)

ترام القاهرة - ويكيبيديا (wikipedia.org)

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Streetcars/Tramways

- First,
  - *Several cities with modern LRT systems to operate some classical streetcar vehicles in center city portions of their LRT networks,*
    - usually as shuttles or loops.
  - *The main role of these lines is creation of a special pedestrian/historic atmosphere and tourist attraction*
- Second,
  - *Several cities have built new lines for classical streetcar vehicles only.*
  - *The function of these lines is usually similar to that of the first category,*
    - but they are independent and longer, often serving an active commercial corridor or CBD with other major activity centers.
- Third,
  - *In the most significant category, have been entirely new streetcar lines that have lengths of several kilometers (miles)*
  - *have primarily a transportation function, carrying substantial passenger volumes throughout the day but also giving the service and areas served a special character and tourist attraction.*

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Streetcars/Tramways

Characteristics

	Streetcar/Tramway
Vehicle/train characteristics	
Minimum operational unit	1
Maximum train consist	3
Vehicle length (m)	14–35
Floor height	Low/high
Vehicle capacity (seats per vehicle)	22–40
Vehicle capacity (total spaces per vehicle)	100–250
Fixed facilities	
Exclusive ROW (% of length)	0–40
Vehicle control	Manual/visual
Fare collection: self-service or:	On vehicle
Power supply	Overhead
Stations	
Platform height	Low
Access control	None
Operational characteristics	
Maximum speed (km/h)	60–70
Operating speed (km/h)	12–20
Maximum frequency	
Peak hour, joint section (TU/h)	60–120
Off-peak, single line (TU/h)	5–12
Capacity (prs/h)	4000–15,000
Reliability	Low-medium
System aspects	
Network and area coverage	Extensive, good coverage
Station spacing (m)	250–500
Average trip length	Short to medium
Relationship to other modes in addition to walking	Can feed higher-capacity modes

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Light Rail Transit (LRT)

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Light Rail Transit (LRT)

- LRT Consisting of electrically powered, high-capacity, quiet vehicles with high riding quality operating in one- to four-car trains on predominantly separated ROW, rights-of-way.
- This mode has in the last 40 years become an important member of the family of transit modes
  - *Actually, in many countries, LRT is the fastest-growing rail transit* mode
- As a transit mode, LRT is in the semirapid transit group; by its performance/cost characteristics, LRT falls between SCR and RRT modes

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Light Rail Transit (LRT)

- LRT systems **typically** have articulated vehicles with two to seven articulated sections and four to ten axles
- They operate as single or multiple-unit trains

LRT: a six-axle low-floor vehicle in Cologne (Siemens K4500; courtesy of Sybic)

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The Light Rail in Portland, Oregon, USA

Source: https://www.youtube.com/watch?v=7XY-3M6ChZE

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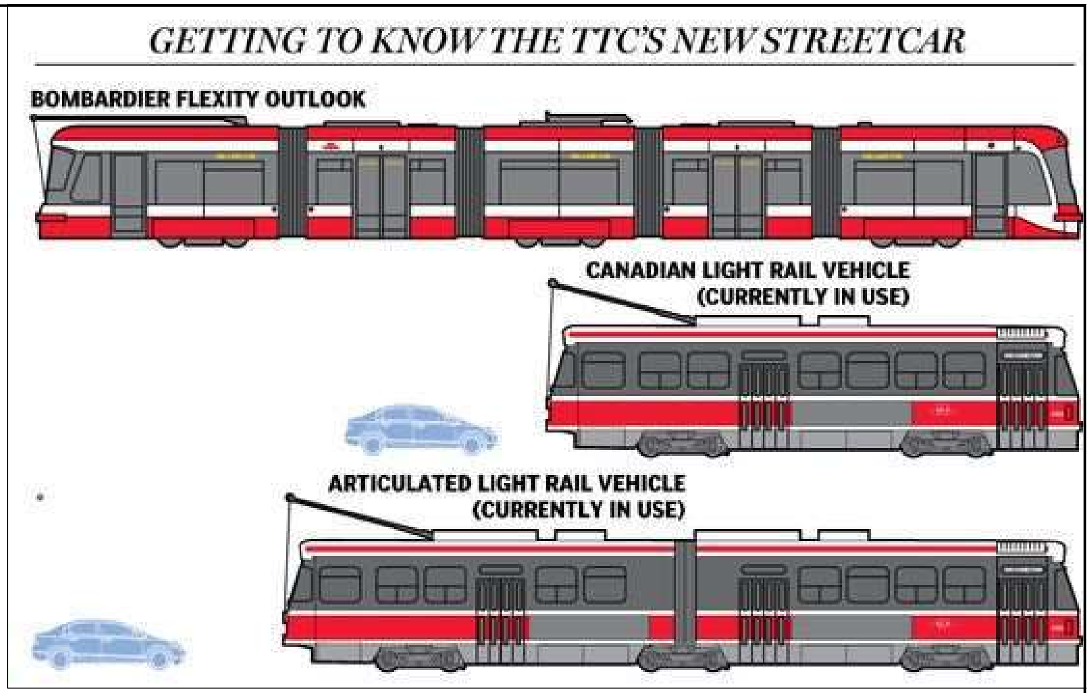
LRT vehicles



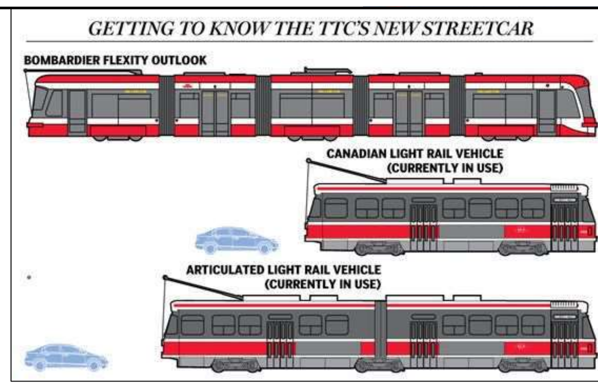
https://www.pinterest.com/pin/569916527822913439/

Light Rail Transit (LRT)

LRT vehicles

	BOMBARDIER FLEXITY OUTLOOK		CANADIAN LIGHT RAIL VEHICLE		ARTICULATED LIGHT RAIL VEHICLE
Seating	70	Seating	46	Seating	61
Standing	62 (average) & 181 (maximum)	Standing	56 (average) & 86 (maximum)	Standing	94 (average) & 144 (maximum)
Length	30.20 m	Length	15.44 m	Length	23.16 m
Width	2.54 m	Width	2.54 m	Width	2.54 m
Height	3.84 m	Height	3.36 m	Height	3.36 m
Weight	48,200 kg	Weight	22,685 kg	Weight	36,745 kg
Maximum speed	70 km/h	Maximum speed	110 km/h	Maximum speed	110 km/h
Number ordered	204	Number in service	195	Number in service	52
Minimum horizontal curve radius	11.6 m*	Minimum horizontal curve radius	10.973 m	Minimum horizontal curve radius	10.973 m

*Special modifications to fit Toronto's unique rail gauge and tighter turns



https://www.pinterest.com/pin/569916527822913439/

Light Rail Transit (LRT)

- LRT is characterized by great variety in its physical components and operational features,
- A particularly useful feature of LRT is that
  1. *It can use many different types of alignment on the same line*
     - Travel in tunnels, in street medians, and through parks and pedestrian zones;
  2. *have high and low platforms at different stations*
  3. *Even be driven by drivers and then switched to fully automatic operation on category A line sections*

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Light Rail Transit (LRT)

- LRT systems usually operate mostly on ROW category B,
  - *Sometimes on category A, and exceptionally on short sections of ROW category C*
  - *The two reserved ROW categories, B and A, generally amount to 70% to 90% of the total network length*
- It is common practice to first separate the most critical sections in the central city or on congested arterials,
  - *So that most sources of service disturbances are eliminated*
- Within City center
  - *LRT in some cities utilizes tunnel sections to penetrate the congested areas of the city, a factor that greatly enhances the quality of service they offer in very high-density areas.*
- Outside the central core area
  - *LRT is usually placed on ROW category B*

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Light Rail Transit (LRT)

- Light rail rapid transit (**LRRT**) is the highest performance form of LRT.
  - *Its basic distinction is that it has a fully separated **ROW, category A***

Light Rail Transit (LRT)

Performance Characteristics

	Streetcar/Tramway	Light Rail Transit
Vehicle/train characteristics		
Minimum operational unit	1	1 (4 to 10 axles)
Maximum train consist	3	2–4 (6 to 8 axles)
Vehicle length (m)	14–35	14–54
Floor height	Low/high	Low/high
Vehicle capacity (seats per vehicle)	22–40	25–80
Vehicle capacity (total spaces per vehicle)	100–250	110–350
Fixed facilities		
Exclusive ROW (% of length)	0–40	40–90
Vehicle control	Manual/visual	Manual/signal
Fare collection: self-service or:	On vehicle	On vehicle/at station
Power supply	Overhead	Overhead
Stations		
Platform height	Low	Low or high
Access control	None	None or full
Operational characteristics		
Maximum speed (km/h)	60–70	60–120
Operating speed (km/h)	12–20	18–50
Maximum frequency		
Peak hour, joint section (TU/h)	60–120	40–90
Off-peak, single line (TU/h)	5–12	5–12
Capacity (prs/h)	4000–15,000	6000–20,000
Reliability	Low-medium	High
System aspects		
Network and area coverage	Extensive, good coverage	Good CBD coverage, Branching common
Station spacing (m)	250–500	350–1600
Average trip length	Short to medium	Medium to long
Relationship to other modes in addition to walking	Can feed higher-capacity modes	P+R, K+R, Bus feeders

Future Plan for Amman BRT

Amman BRT ……………………..to ……………………AMMAN LRT (Or LRRT)

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25

Future Plan for Amman BRT

قطار بين صويلح والمطار

- تتجه أمانة عمان، إلى تطوير نظام نقل سككي (قطار خفيف) من تقاطع صويلح وصولا لمطار الملكة علياء الدولي، لتوفير خط ربط سريع لمحافظات الشمال مع المطار.
- وقالت الأمانة في بيان صحفي إنها وقعت وشركة MAPA للأعمار والتجارة التركية وبالتعاون مع هيئة الاستثمار3 مذكرات تفاهم لدراسة الجدوى الاقتصادية لعدد من مشاريع النقل والمرور في مدينة عمان .
- وتشمل المشاريع نفق التاج : بإنشاء نفق يربط بين تقاطع رغدان/ شارع الأردن مع تقاطع ش. اليرموك / ش.الجسور العشرة وبطول 800 - 1200 متر ، والذي سيسهم في اختصار مدة التنقل بالمركبات من خلال وصل شمال عمان بجنوبها ، حيث يقدر حجم المرور الذي سيستخدم هذا المسار بحوالي 80 الف مركبة يومياً.

نشر: 22-01-2018 15:48

https://royanews.tv/news/146527

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Future Plan for Amman BRT

وزير النقل: دراسة نقل الركاب من المحطة إلى مطار الملكة علياء بالقطار

- قال وزير النقل حسين الصعوب إن الاردن يسعى حالياً لتطبيق نظام نقل مستدام متعدد الوسائط، يلبي احتياجات الوطن والمواطن لكون الأردن ينفرد في موقعه الجغرافي المتميز واستقرار نظامه السياسي، وهما أبرز دعائم جذب الاستثمارات.
- وأشار إلى أن وزارة النقل تقوم حالياً بمراجعة وتحديث دراسات الجدوى الاقتصادية التفصيلية لمشروع شبكة السكك الحديدية في ضوء المستجدات المتعلقة بحجوم النقل الحالية والمستقبلية، والتغيرات الديموغرافية الناجمة عن أزمة اللاجئين، إضافة الى عمل دراسات لإنشاء مينائين بريين مركزين لوجستيين في عمان ومعان والذين سيتم ربطهما مع شبكة سكة الحديد.

نشر بتاريخ : 20/11/2016

http://factjo.com/news.aspx?Id=5411

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Amman Queen Alia Light Rail Project - Pre-Feasibility Study

European Bank for Reconstruction and Development (the "EBRD)

- **Project Description:**
  - *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

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- *The Project aims to utilize the existing rail corridor from Amman central station at El-Mahatta to Jeeza, a 35 km length single track narrow-gauge railway passing through Um El Heran and Elubbeh stations (with passing lines) and including 1 tunnel, 1 bridge, 3 road underpasses and 21 at-grade road crossings, of which 5 major (2x2 road). Connection to Queen Alia International Airport would require additional 2 km branch line and airport terminal.*

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

Rail Rapid Transit (RRT)

- This mode is also called metro and heavy rail
- In many respects, RRT, including rubber-tired rapid transit (RTRT), represents the optimal transit mode for a high-capacity line or network service.
- It has a fully controlled ROW without any external interferences.
  - *Simple guidance, electric traction, and fail-safe signal control allow the maximum speed possible with given station spacings*
- These rail modes also provide
  - *excellent passenger comfort*
  - *High efficiency in energy utilization*
  - *High reliability*
  - *Virtually absolute safety*

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Rail Rapid Transit (RRT)

- Operation of a train with up to 10 long four-axle cars by one person results in
  - *A capacity and labor productivity much **higher** than with any other mode except that which its ''big brother,'' regional rail (RGR)*
  - *off-vehicle fare collection*
  - *High platforms*
  - *Simultaneous boarding/alighting through up to 40 double-channel doors allow this mode to provide total boarding/alighting rates 3 to 5 times greater than those of LRT and 10 to 20 times greater than those of buses,*

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Rail Rapid Transit (RRT)

Rapid transit: Washington Metro (Courtesy of WMATA, photo by Paul Myatt)

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Orange Line Metro Lahore

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Rail Rapid Transit (RRT)

- With its fully protected ROW and physical and operating characteristics,
  - *RRT is the mode most conducive to fully automated train operation of all existing and proposed modes*
- Several metro systems using the AGT mode have been introduced since the late 1990s
  - *for which operation of trains without crews is a required element of economic/performance feasibility*
- RRT requires the greatest investment of all modes
  - *Primarily because of its entirely grade-separation and* ROW and large stations
    - so that its primary applications are in heavily traveled corridors

Dubai Metro runs the world's longest driverless train system

https://www.youtube.com/watch?v=vbywKqHkxpo

Rail Rapid Transit (RRT)

Performance Characteristics

	Streetcar/Tramway	Light Rail Transit	Rapid Transit	Regional Rail
Vehicle/train characteristics				
Minimum operational unit	1	1 (4 to 10 axles)	1–3	1–3
Maximum train consist	3	2–4 (6 to 8 axles)	4–10	4–10
Vehicle length (m)	14–35	14–54	15–23	20-26
Floor height	Low/high	Low/high	High	High/low
Vehicle capacity (seats per vehicle)	22–40	25–80	32–84	80-175
Vehicle capacity (total spaces per vehicle)	100–250	110-350	140-280	140-210
Fixed facilities				
Exclusive ROW (% of length)	0–40	40–90	100	100
Vehicle control	Manual/visual	Manual/signal	Signal/ATC	Signal
Fare collection: self-service or:	On vehicle	On vehicle/at station	At station	At station/on vehicle
Power supply	Overhead	Overhead	Third rail/overhead	Overhead/third rail/diesel
Stations				
Platform height	Low	Low or high	High	High or low
Access control	None	None or full	Full	None or full
Operational characteristics				
Maximum speed (km/h)	60–70	60–120	80–120	80–130
Operating speed (km/h)	12–20	18–50	25–60	40-75
Maximum frequency				
Peak hour, joint section (TU/h)	60–120	40–90	20–40	10-30
Off-peak, single line (TU/h)	5–12	5–12	5–12	1–6
Capacity (prs/h)	4000–15,000	6000–20,000	10,000–60,000	8000–45,000
Reliability	Low-medium	High	Very high	Very high
System aspects				
Network and area coverage	Extensive, good coverage	Good CBD coverage, Branching common	Predominantly radial: good CBD coverage	Radial, limited CBD but good suburban coverage
Station spacing (m)	250–500	350-1600	500-2000	1200–7000
Average trip length	Short to medium	Medium to long	Medium to long	Long
Relationship to other modes in addition to walking	Can feed higher-capacity modes	P+R, K+R, Bus feeders	P+R, K+R, Bus & LRT feeders	Outlying: P+R, K+R, Bus feeders; center city: walk, bus, LRT, metro

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Regional Rail (RGR)

The Hashemite University

- Representing local services of long-distance railroads,
- RGR systems have the highest technical and operating standards of all transit modes
- Most of these systems are operated by railroad agencies on their ROW,
  - *which are grade separated, in some cases with signalized grade crossings in outlying areas*
- Traction is mostly electric, although in many North American cities (Boston, most Chicago lines, Toronto) it is diesel
- Their large highspeed vehicles operated
  - *individually or as multiple-unit*
  - *locomotive-hauled trains, offer excellent riding comfort.*

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Regional Rail (RGR)

Regional rail: Bilevel cars on Los Angeles Metrolink (*Courtesy of James R. Greene*)

Caltrain board approves $4M to buy rail cars to ease capacity crunch – Green Caltrain

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S-Bahn in Hamburg, Germany (regional train)

https://www.youtube.com/watch?v=ETJnq1Y56gY

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Tram-Train Mode

- This is the convenient, popular, although not technically correct name for a system that combines
  - *urban LRT and intercity railway tracks (thus it should be called LRT/intercity mode)*
- The growth of metropolitan areas and increasing travel between central cities and surrounding suburbs and towns has led to the development of this dual-mode rail transit system
- They operate on transit lines in the city, then use connecting tracks to go on railway lines into suburban areas, sharing tracks with intercity trains operating at speeds as high as 200 km/h and with freight trains

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Tram-Train Mode

Tram-train on mainline railway track from Saarbru¨cken to Sarreguemines

Tram-train in center city Saarbru¨cken

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Sheffield Tram-Train

https://www.youtube.com/watch?v=4Cb2V53x5oU

Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 3

3.1_ Transportation Planning

Dr. Hamza 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

Transportation Planning

Definition

- It is a methodological process of preparing physical facilities and services of modes for transportation needs
- It is **Not** intended to furnish a decision or to give a single result that must be followed,
  - *although it can do so in relatively simple situations.*
- It is intended to
  - *provide the appropriate information to those who will be affected* and *those responsible for deciding whether the transportation project should go forward.*

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3

Transportation Planning

Importance

- Transportation planning is needed because of
  - *Increased demand of new facilities and services*
  - *Huge investments in transportation projects*
  - *Land use development*
  - *Many alternatives exist for any transportation project*

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Transportation Planning

Basic elements

- 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*

Basic Elements of Transportation Planning

1. Situation Definition

- Involves all of the activities **required** to understand the situation that gave rise to the perceived need for a transportation improvement
- It includes
  - *The present system is analyzed, and its characteristics are described*
  - *Information about the surrounding area, its people, and their travel habits may be obtained.*
  - *Previous reports and studies that may be relevant to the present situation are reviewed*

Basic Elements of Transportation Planning

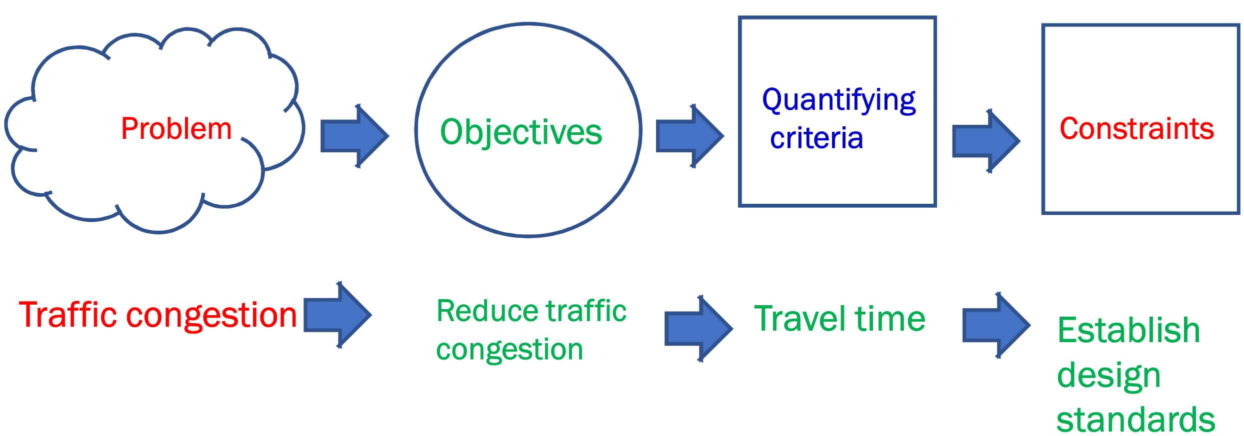
2. Problem Definition:

Used to

- *To describe the problem in terms of the objectives to be accomplished by the project*
- *To translate those objectives into criteria that can be used to quantify the extent to which a proposed transportation project will achieve the stated objective (measures of effectiveness).*
- *Identified the characteristics of an acceptable system*
  - Constraints placed on the project (e.g. physical limitation [presence of other structures])
  - Design standards (e.g., bridge width, clearances)

Basic Elements of Transportation Planning

2. Problem Definition:



Basic Elements of Transportation Planning

3. Search for Solutions (Idea-generating phase)

- Consideration is given to a variety of ideas, designs, locations, and system configurations that might provide solutions to the problem
- Includes
  - *Preliminary feasibility studies*
    - which might narrow the range of choices to those that appear most promising.
  - *Data gathering*
  - *Field testing*
  - *Cost estimating*
    - May be necessary at this stage to determine the practicality and financial feasibility of the alternatives being proposed

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Basic Elements of Transportation Planning

4. Analysis of Performance:

- Used to
  - *Estimate performance of proposed alternatives under present and future conditions.*
  - *Determination of the investment cost of building the transportation project, as well as annual costs for maintenance and operation.*
  - *Estimate environmental effects*
  - *Estimating travel demand using mathematical models*
  - *Determine use of the system*
    - Such as trip length, travel by time of day, and vehicle occupancy

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Basic Elements of Transportation Planning

5. Evaluation of Alternatives:

- How well each alternative will achieve the objectives of the project as defined by the criteria.
  - *Performance data produced in the analysis phase are used to compute the benefits and costs that will result if the project is selected.*

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Basic Elements of Transportation Planning

6. Choice of Project:

- It is made after considering all the factors involved.
  - *Whether the factors were a single criterion such as cost (select the lower cost)*
  - *In more complex projects other factors might be considered,*
  - *Selection is based on how the results are perceived by those involved in decision-making*

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Basic Elements of Transportation Planning

7. Specifications and construction

- Detailed design phase in which each of the components of the facility is specified.
- This involves
  - *Physical location*
  - *Geometric dimensions*
  - *Structural configuration.*

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Transportation Planning

Basic elements

- The elements are :
  - *Interrelated*
  - *Not necessarily carried out sequentially.*
  - *The information acquired in one phase of the process may be helpful in some earlier or later phase*
    - so, there is a continuity of effort that should eventually result in a decision

- *Situation definition*
- *Problem definition*
- *Search for solutions*
- *Analysis of performance*
- *Evaluation of alternatives*
- *Choice of project*
- *Specification and construction*

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Basic Elements of Transportation Planning

Summary

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

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Basic Elements of Transportation Planning

Example 11.2 : Planning the relocation of a rural road (Garber Book)

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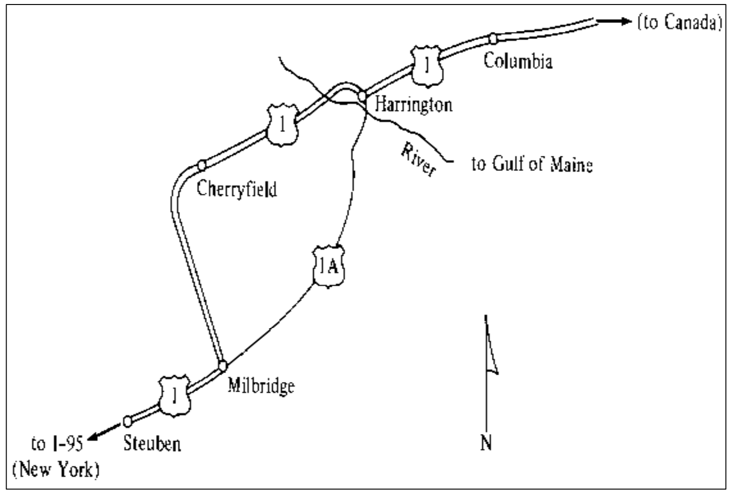
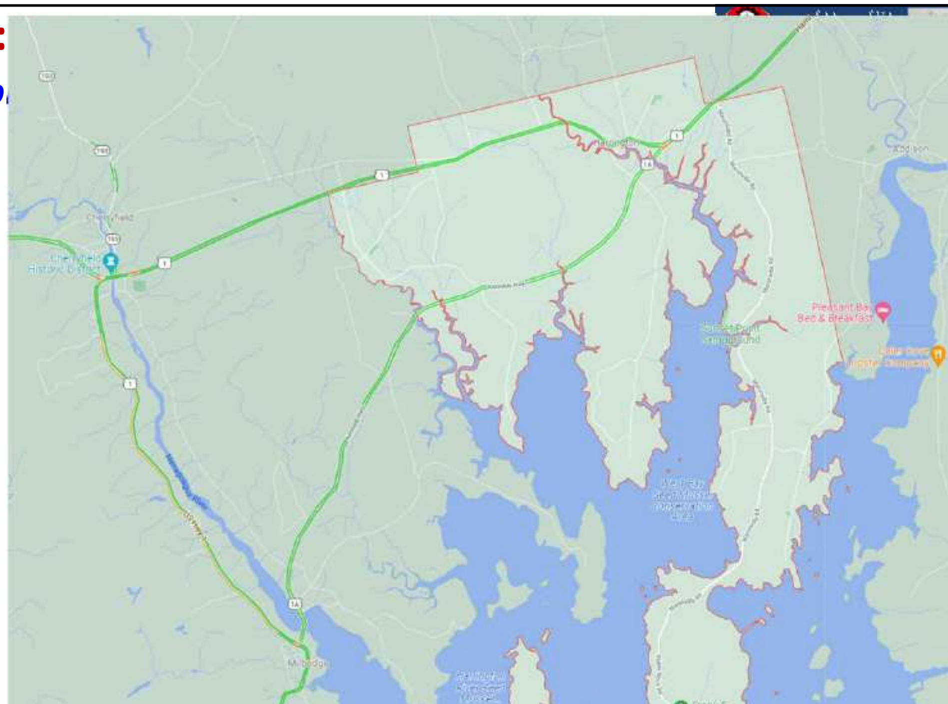
Example 11.2: Planning the relocation of a rural road

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



Example 11.2 :

Step 1- Situatio



ing the relocation of a rural road

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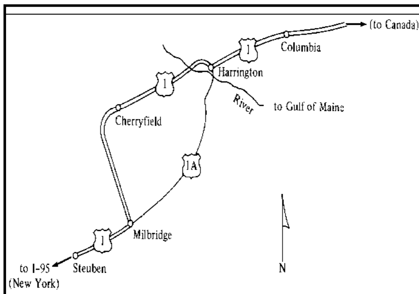
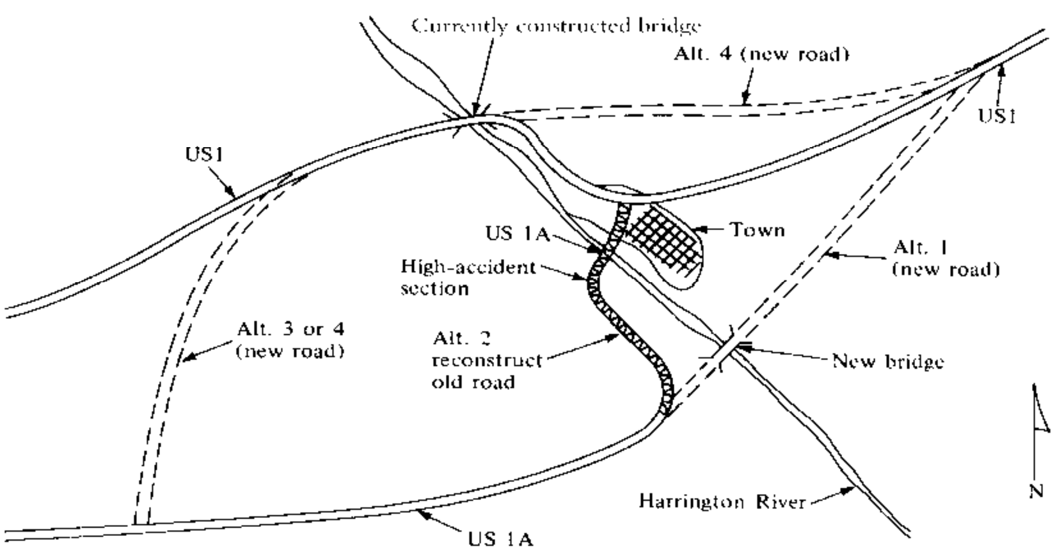


The project is a proposed relocation or reconstruction of 3.3 miles of U.S. 1A located in the coastal town of Harrington, Maine.

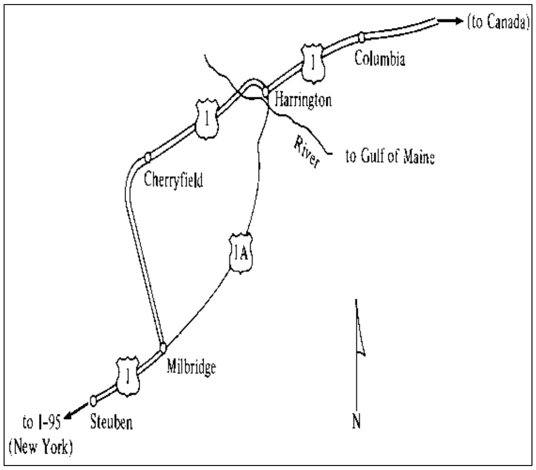
Example 11.2 :Planning the relocation of a rural road



Example 11.2 :Planning the relocation of a rural road

Step 1- Situation definition

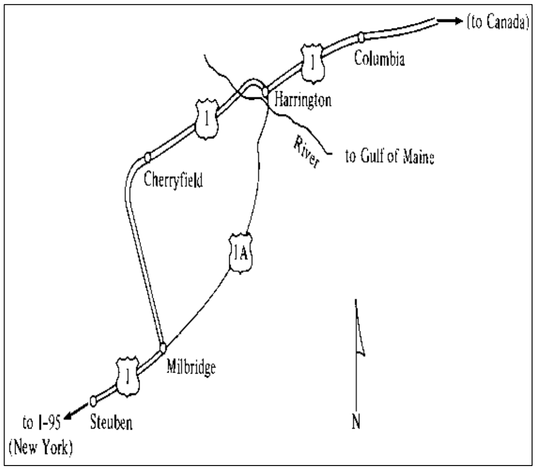
- The town of Harrington
  - *has 553 residents, of whom*
    - 420 live within the study area
    - 350 live in the town center
  - *Most of the town's industry consists of*
    - agriculture or fishing
  - *so, a realignment of the road would*
    - Damage the environment
    - Affect the town's livelihood
  - *The average daily traffic is 2620 vehicles/day of which*
    - 69 percent represent through traffic
    - 31 percent represent local traffic



Example 11.2 :Planning the relocation of a rural road

Step 2- Problem definition

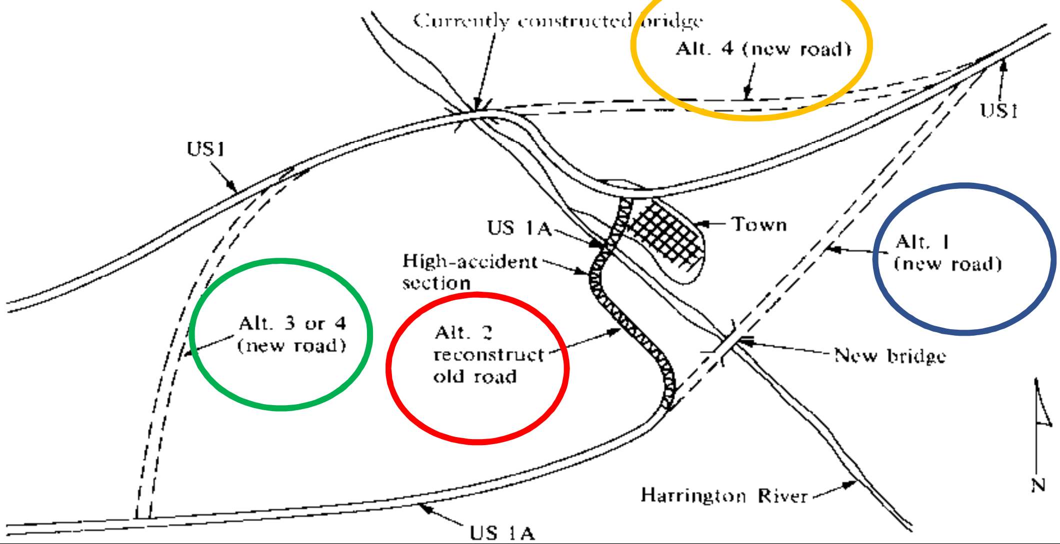
- *Problems*
  - High accident rate on 1A rout
  - Low level of service for through traffic
- *Objective*
  - Reduce the high accident rate on this road
  - Improve the level of service for through traffic by increasing the average speed on the relocated highway.
- *Measures of effectiveness*
  - Accident rate
  - Travel time
  - Construction cost
  - Changes in noise levels and air quality
  - Number of businesses and residences that would be displaced



Example 11.2 :Planning the relocation of a rural road

Step 3- Search for solutions

- Four alternative routes were identified



Example 11.2 :Planning the relocation of a rural road

Step 4- Analysis of performance

Table 11.1 Measures of Effectiveness for Rural Road

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 ($\mu g/m^3$ 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

Example 11.2 :Planning the relocation of a rural road

Step 4- Analysis of performance

Table 11.2 Ranking of Alternatives

	Alternatives				
Criterion/Alternative	*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

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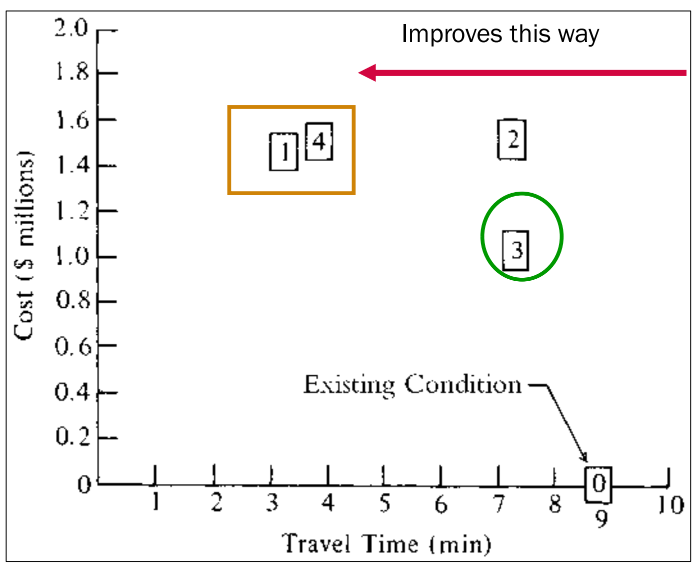
Example 11.2 :Planning the relocation of a rural road

Step 5 – Evaluation of alternatives

- Travel time



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Example 11.2 :Planning the relocation of a rural road

Example : Planning the relocation of a rural road

- Step 6 – Choice of project
- Step 7- Specification and construction

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Basic Elements of Transportation Planning

Example 11.2 : Feasibility of a New Bridge in Amman

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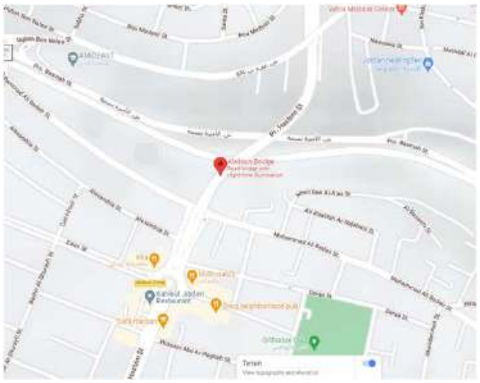
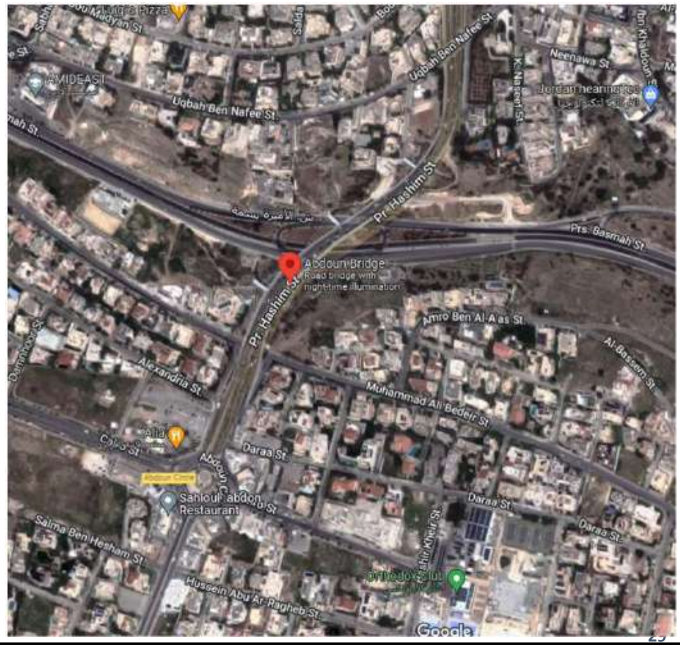
Feasibility of a New Bridge in Amman





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Feasibility of a New Bridge in Am

The Process	Application to Bridge Study
Situation Definition	Inventory transportation facilities Measure travel patterns Review prior studies
Problem Definition	Define objectives • Reduce travel time Establish criteria • Average delay time Define constraints Establish design standards
Search for Solutions	Consider options • Locations and types • Tunnel or don't build • Toll charges
Analysis of Performance	For each option, determine • Cost • Traffic flow • Impacts
Evaluation of Alternatives	For bridge project, determine • Benefits vs. cost • Profitability • Cost-effectiveness
Choice of Project	Consider factors involved: • Revenue cost forecast • Site location • Political judgment
Specification and Construction	Design of bridge • Superstructure • Piers, foundation Construction plans • Contractor selection Transfer of completed bridge to authority for operation and maintenance

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Basic Elements of Transportation Planning

Example 11.2 : Amman Queen Alia Light Rail Project - Pre-Feasibility Study

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Urban Transportation Planning

Urban Transportation Planning

- Involves the evaluation and selection of highway or transit facilities to serve present and future land uses.
- For example,
  - *Construction of a new shopping center, airport, or convention center will*
    - require additional transportation services.
  - *New residential development, office space, and industrial parks will*
    - generate additional traffic, requiring the creation or expansion of roads and transit services.
- Concerned with two separate time horizons
  - *Short-term Planning*
  - *Long-term Planning*

Urban Transportation Planning

Short-term Planning

- To select projects that can be implemented within a 1- 3-year period
- These projects are designed to
  - *Provide better management of existing facilities by making them as efficient as possible.*
- Involve programs such as
  - *Traffic signal timing to improve flow*
  - *Car and van pooling to reduce congestion*
  - *Park-and-ride fringe parking lots to increase transit ridership and Transit improvements.*

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Urban Transportation Planning

Long-term Planning

- Identifies the projects to be constructed over a 20-year period.
- Involve programs such as
  - *Adding new highway elements*
  - *Additional bus lines or freeway lanes*
  - *Additional Rapid transit systems and extensions*
  - *Access roads* airports or shopping malls

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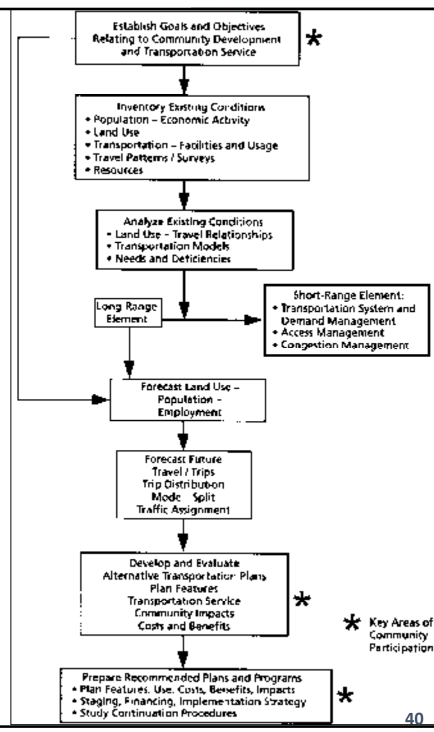
Urban Transportation Planning

- 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*

Urban Transportation Planning

Comprehensive urban area transportation planning process



Urban Transportation Planning

1. Inventory of Existing Travel and Facilities

- This is the data-gathering activity in which urban travel characteristics are described for each defined geographic unit or traffic zone within the study area
- Inventories and surveys are made to determine :
  - *Traffic volumes and land uses*
  - *Origins and destinations of travelers*
  - *Population*
  - *Employment*
  - *Economic activity*
- Inventories are made of existing transportation facilities, both highway and transit.
  - *Capacity, speed, travel time, and traffic volume are determined*
- The information gathered is summarized by geographic areas called traffic analysis zones (TAZ)

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Urban Transportation Planning

2. Establishment of Goals and Objectives

- A statement of goals, objectives, and standards is prepared that identifies
  - *Deficiencies in the existing system*
  - *Desired improvement*
  - *What is to be achieved by the transportation improvements*

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Urban Transportation Planning

3. Generation of Alternatives

- In this phase, the alternatives to be analyzed will be identified

Image source: https://www.slideshare.net/thiagomme/plan-a-vs-plan-b

Urban Transportation Planning

4. Estimation of Project Cost and Travel Demand

- This activity involves two separate tasks:
  - *Planning-Level Demand Estimation*
    - Estimation of the amount of traffic expected in the future
    - Requiring the use of mathematical models and computer
  - *Planning-Level Cost Estimation*
    - Determination of project cost
    - Straightforward process

4. Estimation of Project Cost and Travel Demand

Planning-Level Demand Estimation

- Future travel is determined by forecasting future land use in terms of the economic activity and population
- For example:
  - *Number of jobs, residents, auto ownership and income) that the land use in each Traffic Analysis Zone (TAZ) will produce*
- The traffic that this land use will add to the highway and transit facility can be determined using the four-step process
- The urban traffic forecasting process involves (Will be covered in Module 3)
  - *Tip generation*
  - *Trip distribution*
  - *Modal split*
  - *Network assignment*

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45

4. Estimation of Project Cost and Travel Demand

Planning-Level Cost Estimation

- Project cost estimation at the planning stage may be hampered either because
  - *The project has not yet been well-defined*
  - *A significant amount of time has passed since the project's cost was estimated*
  - *Will be covered in Module 4*

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Urban Transportation Planning

5. Evaluation of Alternatives

- It can be complex in practice because of the conflicting objectives and diverse groups that will be affected
- For example
  - *Traveling public (user)*
    - Improve speed, safety, and comfort
  - *The highway or transit agencies (operator)*
    - Minimize cost
  - *Non-traveling public (community)*
    - preserve its lifestyle and improve or minimize environmental impacts
  - *Will be covered in Module 5*

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Urban Transportation Planning

6. Choice of Project

- Selection of a project will be based on a process that will ultimately involve elected officials and the public
- It may involve
  - *A public referendum*
  - *A vote by a state legislature*

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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 3

3.2_ Urban Transportation Forecasting Process

Dr. Hamza Alkuime

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

Urban Transportation Forecasting Process

3

3

Review

4. Estimation of Project Cost and Travel Demand

- This activity involves two separate tasks:
  - *Planning-Level Demand Estimation*
    - Estimation of the amount of traffic expected in the future
    - Requiring the use of mathematical models and computer
  - *Planning-Level Cost Estimation*
    - Determination of project cost
    - Straightforward process

4

4

Urban Transportation Forecasting Process

- The process involves :
  1. *Defining the Study Area*
  2. *Data Collection*
  3. *Calibration*

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Urban Transportation Forecasting Process

1. Defining the Study Area

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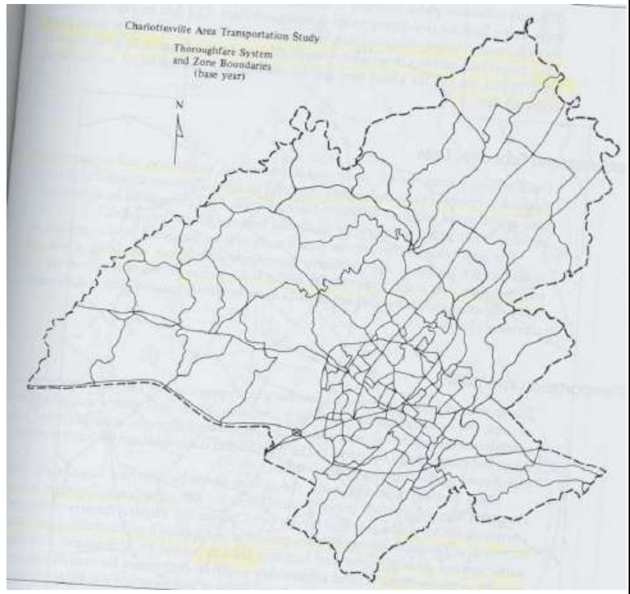
Defining the Study Area

Introduction

- The study area for which transportation facilities are being planned is defined before the conduct of the study.
- The study on transportation planning can be undertaken at
  - *The national level*
  - *The regional level*
  - *The urban level*
- The study area comprises a number of internal traffic zones and is studied in detail with respect to the present and future land uses.
  - *The details of travel and socio-economic characteristics of the people are analyzed to assess the nature and magnitude of the problems of travel in the study area.*



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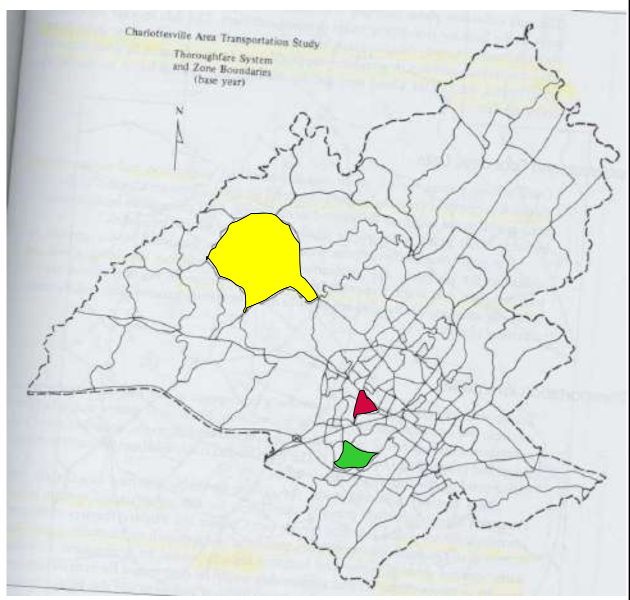
Defining the Study Area

Zoning system

- It is usually necessary to delineate the study area boundaries and to further subdivide the area into traffic analysis zones (TAZ) for data tabulation
- Traffic Analysis Zones (TAZ)
  - *It is considered to be various spatial units of the study area*
- Needs for TAZ
  - *To facilitate the spatial quantification of land use and economic factors which influence the travel pattern.*
- Zone may be
  1. *Internal traffic zones*
     - which are located within the study area
  2. *External zone*
     - which are located outside the study area



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Zoning system

Guidelines for defines traffic zones

1. Physical, political, and historical boundaries <u>should</u> be utilized where possible
2. The traffic zone sizes are required to be smaller so as
   - *to obtain the accuracy of traffic movement and reliable trip generation rate.*
3. Two-tier system may be followed for delineating the zones. For example
   - *The study area has to be subdivided first in the form of sectors*
   - ***<u>then</u>*** *further sub-divisions have to he made in the sectors to create traffic zones on the basis of predominant land uses such as residential, commercial. recreational and industrial. Further sub-zones may also be prepared if required.*
4. Zones <u>should not</u> be created within other zones.
5. Population size may range from
   - *3000-5000 for a small area*
   - *8000-10000 for a large area*
6. It may have production or attraction point.
7. Socioeconomic characteristics <u>should</u> be homogeneous.
8. Intrazonal trips <u>should</u> be minimized.
9. The total number of zones <u>should not</u> be so large as to overwhelm computer resources

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Zoning system

Amman Map

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Defining the Study Area

Traffic Analysis Zones (TAZ)

- 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 to employment must be at least 0.80*

Defining the Study Area

Transport Network

- Transport network along with zoning system provides an insight into the understanding of the study area.
- It comprises different types of transport network such as road, rail and metro system.
- For the representation of a transport network, the concept of graph theory is applied
- Dealing with abstract configuration consisting of
  - *links*
  - *Nodes*
  - *Centroids*
  - *External stations*

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Defining the Study Area

Transport Network

1. Links

➢ *A portion of the highway system that can be described by its **capacity, lane width, and speed***

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Defining the Study Area

Transport Network

1. Nodes :The <u>end point of a link</u> and represents an

❖ Intersection or location where a link changes direction, capacity, width, or speed

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Defining the Study Area

Transport Network

1. Centroids
   - *The location <u>within a zone</u> where trips are considered to begin and to end.*

Defining the Study Area

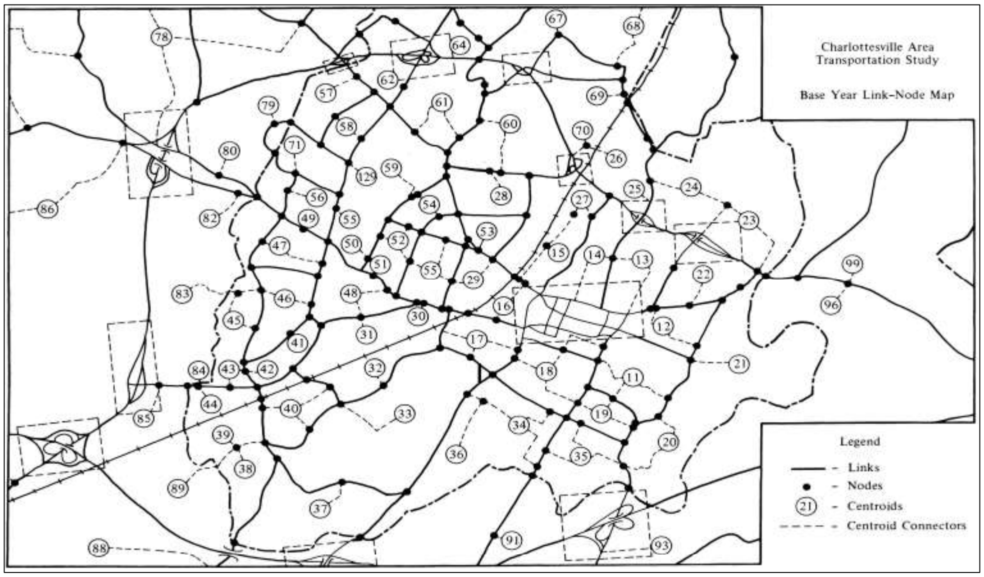
Transport Network

1. External stations
   - *Roadways where <u>traffic is likely to</u> enter or exit the study area. It established at the study area boundary*

Defining the Study Area

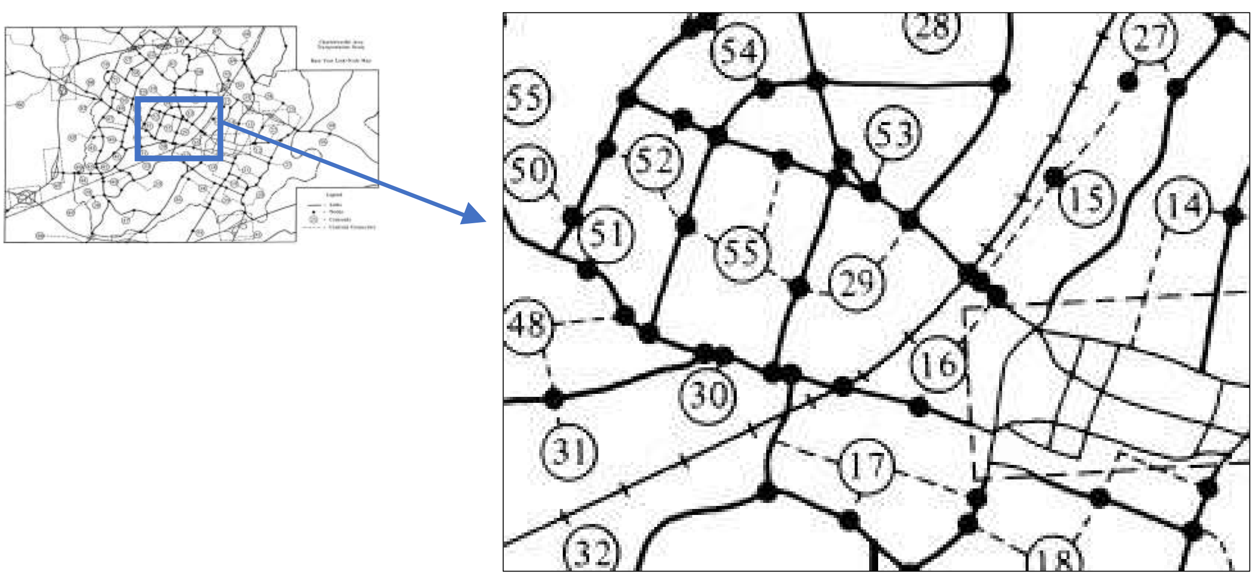
Transport Network

A computerized network of the existing street and highway system



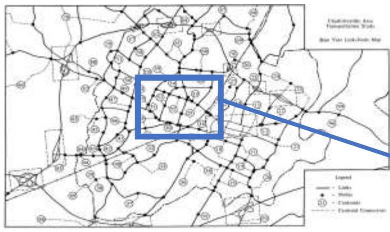
Defining the Study Area

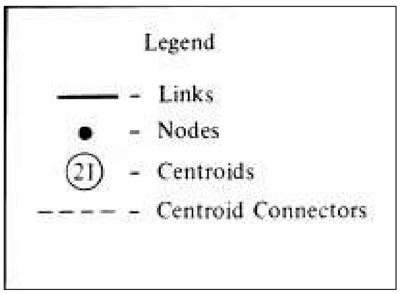
Transport Network

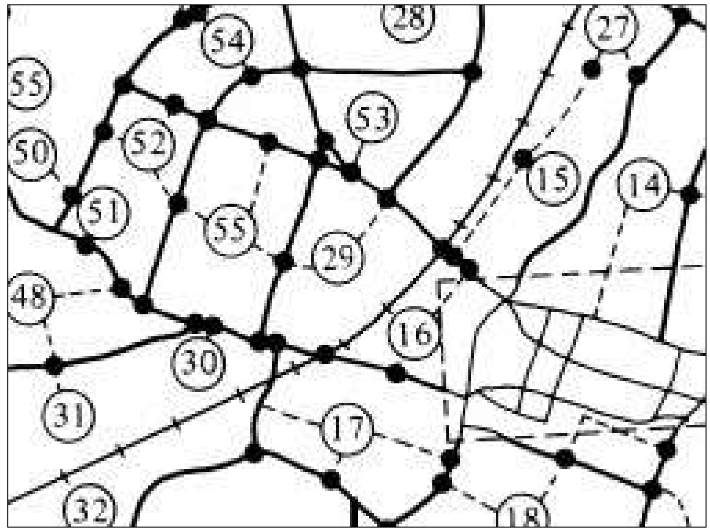


Defining the Study Area

Transport Network







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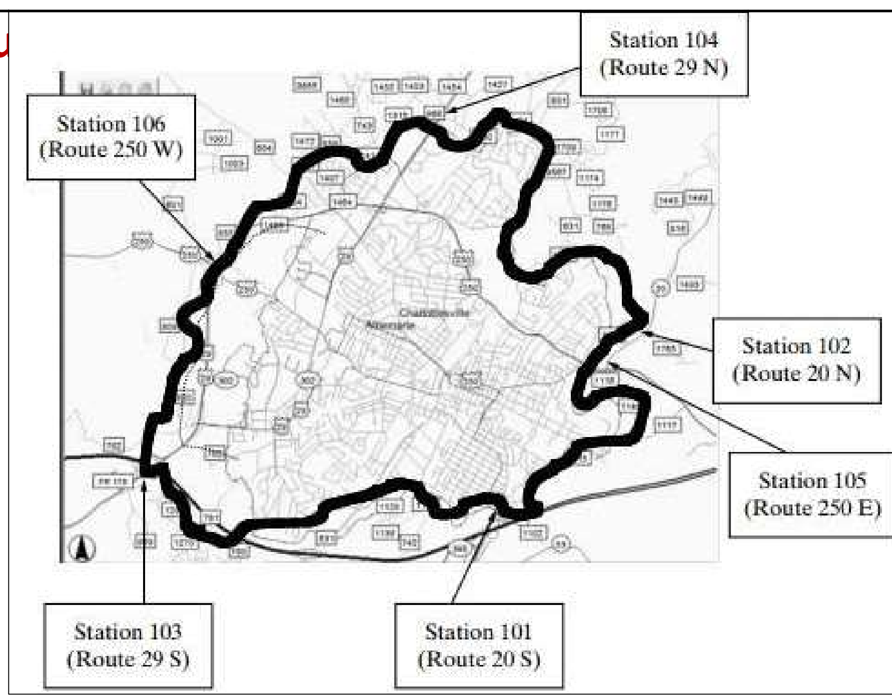
Defining the Stu



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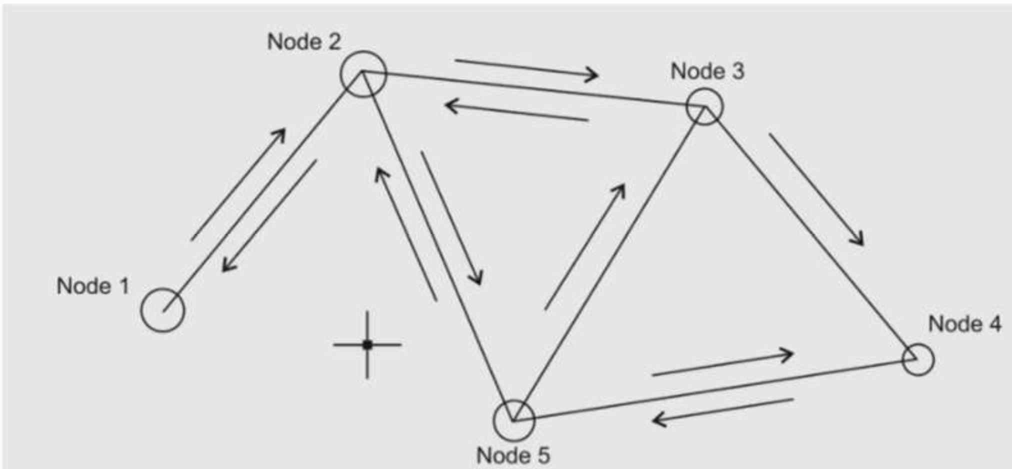
Transport Network

- Figure shows network with one way and two-way directions



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Urban Transportation Forecasting Process

2. Data Collection

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2.Data Collection

- Provides information about the city and its people that will serve as the basis for developing travel demand estimates
- This phase may involve
  - *Travel Surveys*
  - *Secondary data*
    - The secondary data are related to the existing land use, demography, road network, transportation systems, and mad traffic accidents from various sources besides the collection of primary data.
- The collection of data from the primary sources and other secondary sources helps in preparing the baseline data which forms the basis of appreciation of traffic and travel characteristics.
- Therefore,
  - *After collecting the basic data, relationship among the land use, transport system and the resulting travel pattern is analyzed and quantified by using statistical as well as mathematical modelling techniques.*
  - *These become finally the basis for developing transport demand model.*

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2.Data Collection

Travel Survey

- Travel survey is primarily concerned with
  - *the collection of traffic data with respect to the traffic and travel characteristics of passengers as well as goods traffic in the study area, which provides inputs for the preparation of any transportation plan.*
- The followings are the basic traffic surveys essential for the conduct of transportation studies:

1. *Road inventory survey*
2. *Classified traffic volume survey at inner and outer screen points*
3. *Origin and destination survey*
4. *Household travel survey*
5. *Speed and delay survey*
6. *Parking survey*
7. *Pedestrian survey*
8. *Bus transport survey*
9. *Intermediate public transport OPT) survey*
10. *Truck operator survey*
11. *Establishment survey*
12. *Goods survey*

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Travel Survey

Data output table

Survey	Outputs	Use
Household survey	Travel characteristics O-D matrix by mode and purpose, socio-economic characteristics	For development of travel demand model
Traffic volume survey	Intensity and composition of traffic	Expansion factors for O-D and validation of the model
Origin and destination survey	O-D of passengers and their trip characteristics	To assess the inter and intracity travel demand
Bus passenger users and terminal survey	O-D of intra-city and intercity passengers and their interchange details	To estimate passenger demand and plan the terminal requirements for the base and horizon years
Speed and delay survey	Journey and running speed	Distribution and shortest path

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Travel Survey

Data output table

Parking survey	Parking accumulation and duration	To plan for parking management and parking design
Road inventory	Road cross section, road capacity	To plan road network improvements and transport demand modelling
Pedestrian survey	Pedestrian flows along and across the road	To assess the level of service
Parking survey	To assess the nature and magnitude of parking problems in terms of parking accumulation, index, turnover, load, short and long-term parking demand	To design the parking facilities as well as to evolve parking policies

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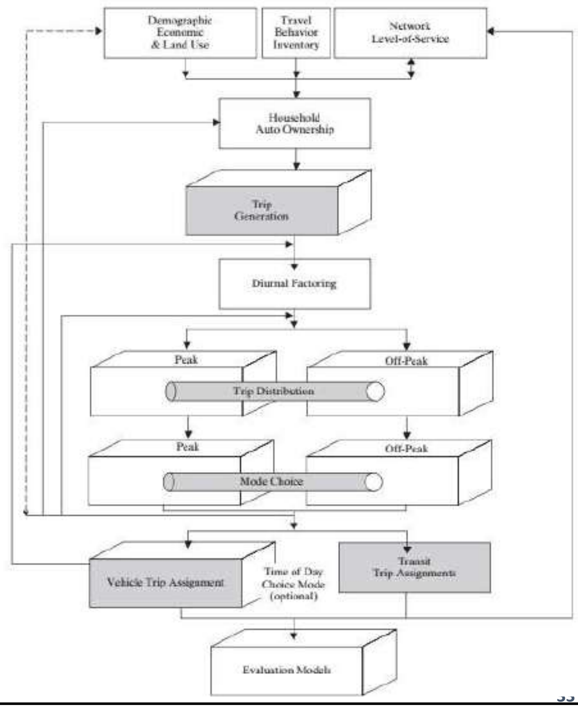
Travel demand



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Travel Survey

1.Road Inventory Data

- The purpose of the survey is to
  - *Understand the present physical characteristics* and *condition of the road network*
  - *Identify the problems, issues and constraints.*
  - *Assess the potential capacity of the road network.*
- Details of road inventory can be carried out by
  - *Visual inspection evaluation*
  - *Physical measurements*

	Types of Roads			
Road Characteristics Data	**Limited Access**	**Arterials**	**Collectors**	**Local**
Cross-Section Elements				
Number of lanes				
Lane width				
Lane type				
Shoulder width				
Shoulder type				
Edge treatments (SafetyEdge)				
Median width				
Median type				
ROW width				
Cross-slope (normal crown)				
Barriers (type, length)				
Roadway Structure Elements				
Bridges				
Railroad crossings				
Multi-use paths/bike paths				
Pedestrian facilities				
Tunnels				
Geometric Elements				
Grade				
Vertical curvature				
Horizontal curvature				
Superelevation				
Sight distance				
Speed limit				
Sign inventory				
Truck/weight restrictions				
Intersection Elements				
Number of lanes/approach				
Signal timing				
Traffic control				
Pavement Elements				
Pavement material				
Pavement distress data				
Skid resistance				
Ride quality				
Pavement markings				

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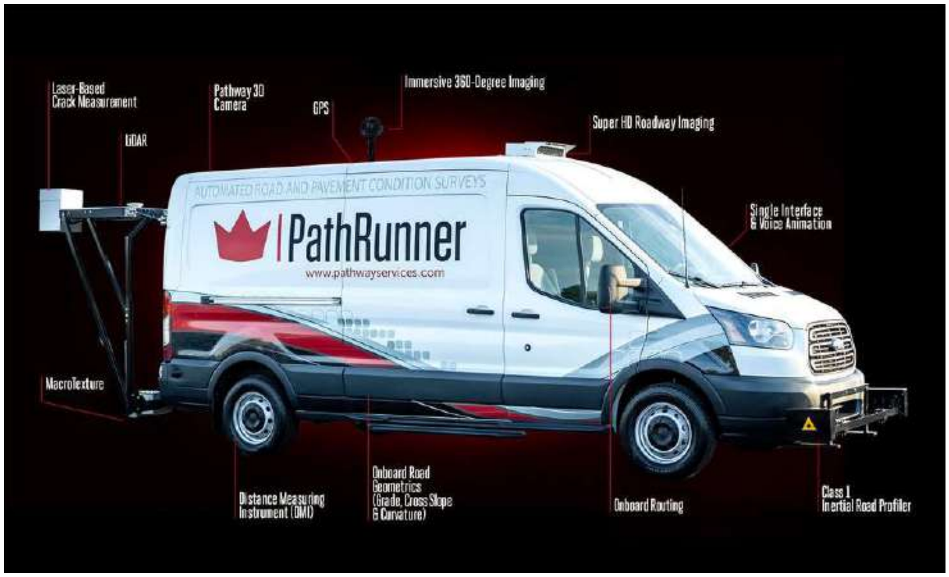
Traffic Survey

1.Road Inventory Data



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Pavement Distress Measurement

Pathrunner

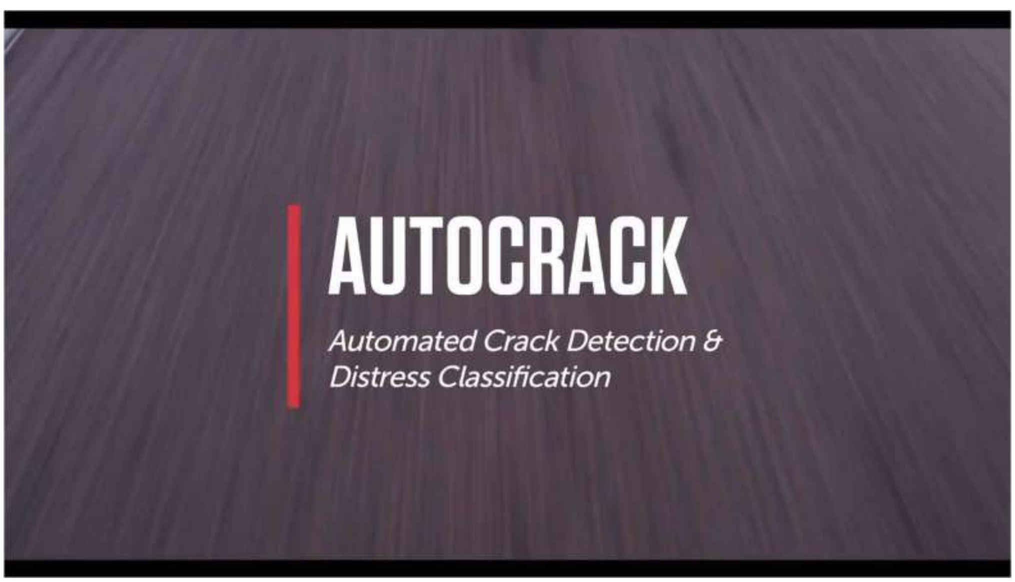

Image Source https://vimeo.com/185700798

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Travel Survey

2. Classified traffic volume survey at inner and outer screen points

- Classified traffic volume count surveys are conducted for 24 or 16 hours on a typical working day to assess the magnitude of traffic at various locations of outer cordon line, mid-block and screen lines.
- Traffic volume survey is designed to capture
- all modes of transport at the location identified for the study.
- The manual method is used for recording the classified traffic volume for every 15 minutes interval.
- Traffic counts may also be recorded continuous using automatic vehicle classifiers if average da traffic or average annual daily traffic is to be calculated.

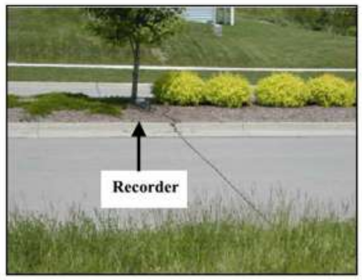
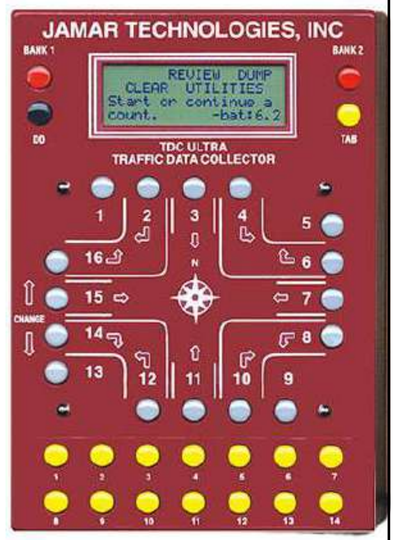


Figure 3.5. Pneumatic Road Tube and Recorder



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Travel Survey

2. Classified traffic volume survey at inner and outer screen points

How to Install Inductive Loops for Traffic Data | RoadPod VL | MetroCount - YouTube

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Travel Survey

2. Classified traffic volume survey at inner and outer screen points

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Travel Survey

3. Origin and destination (O-D) survey

- O-D survey is one of the primary surveys by which one appreciates the travel characteristics of any mode of transport.
- Therefore, all the parameters related to travel characteristics are collected such as
  - *Origin destination of trip*
  - *Trip purpose*
  - *Trip length*
  - *Trip mode*
  - *Trip cost*
  - *Frequency of travel.*
  - *The vehicle involved (auto or transit)*

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Traffic Survey

3. Origin and destination (O-D) survey

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

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: ______

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Traffic Survey

3. Origin and destination (O-D) survey

TRI MET
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

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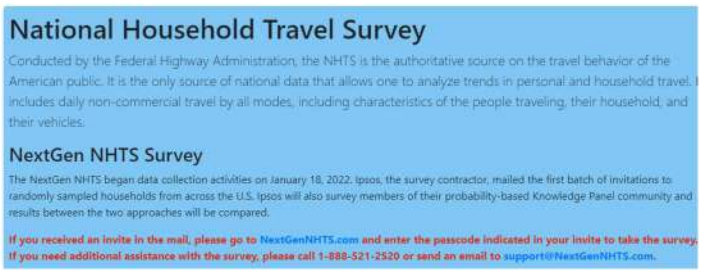
Travel Survey

4. Household travel survey

- The objective of household travel survey is to assess of the following characteristics of residents within the study area.
  - *The household*
  - *Socio-economic*
  - *Trip characteristics*
- Household survey is the most important survey for conducting any transportation study for an urban area.



National Household Travel Survey

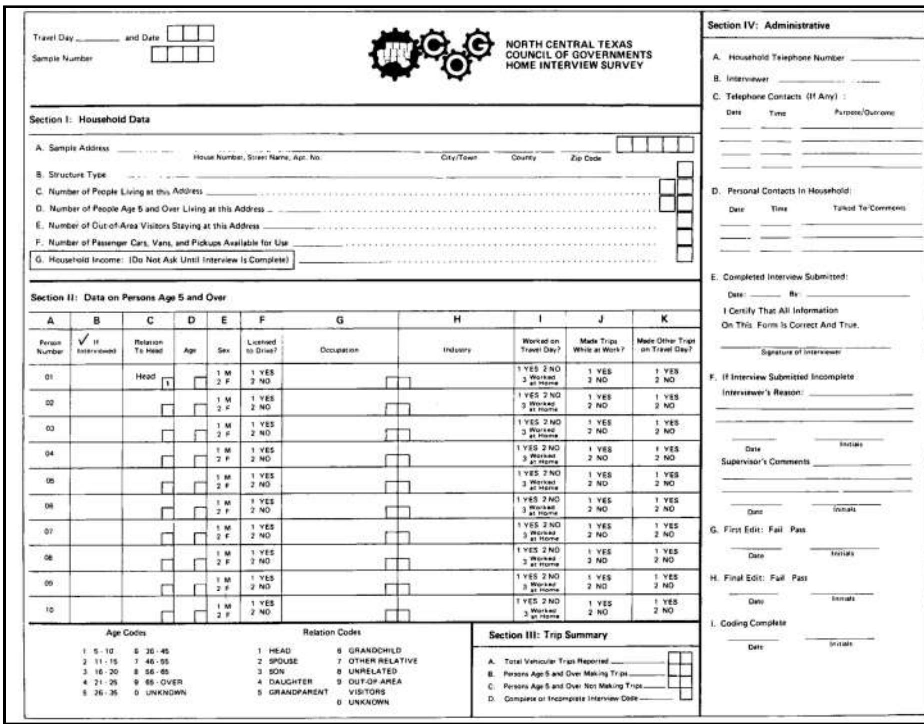
Conducted by the Federal Highway Administration, the NHTS is the authoritative source on the travel behavior of the American public. It is the only source of national data that allows one to analyze trends in personal and household travel. It includes daily non-commercial travel by all modes, including characteristics of the people traveling, their household, and their vehicles.

NextGen NHTS Survey

The NextGen NHTS began data collection activities on January 18, 2022. Ipsos, the survey contractor, mailed the first batch of invitations to randomly sampled households from across the U.S. Ipsos will also survey members of their probability-based Knowledge Panel community and results between the two approaches will be compared.

If you received an invite in the mail, please go to NextGenNHTS.com and enter the passcode indicated in your invite to take the survey. If you need additional assistance with the survey, please call 1-888-521-2520 or send an email to support@NextGenNHTS.com.

[National Household Travel Survey (ornl.gov)]



Travel Day ______ and Date

Sample Number

NORTH CENTRAL TEXAS COUNCIL OF GOVERNMENTS HOME INTERVIEW SURVEY

Section I: Household Data

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)

Section II: Data on Persons Age 5 and Over

A	B	C	D	E	F	G	H	I	J	K
Person Number	✓ If Interviewed	Relation To Head	Age	Sex	Licensed to Drive?	Occupation	Industry	Worked on Travel Day?	Made Trips While at Work?	Made Other Trips on Travel Day?
01		Head 1		1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
02				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
03				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
04				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
05				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
06				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
07				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
08				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
09				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO
10				1 M 2 F	1 YES 2 NO			1 YES 2 NO 3 Worked at Home	1 YES 2 NO	1 YES 2 NO

Age Codes

1 5 - 10	6 36 - 45
2 11 - 15	7 46 - 55
3 16 - 20	8 56 - 65
4 21 - 25	9 66 - OVER
5 26 - 35	0 UNKNOWN

Relation Codes

1 HEAD	6 GRANDCHILD
2 SPOUSE	7 OTHER RELATIVE
3 SON	8 UNRELATED
4 DAUGHTER	9 OUT-OF-AREA VISITORS
5 GRANDPARENT	0 UNKNOWN

Section III: Trip Summary

A. Total Vehicular Trips Reported

B. Persons Age 5 and Over Making Trips

C. Persons Age 5 and Over Not Making Trips

D. Complete or Incomplete Interview Code

Section IV: Administrative

A. Household Telephone Number

B. Interviewer

C. Telephone Contacts (If Any):

Date Time Purpose/Outcome

D. Personal Contacts In Household:

Date Time Talked 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

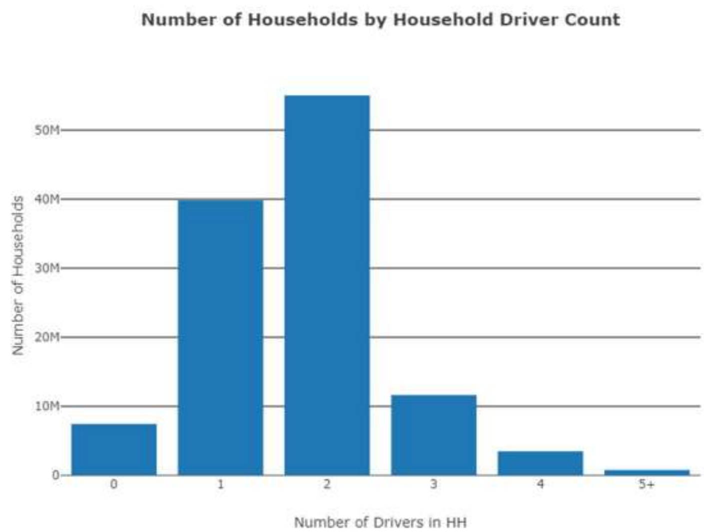
Date Initials

I. Coding Complete

Date Initials

4. Household travel survey

National Household Travel Survey (ornl.gov)



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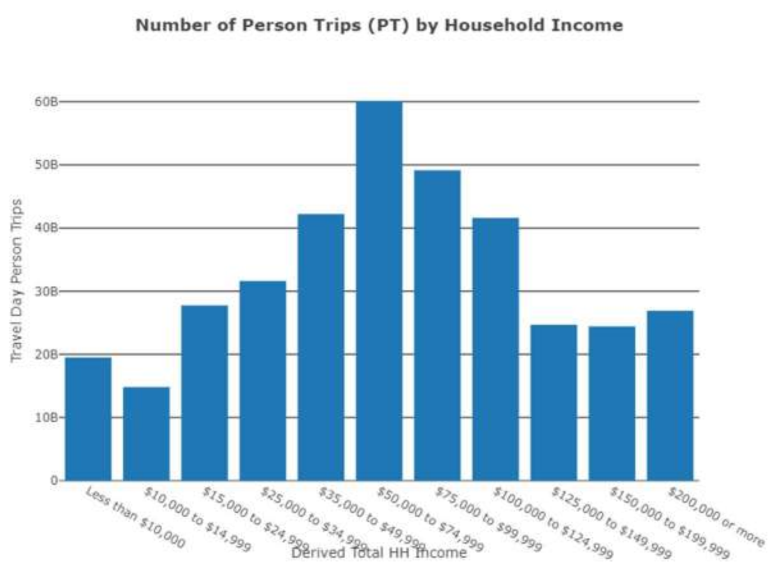
4. Household travel survey

National Household Travel Survey (ornl.gov)



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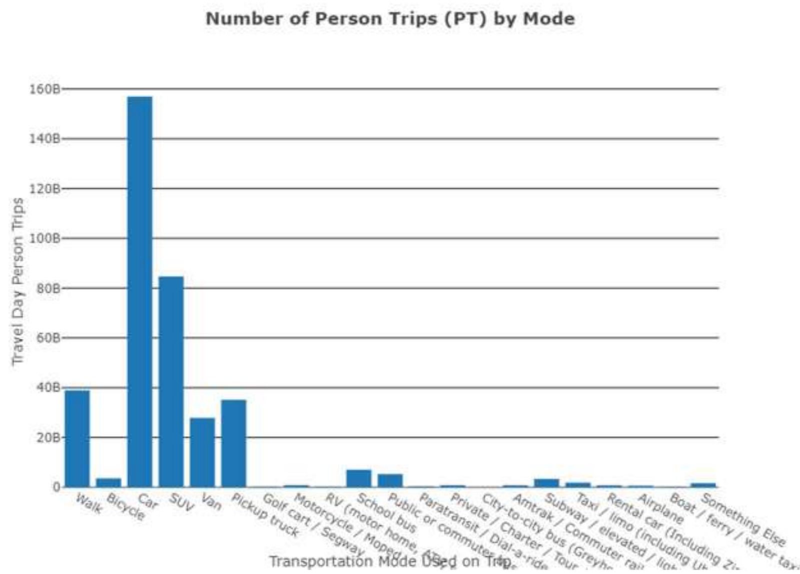
4. Household travel survey

[National Household Travel Survey (ornl.gov)]



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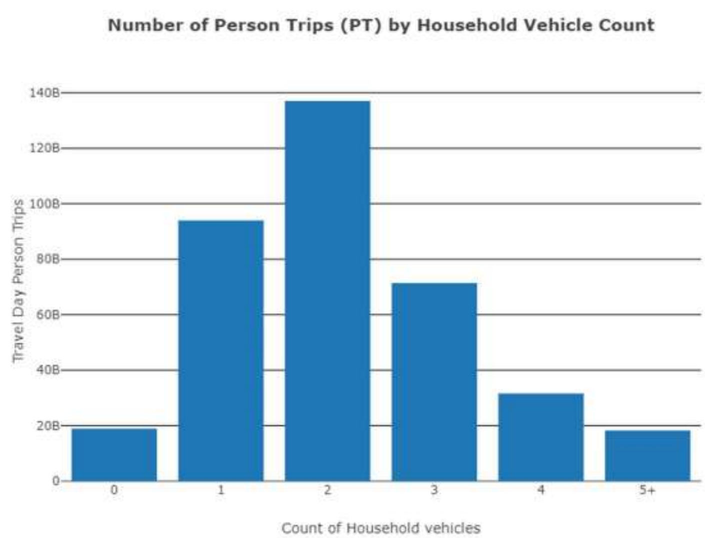
[National Household Travel Survey (ornl.gov)]



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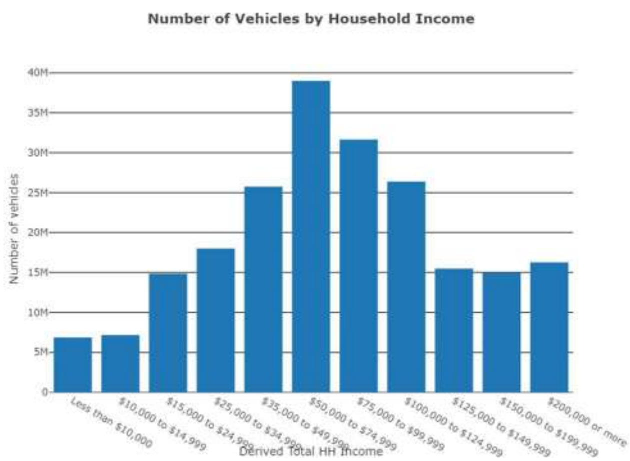
4. Household travel survey

National Household Travel Survey (ornl.gov)



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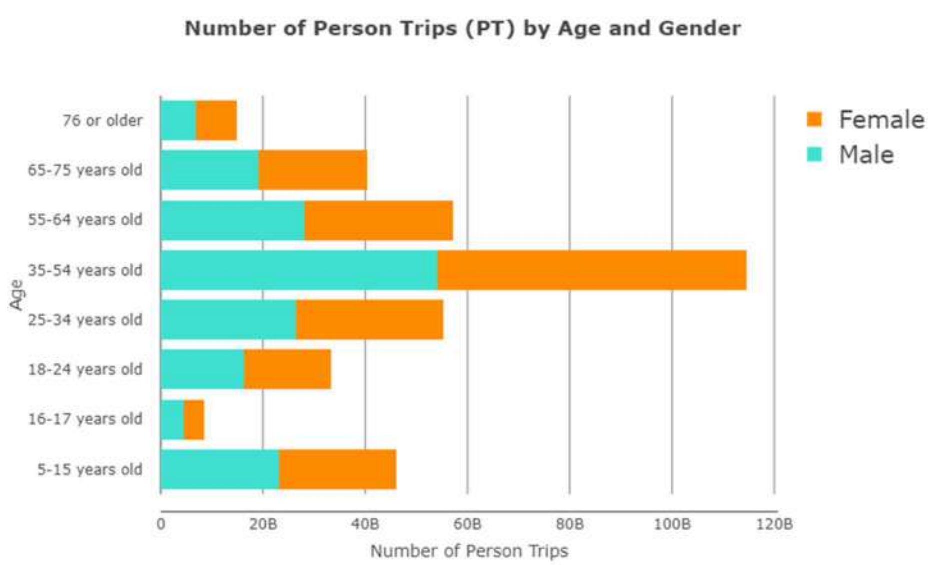
National Household Travel Survey (ornl.gov)



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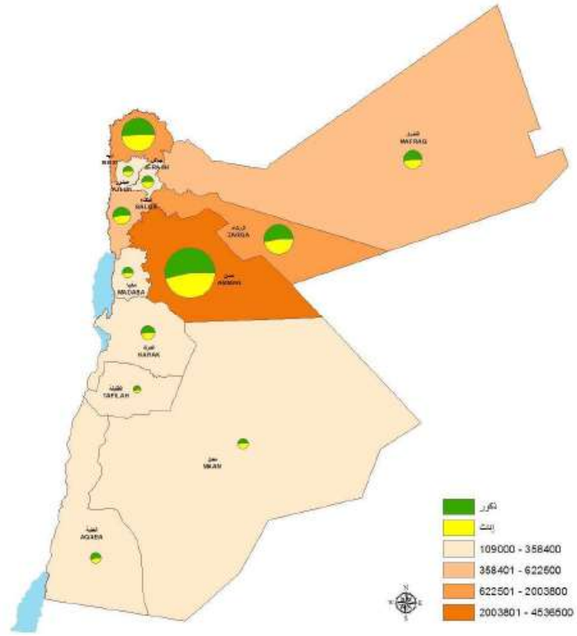
Department of Statistics / Jordan /2020

Estimated Population of the Kingdom by Governorateat and Sex the End of 2020



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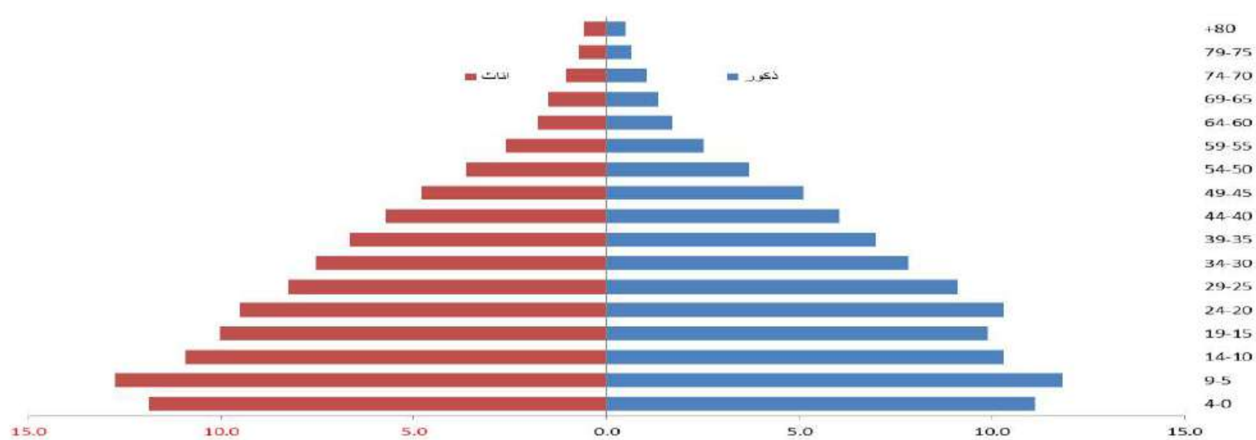
Department of Statistics / Jordan /2020

Population Pyramid (%)



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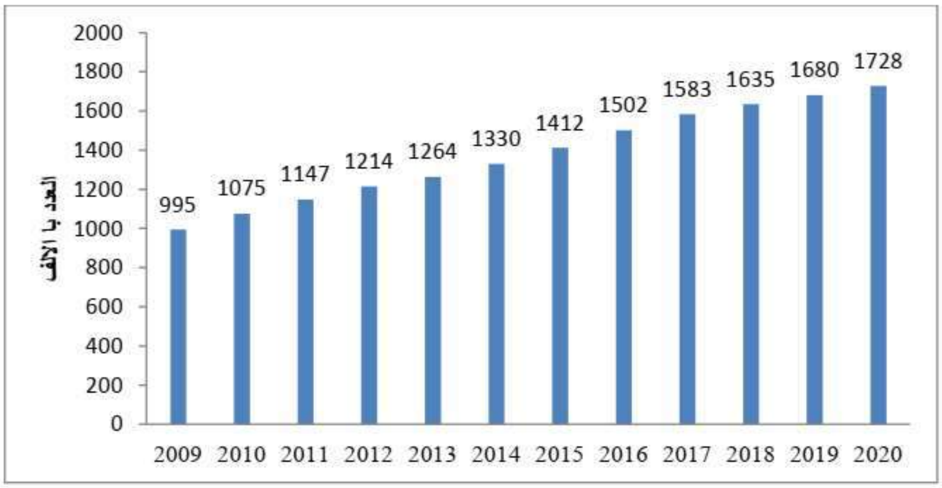
Department of Statistics / Jordan /2020

Number of Licensed Vehicles (000), 2009-2020



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2.Data Collection

Secondary data

- The recommendations for the expenditures of public funds must be obviously based upon the detailed economic and financial analysis.
  - *Therefore, inventory and data collection are undertaken to obtain a measured understanding of the subject.*
- The concerned departments and agencies may have the required data on
  - *Network, travel and traffic, economies, finance and engineering.*
- Specially designed studies and surveys are often undertaken to collect the following basic data required for urban transport planning

1. *Traffic data*
2. *Economic data*
3. *Financial planning data*
4. *Engineering data*
5. *Statistics data*

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Secondary data (or Inventories of Existing Conditions)

1. Traffic data

- Studies are undertaken to obtain knowledge of the type and volume of the base year traffic to project future travel demands.
- The following information is collected:
  1. *Traffic census counting number of vehicles and volume yearly, monthly, weekly or hourly*
  2. *Type of traffic such as trucks, buses, cars, tongas, etc.*
  3. *Nature of traffic (heavy at certain times of the day)*
  4. *Purpose of trip (business, official, recreational, educational, etc.)*
  5. *Origin and destination-where a trip starts and where it ends*
  6. *Speed of traffic*
  7. *Conditions of vehicles*
  8. *Accident records*
  9. *Miscellaneous information such as axle load, type of tires, etc.*
  10. *Parking supply and demands*
  11. *Special surveys and data on bus passenger service, taxi users and passenger fare.*
  12. *Commercial vehicles and their utilization*

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Secondary data (or Inventories of Existing Conditions)

2. Economic Data

- Economic data determine the economic status and development of the locality.
  - *This information helps in planning road system based on its population, development, mobility and economic life of the people*
- These include information on
  1. *Dispersal and location of the population*
  2. *Towns and villages classified on population basis*
  3. *Location of existing industries and sources of material*
  4. *Anticipated future development of industries*
  5. *Classification of area as agricultural, semi-agricultural and non-agricultural*
  6. *Location of marketing centers, size and goods sold*
  7. *Number of people going to market and industry, etc. and their mode of transportation*
  8. *Per capita income of people living in the area*

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Secondary data (or Inventories of Existing Conditions)

2. Financial planning data

- This data concerns itself with the financial aspects such as
  1. *Allotment of funds*
  2. *Compilation of statistics for income from different roads*
  3. *Study of the sources of revenue and expenditures incurred under different heads of transportation improvement.*
- Any organization must review its ability for transportation development program as a part of comprehensive transportation planning.
  - *Accordingly, any transportation improvement plan developed should be seen against the available fund allocated and costing may be done as per the fund allocation.*

Secondary data (or Inventories of Existing Conditions)

3. Engineering data

- The engineering data includes
  1. *Topography of the area under study*
  2. *Types of soil*
  3. *Available materials of construction*
  4. *Methods of construction and maintenance of transport facilities*
  5. *Drainage problems*
  6. *Availability of labour*
  7. *Road life cycle studies, etc.*

Secondary data (or Inventories of Existing Conditions)

4. Statistics data

1. Basic statistics: It involves the following:
   1. *Rate on import of motor vehicles and parts revenue from customs*
   2. *Revenue from excise duty on tires, etc. Revenue from motor taxes*
   3. *Registration fee of motor vehicles*
   4. *Sales tax on motor vehicles*
   5. *Income from other taxes, etc.*
   6. *Income from property taxes*
2. Motor vehicle use statistics: It involves the following:
   1. *How the owners of vehicles are distributed among rural and urban area.*
   2. *Finding the age of various automobiles and weight of commercial vehicles.*
   3. *Estimates of annual travel, trip lengths, purpose of trip and mad use.*
   4. *Rates of fuel consumption by different vehicles and their age.*
   5. *Transport modes used by different types of employees, etc.*
3. Road life statistics: This includes
   - *Facts regarding life of various roads, their construction and maintenance cost, salvage value of road elements.*
   - *History of each section of the road if maintained, regarding its maintenance and repair, condition of pavement.*

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Urban Transportation Forecasting Process

3. Calibration

- Concerned with establishing mathematical relationships that can be used to estimate future travel demand
- Analysis of the data will reveal the effect on travel demand of factors such as
  - *Land use*
  - *Socioeconomic characteristics*
  - *Transportation system factor*

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Urban Transportation Forecasting Process

*Example No. 1 :*Estimating Trips per Day Using Multiple Regression

7. Calibration

*Example :*Estimating Trips per Day Using Multiple Regression

Example 11.3 Estimating Trips per Day Using Multiple Regression

A multiple regression analysis shows the following relationship for the number of trips per household.

$$T = 0.82 + 1.3P + 2.1A$$

where

T = number of trips per household per day
P = number of persons per household
A = number of autos per household

If a particular TAZ contains 250 households with an average of 4 persons and 2 autos for each household, determine the average number of trips per day in that zone.

7. Calibration

Solution

Solution:

Step 1. Calculate the number of trips per household.

$$\begin{aligned} T &= 0.82 + 1.3P + 2.1A \\ &= 0.82 + (1.3 \times 4) + (2.1 \times 2) \\ &= 10.22 \text{ trips/household/day} \end{aligned}$$

Step 2. Determine the number of trips in the entire zone.

$$\text{Total trips in TAZ} = 250\,(10.22) = 2{,}555 \text{ trips/day}$$

Other mathematical formulas establish the relationships for trip length, percentage of trips by auto or transit, or the particular travel route selected.

TRANSPORTATION ENGINEERING AND PLANNING (110 401367)

Spring 2021-2022

Module No. 4

4.1_ Introduction and Trip generation

Dr. Hamza Alkuime

1

Nature and Analysis of Transportation Demand

2

2

Planning definitions and terms

- Capacity
  - *A transportation facility's ability to accommodate a moving stream of people or vehicles in a given time period*
- Land use
  - *Refers to the manner in which portions of land or the structures on them are used (or designated for use in a plan),*
    - Commercial, residential, retail, industrial, etc
  - *Land use affects the transportation demand through generation and distribution of trips*
- Mode:
  - *A specific form of transportation, such as*
    - automobile, subway, bus, rail, air, bicycle, or foot.
- Performance measures:
  - *Indicators of how well the transportation system is performing such as*
    - Average speed, reliability f travel, and accident rates. Used as feedback in the decision-making process

3

3

Transportation Demand 47

Definition

- 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.

- Understanding demand is important for Transport Planning in general and is particularly important Transportation Demand Management, which includes various strategies that influence travel behavior.

Online TDM Encyclopedia - Transportation Demand (vtpi.org)

4

4

Transportation Demand

Nature and Analysis

- Transportation demand is a derived demand
  - *That is, a person generally demand to be transported not because he/she just wants to move, but because he/she wants to achieve some other purpose such as reaching school, university, or office.*
- Therefore, it is not surprising that two of the major aspects in travel demand analysis are
  - *Land use*
  - *Trip-purpose*

Online TDM Encyclopedia - Transportation Demand (vtpi.org)

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Transportation Demand

Factors That Affect Transport Demand

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

Travel Demand Models can be used to predict how these factors affect travel behavior.

Online TDM Encyclopedia - Transportation Demand (vtpi.org)

6

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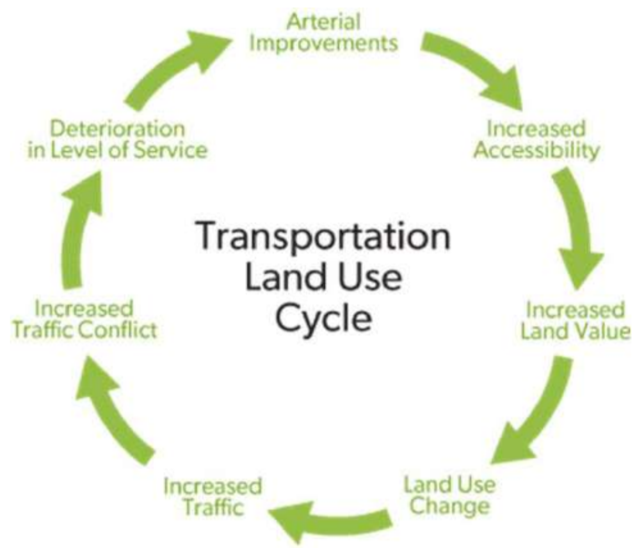
Transportation Demand

Relationship between land-use and transportation demand

- It is not necessarily a one-way effect but rather a part of a cycle
  - *In this cycle in which land-use changes the transportation needs which in turn change land-use*

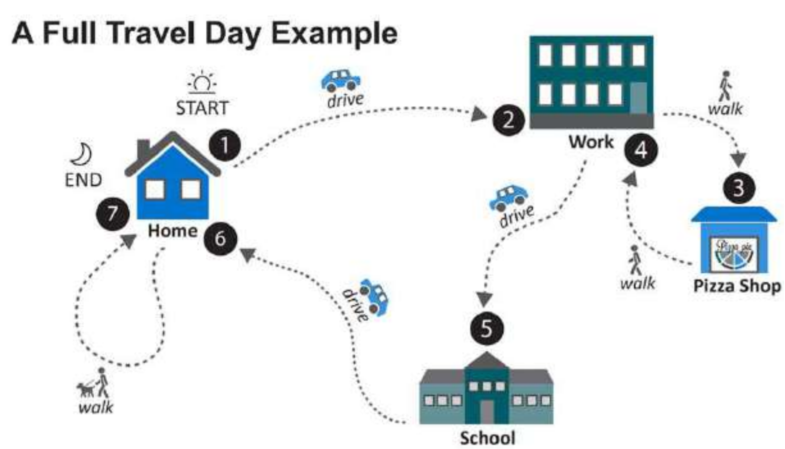


Land Use & the Natural Environment - 2050 Metropolitan Transportation Plan (oki.org)

Analysis of Transportation Demand

Definition of a trip

- Trip
  - *Is an out-way movement from a point of origin to a point of destination.*
  - *The basic quantity in travel demand*
  - *It materializes after the trip-maker makes certain decisions*

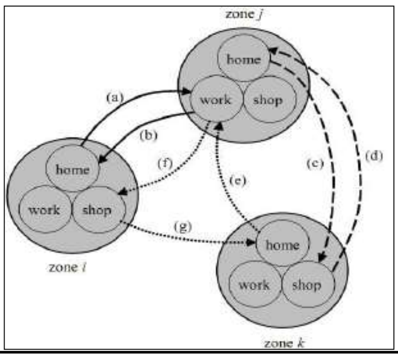


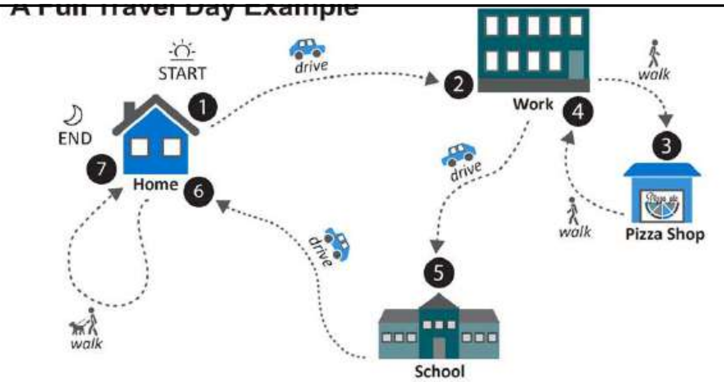
NHTS2017_TravelLog.pdf (ornl.gov)

Transportation Demand

Trip generation terminology

- Home-based trips
  - If either origin or destination of a trip is the home of the trip maker
- Non-home-based trips
  - *Any trip that is not a home-based trip*





Transportation Demand

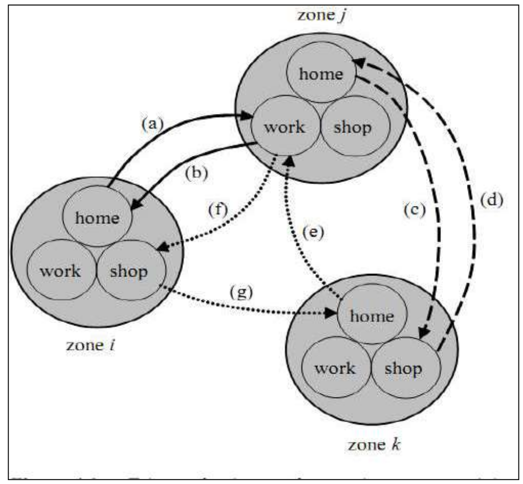
Trip generation terminology

- Travel demand behaviors changes with the trip-purpose
  - *Work trips*
    - Limited number of decisions are available
    - A person does not necessarily decide every time whether to go to work or not
    - Generally fixed location and time
    - The choice of rout and mode of travel are not daily decisions
  - *Recreation trips*
    - A large number of decisions are available
    - To go or not
    - Where, when, and how to go
  - *Shopping trips*

Transportation Demand

Trip generation terminology

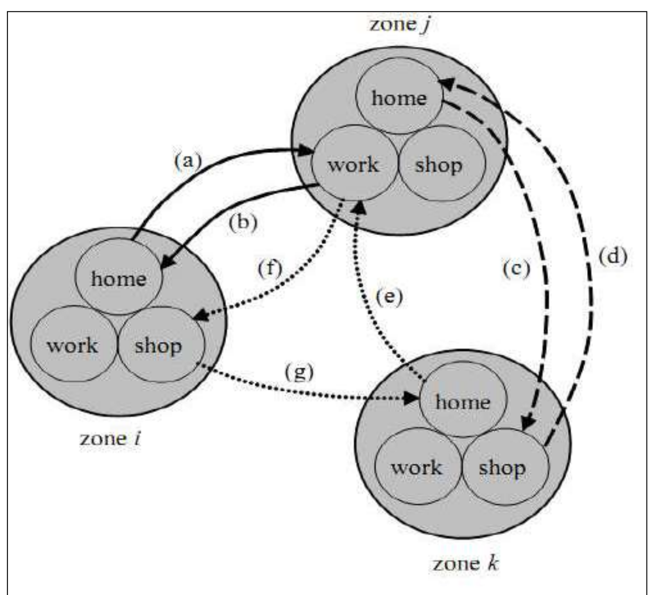
- The trip is classified based on its purpose
  - *Homebased (HB)*
    - Work (HBW)
    - School (HBS)
    - Shopping (HBSH)
    - Social and recreation (HBR)
    - Other (HBO)
  - *None-homebased(NHB)*
    - Not classified into categories



Nature and Analysis of Transportation Demand

Trip-purpose

- Home-based work (HBW)
  - If the trip is between the home and the work of the trip maker.
- Home-based other (HBO)
  - If the trip is between the home and destination except the work of the trip maker
- Non-home based (NHB)
  - *Any trip is not HBW or NBO*



Nature and Analysis of Transportation Demand

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*

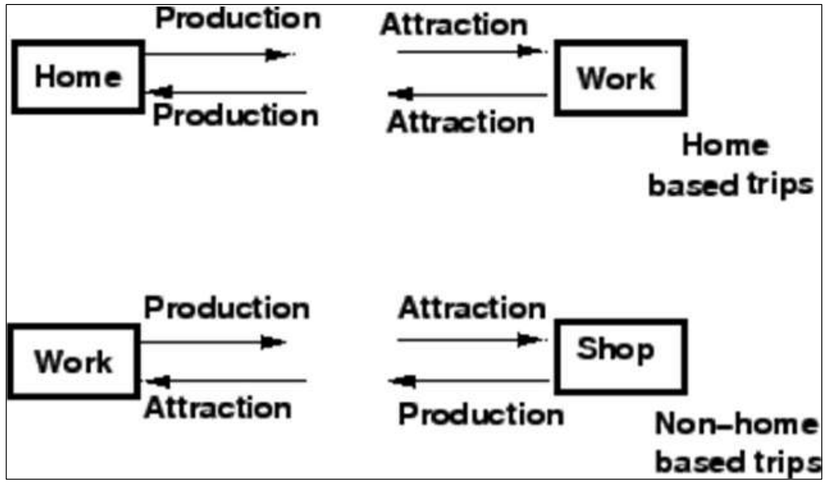


Image source: https://www.civil.iitb.ac.in/~vmtom/1100_LnTse/203_InTse/plain/

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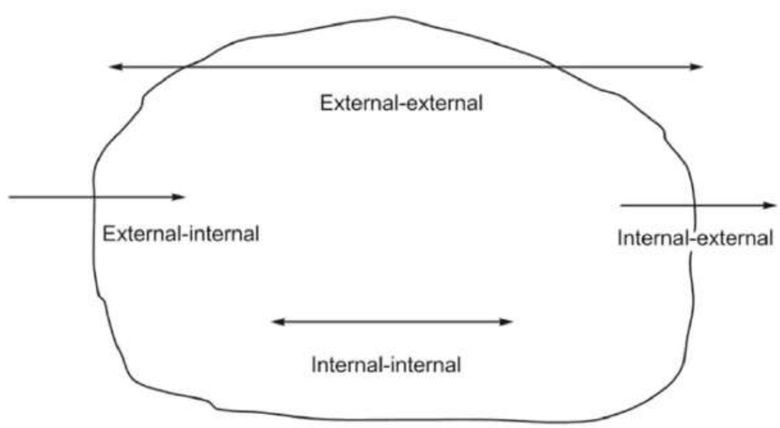
Zoning system

- There are four types of movement patterns studied by delineating the various internal and external zones. These are as follows:
  1. *Internal to internal (I-I)*
  2. *Internal to external (I-E)*
  3. *External to internal (E-I)*
  4. *External to external (E-E)*



TRANSPORTATION PLANNING : PRINCIPLES, PRACTICES AND POLICIES book, (TRANSPORTATION PLANNING : PRINCIPLES, PRACTICES AND POLICIES - PRADIP KUMAR SARKAR,, VINAY MAITRI,, G.J. JOSHI, - Google Books)

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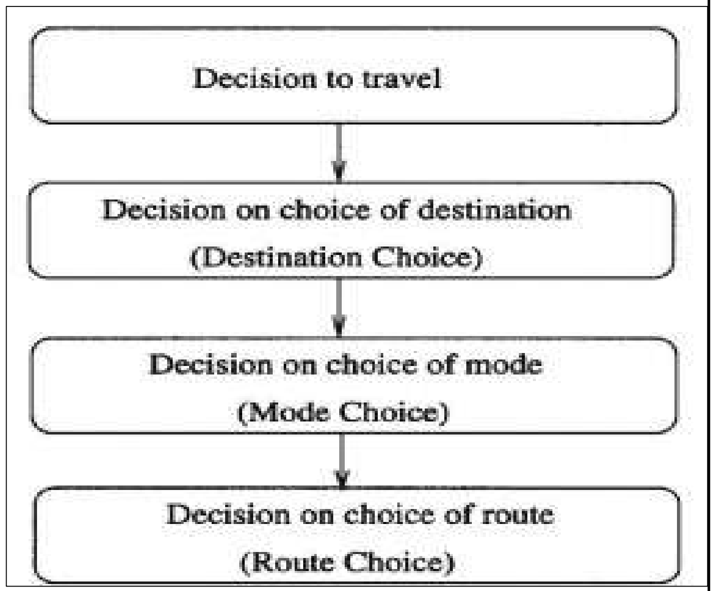
Trip-maker travel decisions

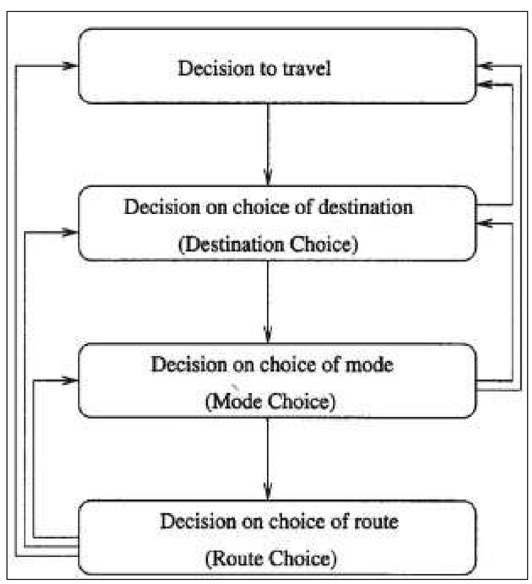
- This decisions can be broadly classified into:
  1. *The decision to travel*
  2. *The decision on the choice of destination*
  3. *The decision on the choice of mode*
  4. *The decision on the choice of route*



Trip-maker travel decisions

Assumptions of non-sequential decision making

Usually, the sequential demand analysis is used to determine the travel demands, even thought this assumption may be debatable



Travel demand forecasting

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Forecasting travel demand

Travel demand definition

- 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.

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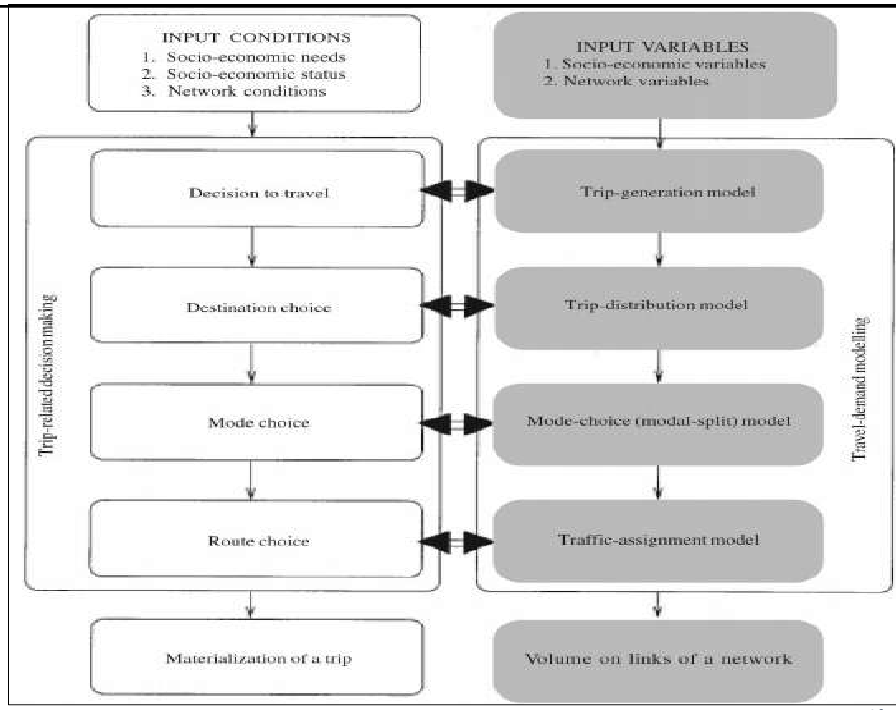
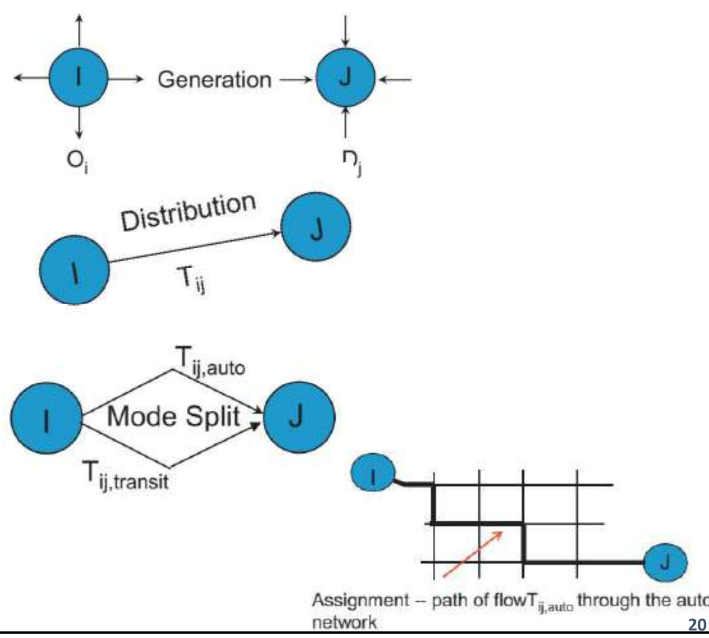
Sequential demand analysis



Introduction

Travel Forecasting Process

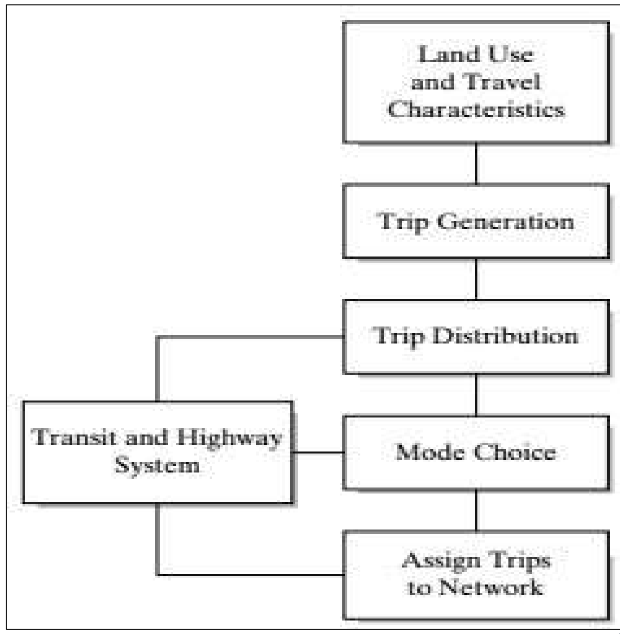
- Four-step process"
  - *Trip generation*
    - How many trips ?
  - *Trip distribution*
    - From where to where ?
  - *Modal choice*
    - On what mode ?
  - *Traffic assignment*
    - On what route ?



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 ?

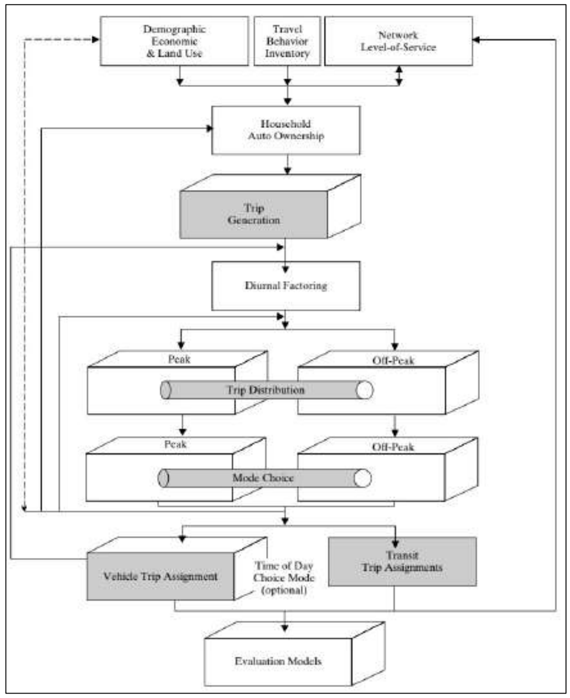


Sequential demand analysis

The analysis procedure

1. Population and economic analysis are performed to determine the magnitude and extent of activity in the urban area
2. Land use analysis are performed to determine where the activities will be located
3. The entire study area is divided into various zones based on land-use
4. The total number of trips generated in the zone are estimated using trip generation models
5. The number of trips between all zone is determined using the trip- distribution models
6. The relative shares of the generated trips for the different modes are estimated using the mode-choice models
7. The volume on each link of the network is estimated using traffic –assignment models

Travel Demand Model Flowchart



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Travel Forecasting Process

Trip generation

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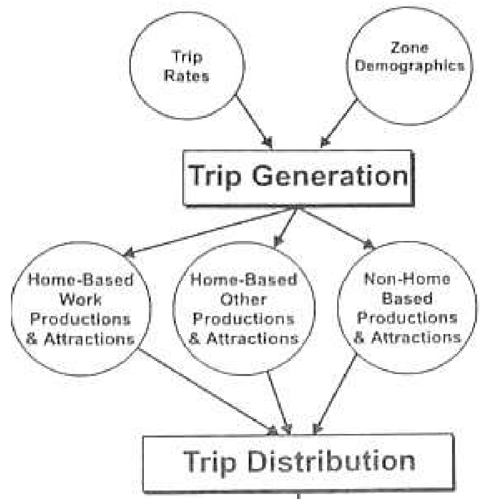
Trip generation

- Definition:
  - *Total number of trips generated by households in a zone (HB and NHB)*
- Task:
  - *Estimating the number of trips generated for a given land use, based on prior data of traffic generators in the same land use category*
  - *The number of trips are typically a function of the type of land use, as well as its size .*
- Inputs:
  - *Socioeconomic data*
  - *Land use data*



NHI 5 Tripgen.ppt (live.com)

Source: NHI course on Travel Demand Forecasting (152054A)

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Socio-Economic data

- Data about humans, human activities, and the space and/or structures used to conduct human activities

Table 1.1: Typical Regression Variables used in Trip Generation

Household Counts	*Employment Counts*
Total and Group Quarters Population	Total, Basic, Service, Retail and Non-retail, Industrial, Construction, Manufacturing, Wholesale, Public Administration, Educational, Health, and Social Services, and Arts, Entertainment, Recreation, Accommodation, and Food Services Employment
Average Number of Children Under Age 5	Average Number of Employees per Household
Number of Total, 1, 2, 3, 4, and 5+ Person Households	Total Labor Force
Average Household Size	Average Number of Labor Force per Household
Number of Vehicles Available	
Number of 0, 1, 2, and 3+ Vehicle Households	
Number of 0, 1, 2, and 3+ Worker Households	

Educational Enrollment	*Floor Areas*
Total, Primary, and Secondary School Enrollement	Retail, Manufacturing, Trade, Services, and Public and Quasi-public Floor Area
College Enrollment	

Real-Time Socio-Economic Data for Travel Demand Modeling and Project Evaluation (core.ac.uk)

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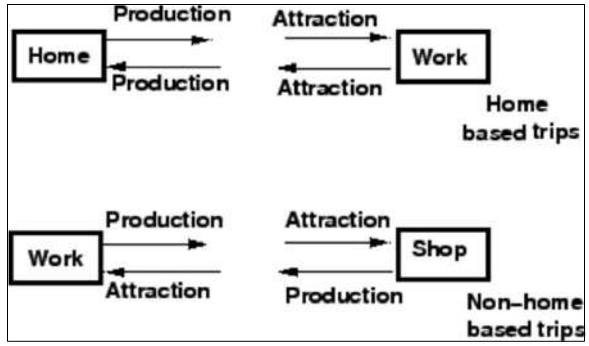
Trip generation

Factors affecting Trip Generation—Personal Trips (Production)

- Income
- Car ownership
- Household structure
- Family size
- Value of land
- Residential density
- Accessibility



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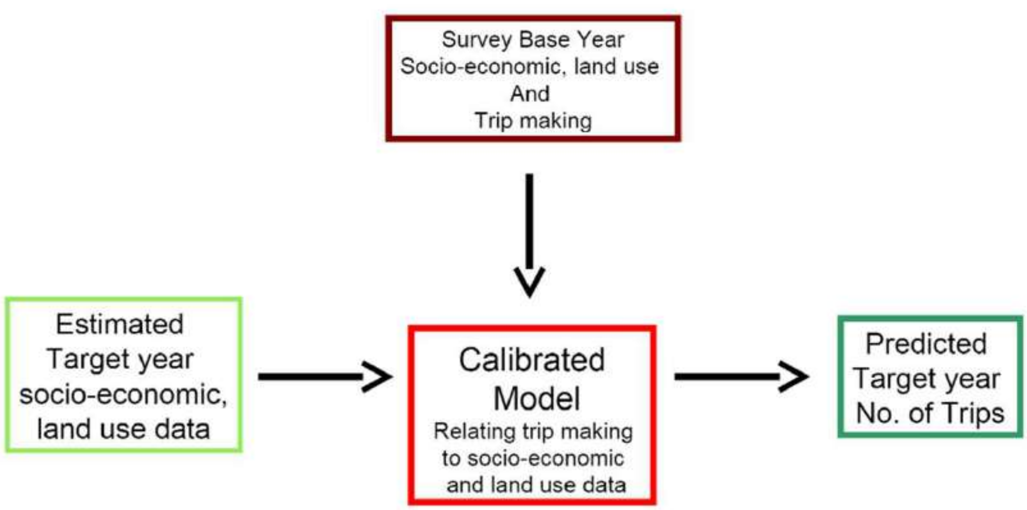
Trip generation

Process



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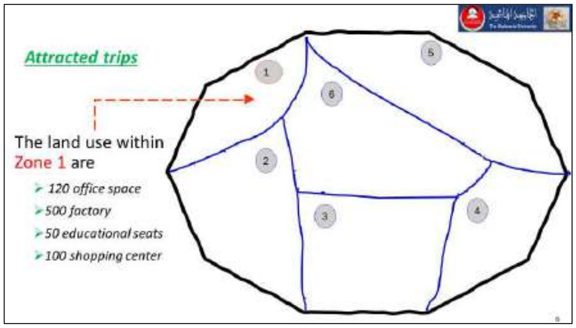
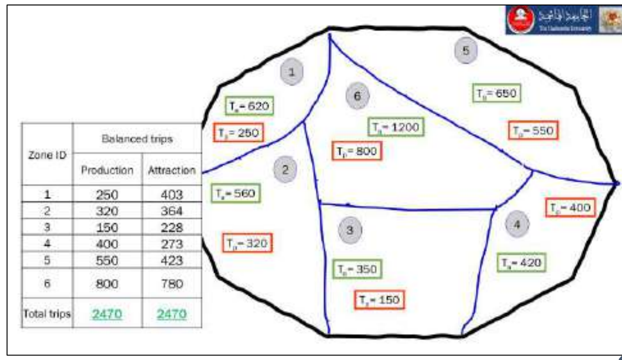
Trip generation

Process

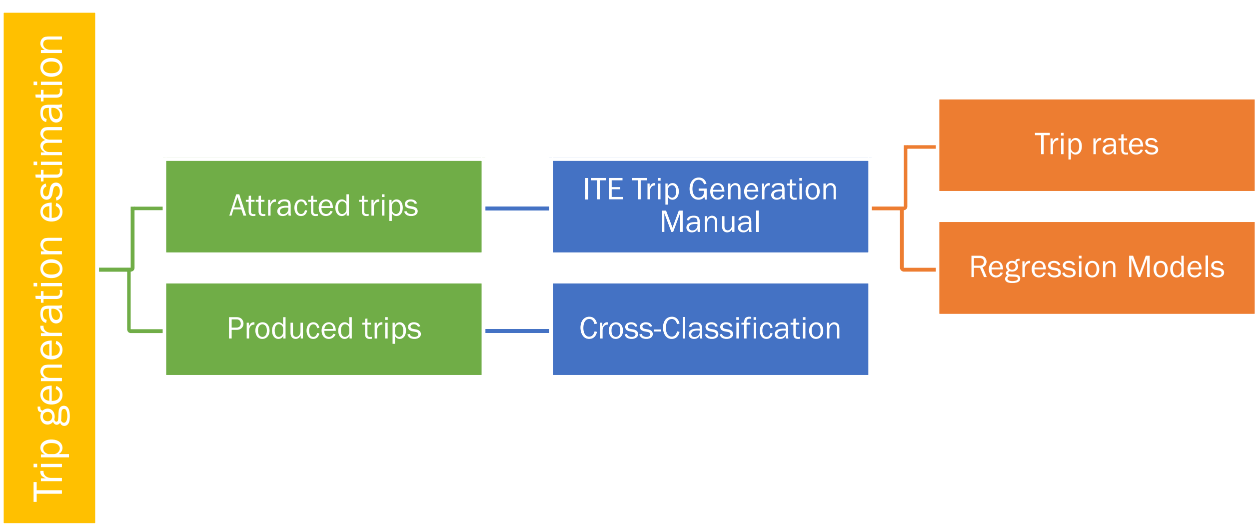




Zone ID	Balanced trips	
	Production	Attraction
1	250	403
2	320	364
3	150	228
4	400	273
5	550	423
6	800	780
Total trips	2470	2470

Trip generation

Modeling approaches



Travel Forecasting Process

Trip generation

Trip Rates and regression methods

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Regression Analysis

- You can learn more about Regression Analysis using these links:
  - *An Introduction to Linear Regression Analysis – YouTube*
  - *Linear Regression, Clearly Explained!!! – YouTube*
  - *Excel - Simple Linear Regression – YouTube*
  - *Excel 2016 Regression Analysis – YouTube*
  - *مبادئ الإحصاء - الإنحدار الخطي البسيط 1 – YouTube*
  - *تحليل وتفسير الانحدار باستخدام الاكسيل – YouTube*
  - *الإنحدار الخطي البسيط - Linear Regression – YouTube*

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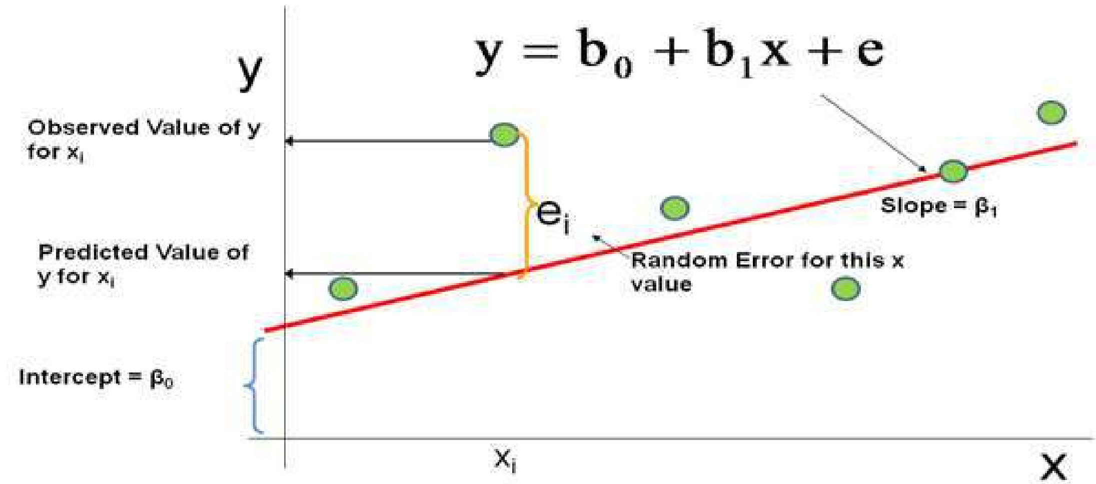
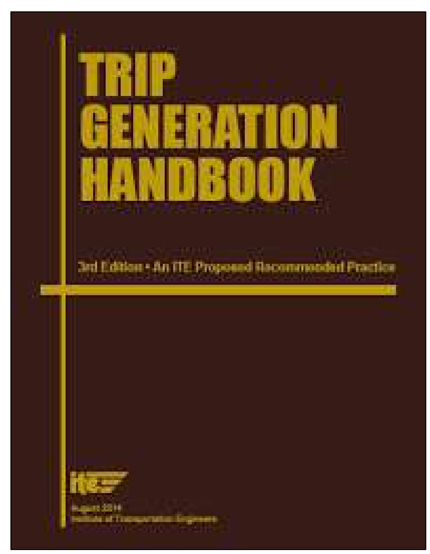
Regression Analysis



Trip generation

Rates based on activity units

- Rate:
  - *Refers to the number of trips per day per activity center.*
- Trip generation rates and characteristics in the United States are collected and distributed in the ITE Trip Generation Manual
  - *It contains data for a total of 172 land use types, based on a sample of more than 5500 sites across the United States*
  - *The ITE manual applies to single land use, homogeneous sites or zones and covers significantly more than 100 land uses*



ITE Trip generation manual

Land use types

- Common land use types featured in the manual include:
  - *Port and terminal*
    - 6 land uses, including water ports, airports, transit stations, etc.
  - *Residential*
    - 19 land uses, including single-family homes, various types of apartments, senior living, mobile home parks, etc.
  - *Recreational*
    - Institutional
  - *Medical*
  - *Industrial*
  - *Office*
  - *Retail*
  - *Services*

Land Use Codes

Port and Terminal (Land Uses 000–099)

CODE	LAND USE
021	Commercial Airport
022	General Aviation Airport
030	Intermodal Truck Terminal
090	Park-and-Ride Lot with Bus or Light Rail Service

Industrial (Land Uses 100–199)

CODE	LAND USE
110	General Light Industrial
130	Industrial Park
140	Manufacturing
150	Warehousing
151	Mini-Warehouse
154	High-Cube Transload and Short-Term Storage Warehouse
155	High-Cube Fulfillment Center Warehouse
156	High-Cube Parcel Hub Warehouse
157	High-Cube Cold Storage Warehouse
160	Data Center
170	Utility
180	Specialty Trade Contractor

Residential (Land Uses 200–299)

CODE	LAND USE
210	Single-Family Detached Housing
220	Multifamily Housing (Low-Rise)
221	Multifamily Housing (Mid-Rise)
222	Multifamily Housing (High-Rise)
225	Off-Campus Student Apartment
231	Mid-Rise Residential with 1st-Floor Commercial
232	High-Rise Residential with 1st-Floor Commercial
240	Mobile Home Park
251	Senior Adult Housing—Detached
252	Senior Adult Housing—Attached
253	Congregate Care Facility
254	Assisted Living
255	Continuing Care Retirement Community
260	Recreational Homes
265	Timeshare
270	Residential Planned Unit Development

Lodging (Land Uses 300–399)

CODE	LAND USE
310	Hotel
311	All Suites Hotel
312	Business Hotel
320	Motel
330	Resort Hotel

Recreational (Land Uses 400–499)

CODE	LAND USE
411	Public Park
416	Campground/Recreational Vehicle Park
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

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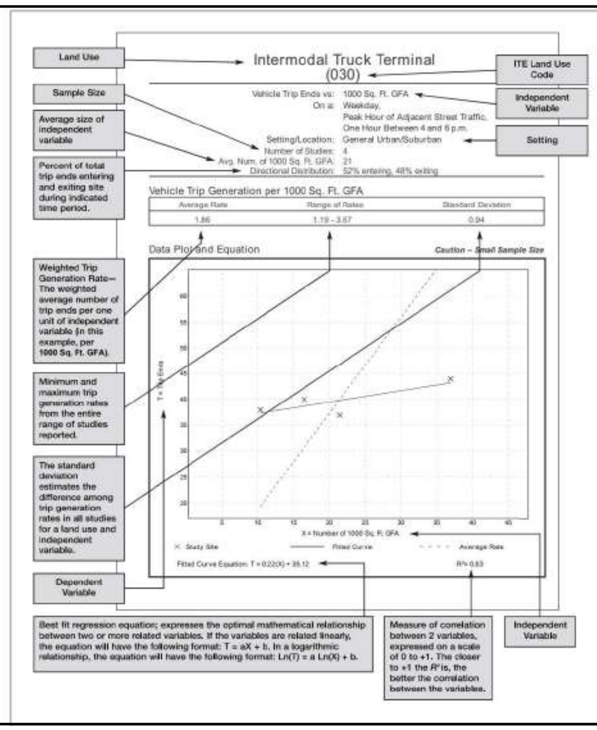
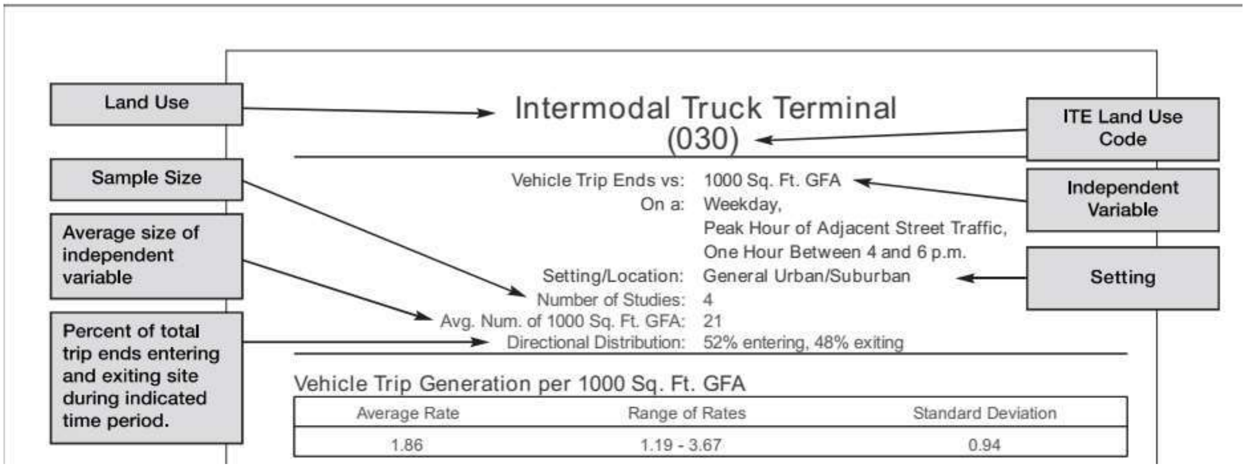
ITE Trip generation manual

Sample Data Page in Trip Generation Manual



ITE Trip generation manual

Sample Data Page in Trip Generation Manual



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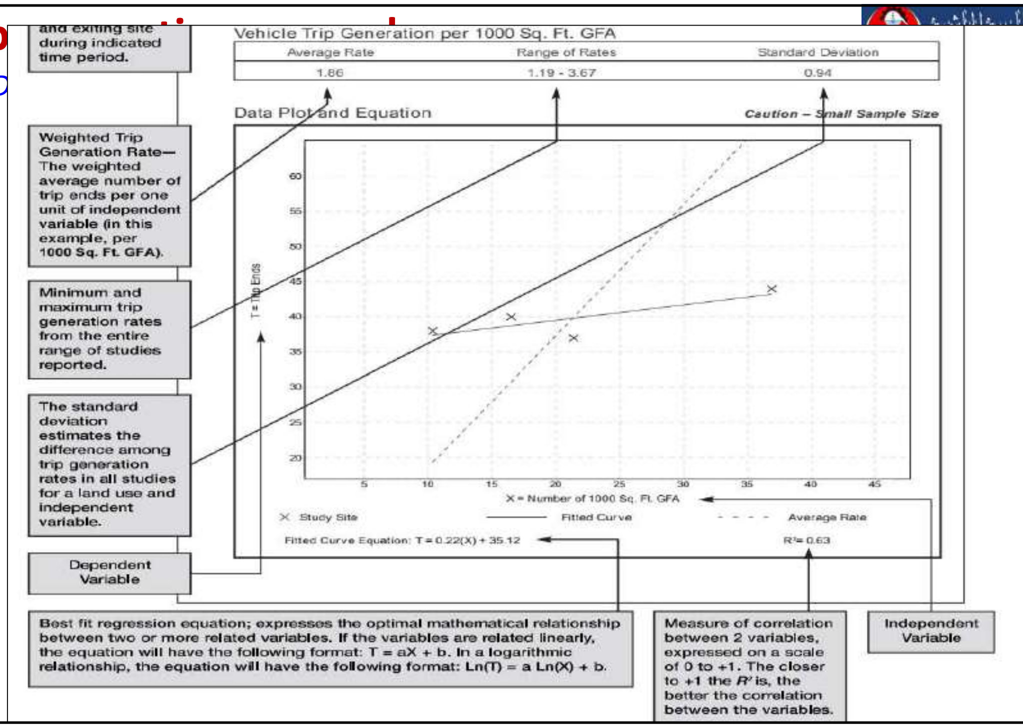
ITE Trip

Sample D



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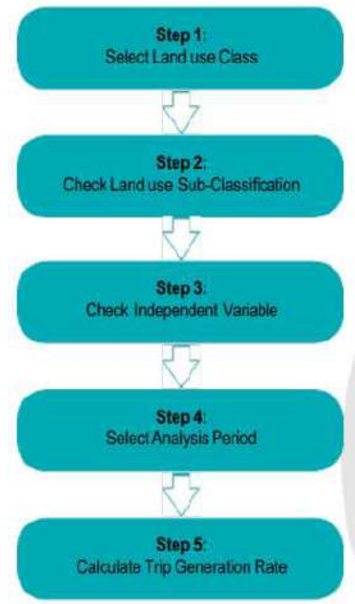
ITE Trip generation manual

Generated trips estimation process

- The process including:
  1. *Choosing land use*
  2. *Choosing analysis period*
  3. *Choosing independent variable(s)*
  4. *Calculate the trip generation rates*
     1. ***Graphic Plot***
     2. ***Regression Equation***
     3. ***Weighted Average Trip Rate***

"Selecting an appropriate method for estimating trips requires the use of engineering judgment and a thorough understanding of the three methodologies listed above"



ITE Trip generation manual

Generated trips estimation process

The general guidelines for use of the ITE manual are as follows:

1. *Make sure that your zone is within the calibration limits on the independent variables*
2. *Use equation first*
   - **if the model statistical fit defined through the R^2 is greater than 0.75.**
3. *Use average rate,*
   - **If standard deviation (S.D) is less than 1.1 times the average rate.**

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 ?

University/College
(550)

Vehicle Trip Ends vs: Students
On a: Weekday

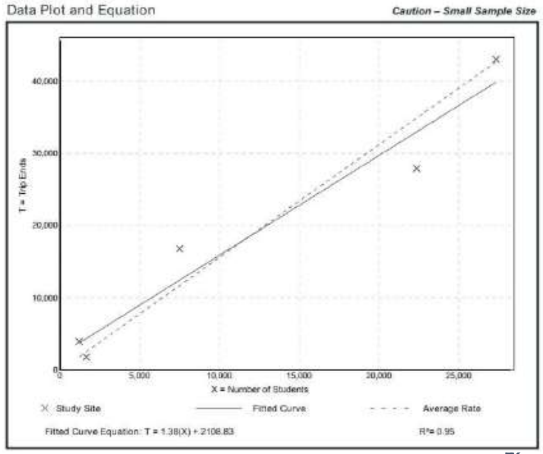
Setting/Location: General Urban/Suburban
Number of Studies: 5
Avg. Num. of Students: 12010
Directional Distribution: 50% entering, 50% exiting

Vehicle Trip Generation per Student

Average Rate	Range of Rates	Standard Deviation
1.56	1.10 - 3.31	0.45

Data Plot and Equation

Caution – Small Sample Size



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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

University/College
(550)

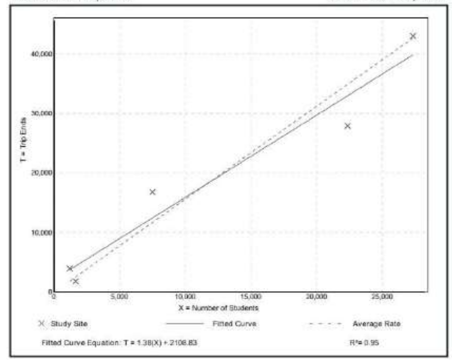
Vehicle Trip Ends vs: Students
On a: Weekday

Setting/Location: General Urban/Suburban
Number of Studies: 5
Avg. Num. of Students: 12010
Directional Distribution: 50% entering, 50% exiting

Vehicle Trip Generation per Student

Average Rate	Range of Rates	Standard Deviation
1.56	1.10 - 3.31	0.45

Data Plot and Equation *Caution – Small Sample Size*



ITE Trip generation manual

Example No .2

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.**

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ITE Trip generation manual

Example No .2

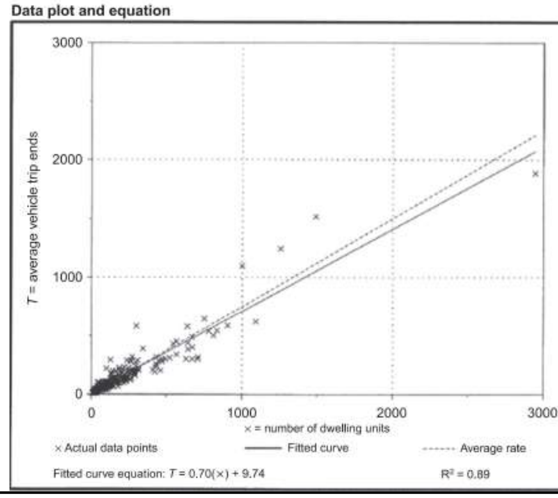
Average vehicle trip ends vs: **Dwelling units**
On a: **Weekday, peak hour of adjacent street traffic, one hour between 7 and 9 am**

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



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ITE Trip generation manual

Solution of example No .2

Solution

1. 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.
2. $R^2 = 0.89$. Because this is >0.75, we can use the fitted curve equation to solve for the answer versus looking at the average rate.
3. $T = 0.70\ (X) + 9.74$, where X is the number of dwelling units.
   $T = 0.70\ (400) + 9.74$
   $T = 290$ total trips

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

ITE Trip generation manual

Example No .3

ITE Trip generation manual

Example No .3

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.

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)

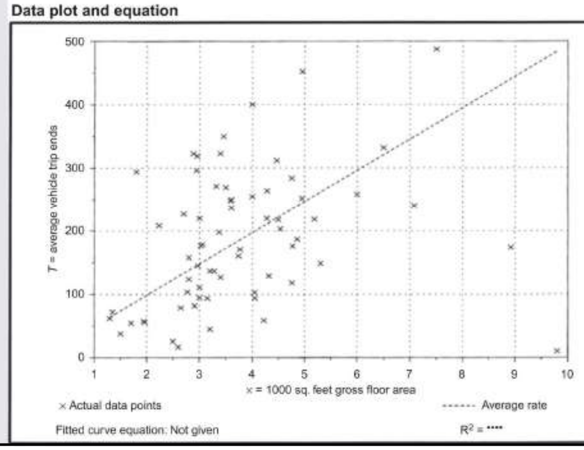
Average vehicle trip ends vs: 1000 sq. feet gross floor area
On a: Weekday, peak hour of adjacent street traffic, one hour between 7 and 9 am

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



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).

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ITE Trip generation manual

Example No .4

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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

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

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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

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

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

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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	y Trip Purpose and Employee Categc	
	Attractions per Nonretail Employee	*Attractions per Downtown Retail Employee*
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated HBW trips

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

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	y Trip Purpose and Employee Categc	
	Attractions per Nonretail Employee	*Attractions per Downtown Retail Employee*
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated HBO trips

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

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	y Trip Purpose and Employee Catego	
	Attractions per Nonretail Employee	*Attractions per Downtown Retail Employee*
HBW	1.7	1.7
HBO	2.0	5.0
NHB	1.0	3.0

Estimated NHB trips

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

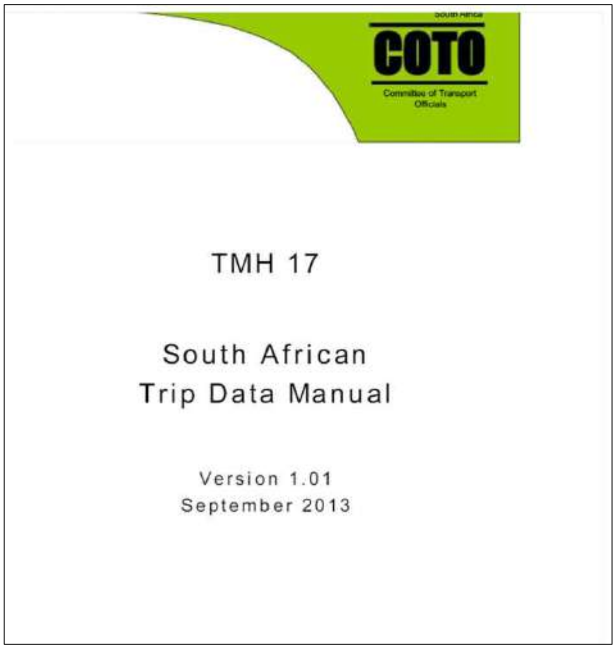
ITE Trip generation manual

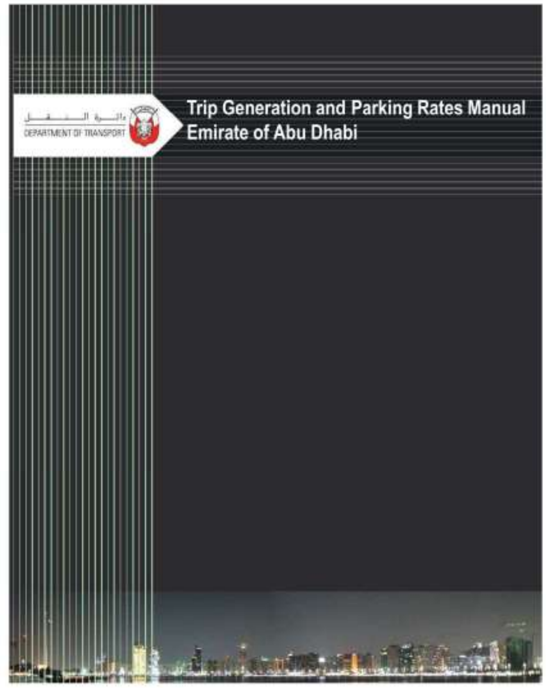
Solution of example No .4

Estimated Total trips

$$\begin{aligned} &\text{HBW: } (220 \times 1.7) + (650 \times 1.7) = 1479 \\ &\text{HBO: } (220 \times 5.0) + (650 \times 2.0) = 2400 \\ &\text{NHB: } (220 \times 3.0) + (650 \times 1.0) = 1310 \\ &\qquad\qquad\qquad\qquad \text{Total} = 5189 \text{ trips/day} \end{aligned}$$

Other Manuals





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Develop a customized equation

Case studies in Jordan

60

60

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

Case studies in Jordan

- 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

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

Trip Attraction Model For Universities In Jordan

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

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

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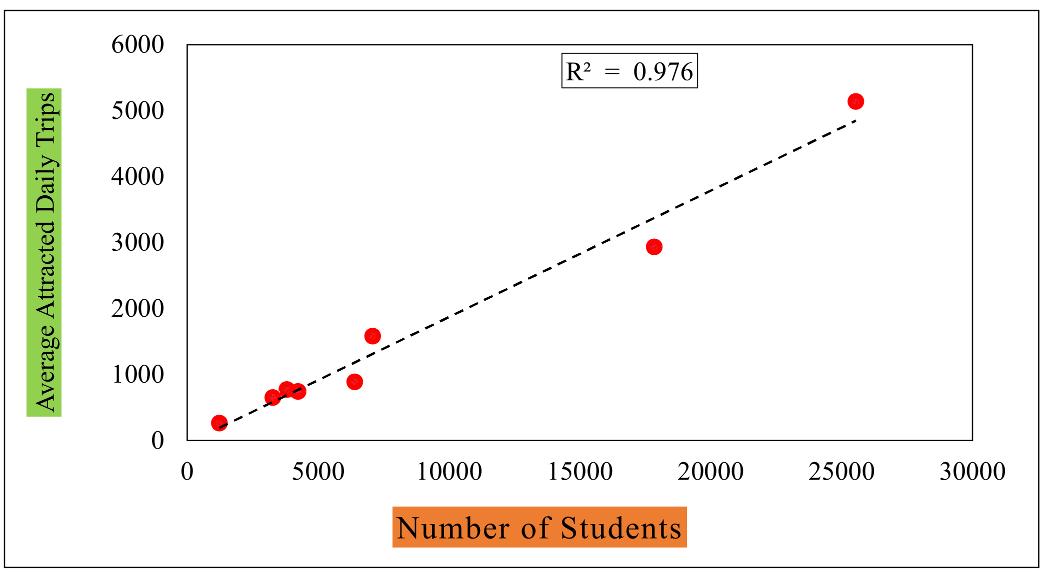
Develop a customized equation (e.g., planning model)

Trip Attraction Model For Universities In Jordan



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

Trip Attraction Model For Universities In Jordan

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

Reading Assignment

Read the short paper:

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,

Then:

1. Prepare a two-page summary of the paper.
2. Suggest additional independent factors that may influence the number of generated trips? Justify your suggestion.
3. The study used two approaches to model trip generation rates, which one do you think would provide better results? Explain your answer.
4. Do you agree with the study findings or not? Explain why?

Reading Assignment

Table 12: Comparison between Proposed, Regional and International Rates

Land Use Category	Amman Trip Rates			ITE Manual			Abu Dhabi Manual			Dubai Manual		
	AM	Noon	PM	AM	Noon	PM	AM	Noon	PM	AM	Noon	PM
Restaurants	0.889	0.675	0.958	9.94	7.49	14.13	0.03	0.35	0.45	0.29	6.93	8.12
Variable	Parking capacity	Parking capacity	Parking capacity	1000 ft^2 of GFA	1000 ft^2 of GFA	1000 ft^2 of GFA	Number of seats	Number of seats	Number of seats	100 m^2 of GFA	100 m^2 of GFA	100 m^2 of GFA
Fast Food	-	0.902	0.902	183.07	-	38.9	-	12.71	19.53	0	13.06	12.65
Variable	Not available	Parking capacity	Parking capacity	1000 ft^2 of GFA	Not available	1000 ft^2 of GFA	Not available	100 m^2 of GFA	100 m^2 of GFA	100 m^2 of GFA	100 m^2 of GFA	100 m^2 of GFA

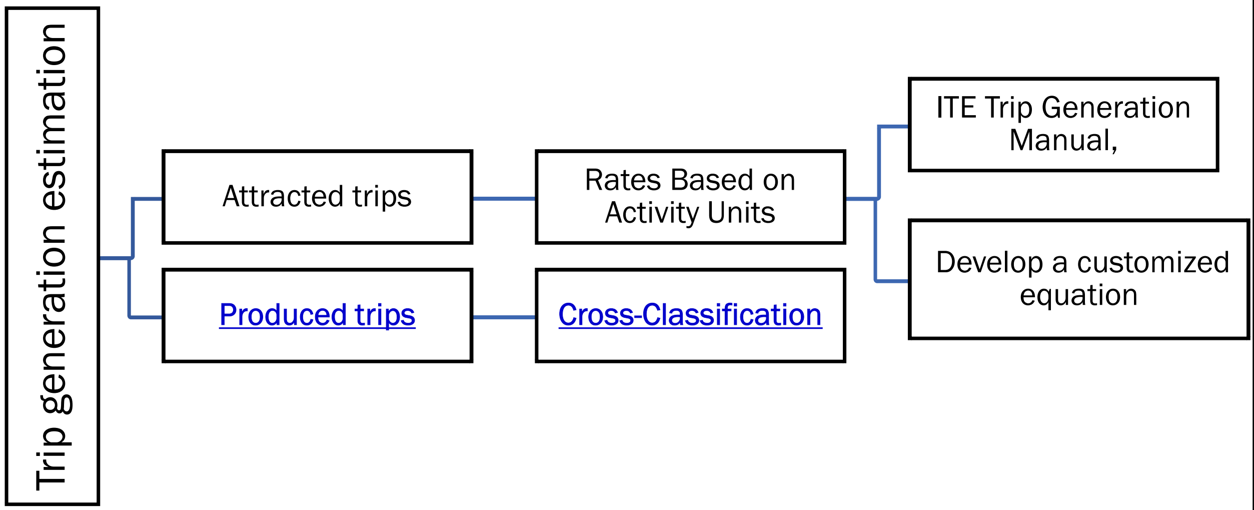
Travel Forecasting Process

Trip generation

Cross-Classification

Trip generation

The main methods for estimating generated trips



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Cross – Classification

- Cross-Classification: A technique developed by FHWA to determine the number of trips that begin or end at the home
  - *Home based trips*
- The two variables most commonly used are
  - *Average income*
  - *Auto ownership*
  - *household size and stage in the household life cycle*

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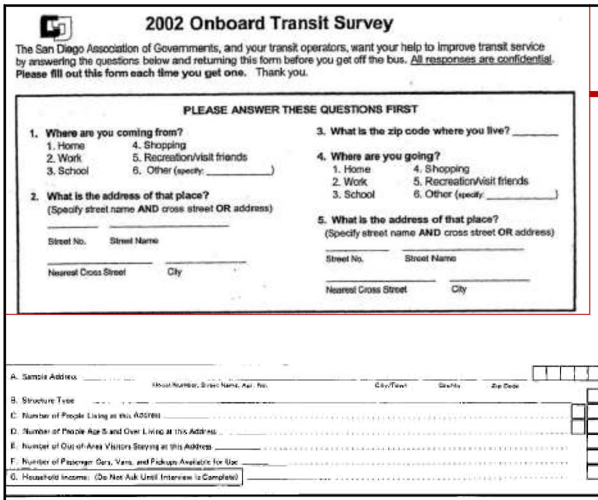

2002 Onboard Transit Survey

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 State 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)

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

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

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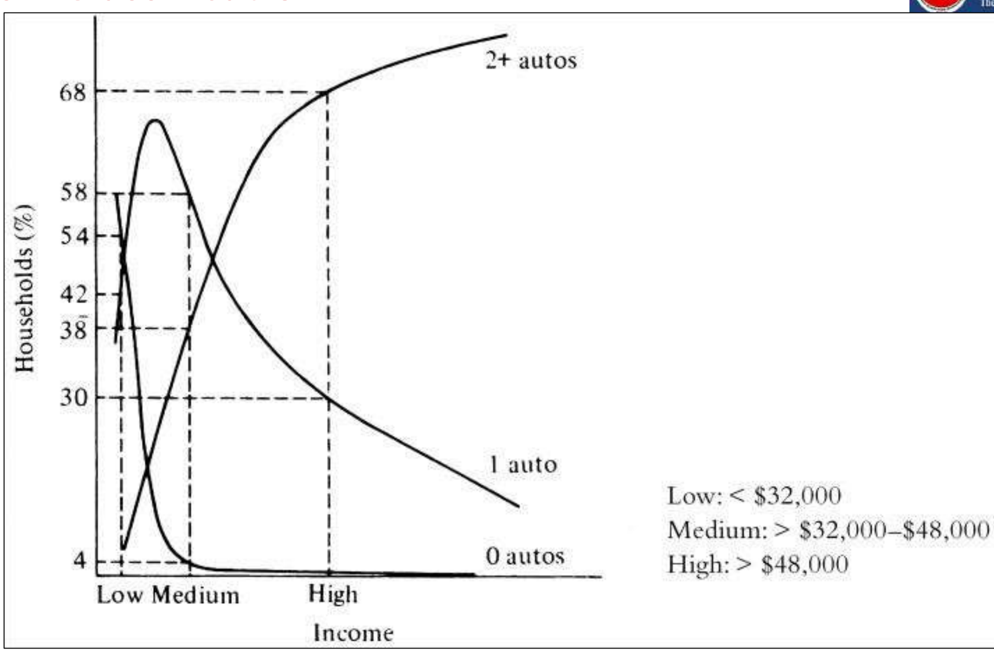
Cross – Classification



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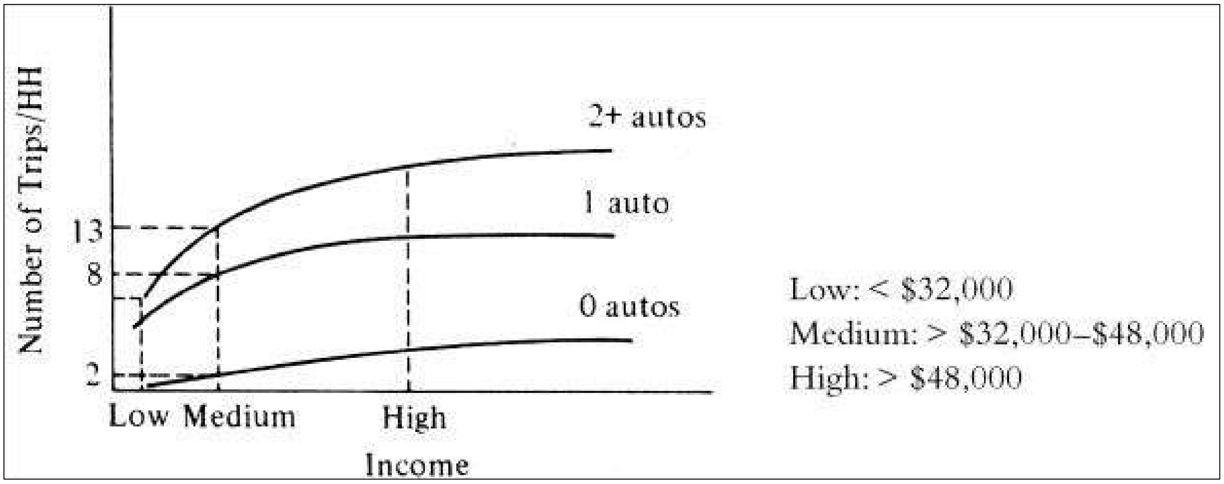
Cross – Classification



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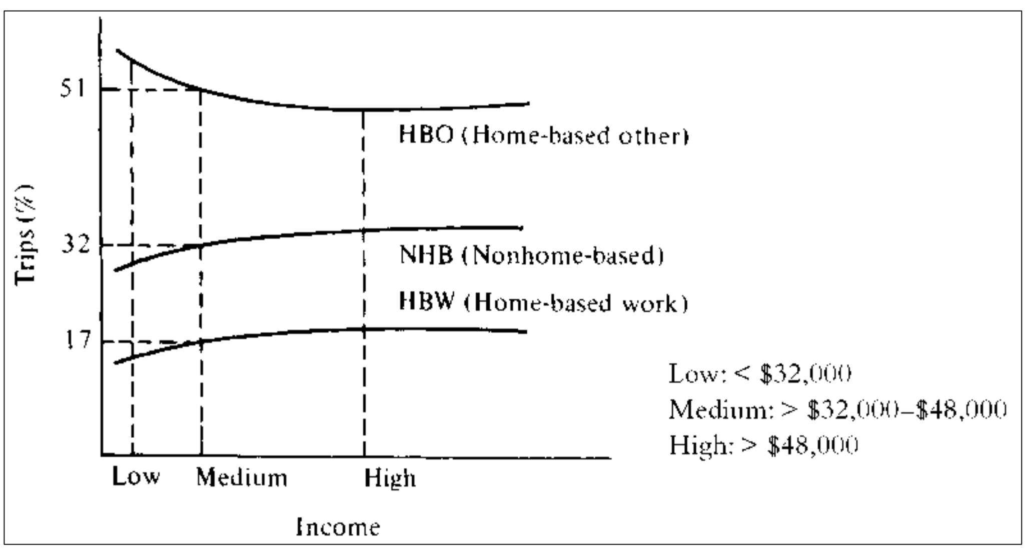
Cross – Classification

Solution of Example No.1:



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Cross – Classification

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

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Cross – Classification

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

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

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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

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

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

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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

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

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Cross – Classification

Solution of Example No.1:

Step 2: Plot ***Average*** Trips per Household versus Income and Car Ownership

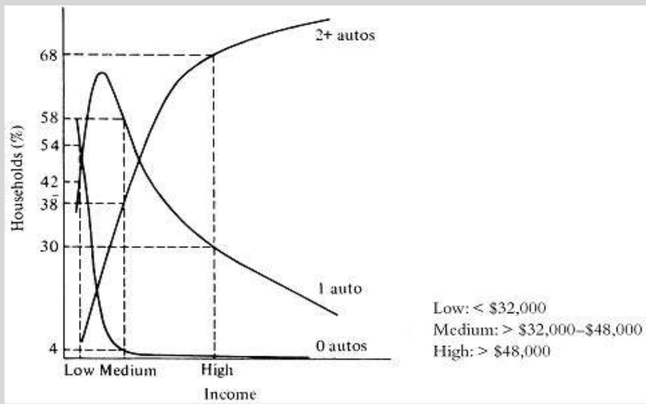
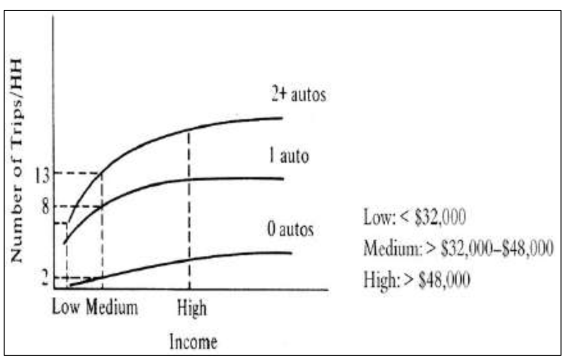


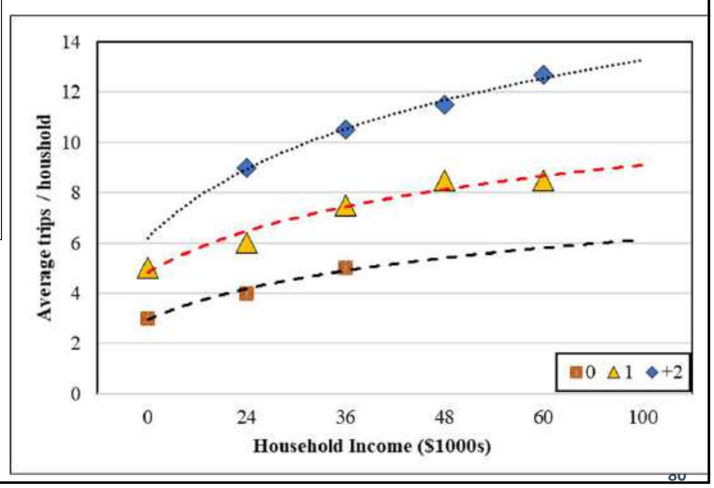
Figure 12.3 Households by Automobile Ownership and Income Category

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:

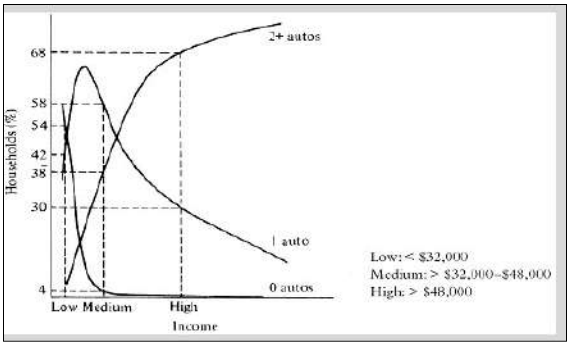


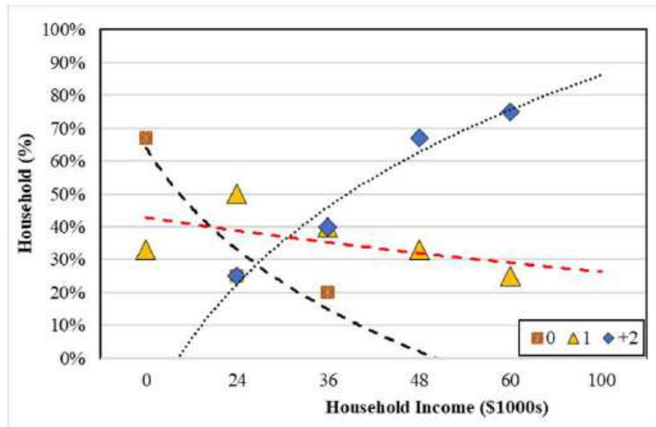


SOURCE: Modified from *Computer Programs for Urban Transportation Planning*, U.S. Department of Transportation, Washington, D.C., April 1977

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

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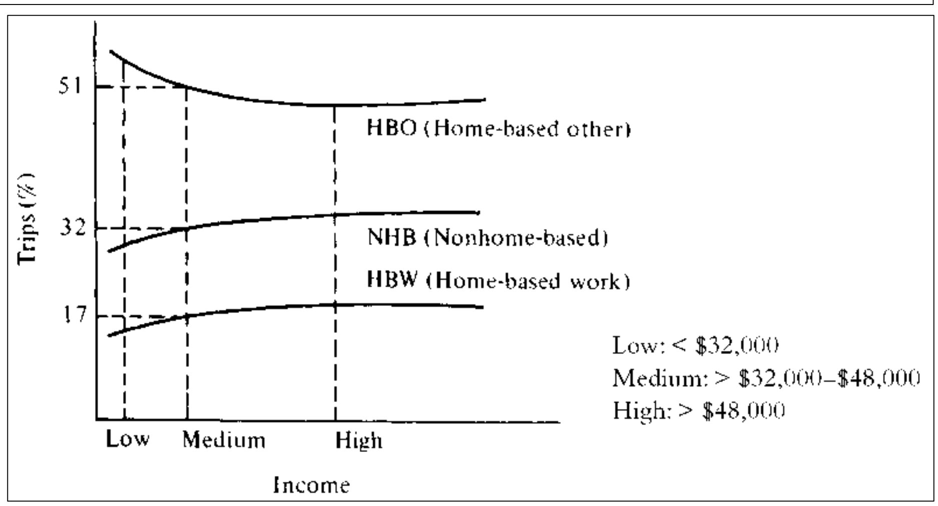
Cross – Classification

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

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Cross – Classification

Example No .2 : Computing Trips Generated in a Suburban Zone

Cross – Classification

Example No .2 : Computing Trips Generated in a Suburban Zone

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

Cross – Classification

Solution of Example No .2

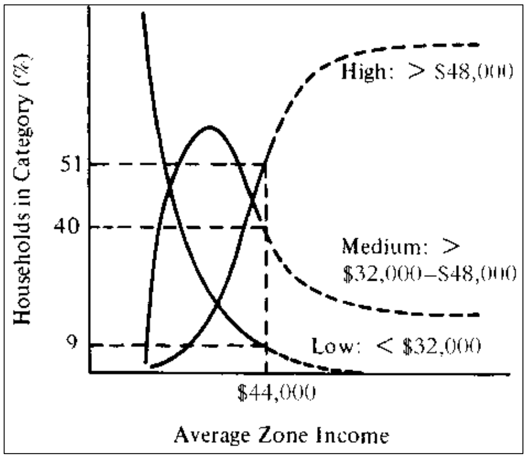

Figure 12.2

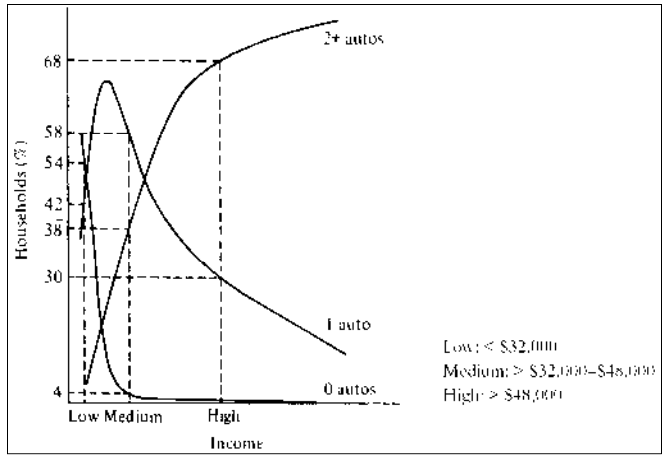

Figure 12.3

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Cross – Classification

Solution of Example No .2

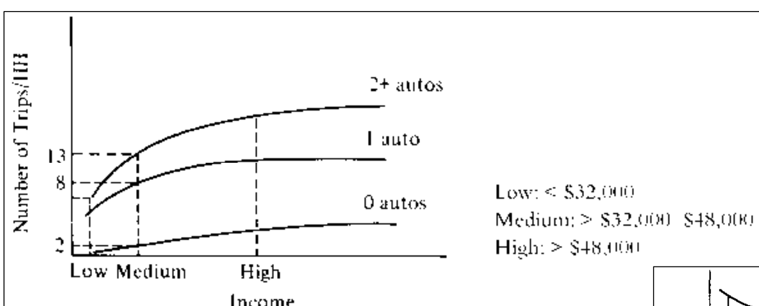
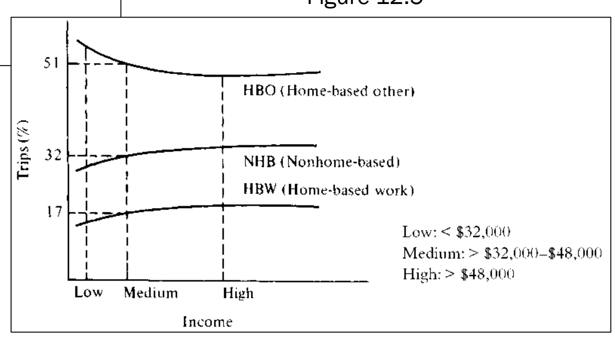


Figure 12.4

Figure 12.5



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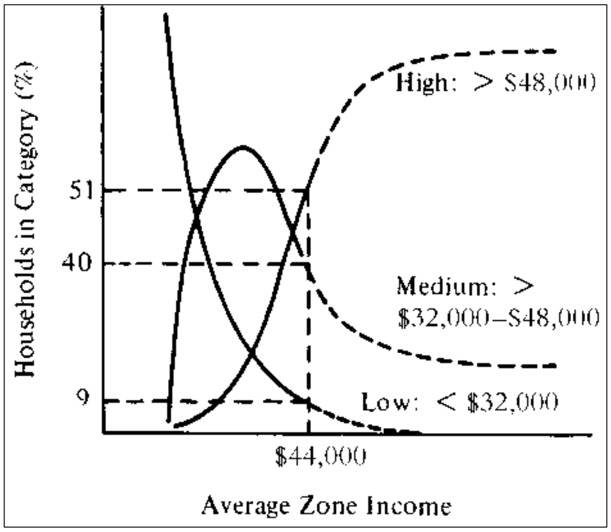
Cross – Classification

Solution of Example No .2

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

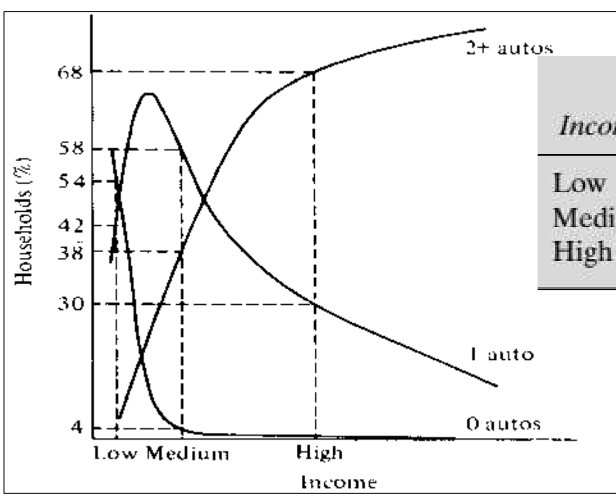


Income ($)	*Households (%)*
Low (under 32,000)	9
Medium (32,000 – 48,000)	40
High (over 48,000)	51

Cross – Classification

Solution of Example No .2

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

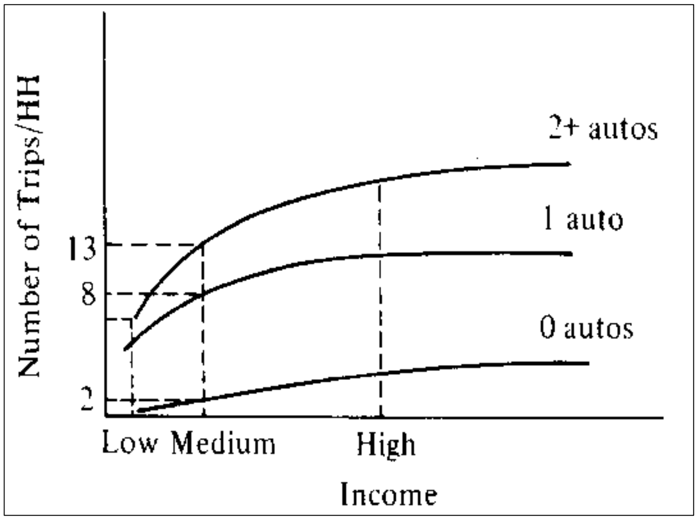


	Autos/Household		
Income	*0*	*1*	*2+*
Low	54	42	4
Medium	4	58	38
High	2	30	68

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.

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, 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

Cross – Classification

Example No .2 : Computing Trips Generated in a Suburban Zone

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

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

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

Where

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

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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

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

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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 × 0.17 = 40 HBW, 232 × 0.51 = 118 HBO, and 232 × 0.32 = 74 NHB. (Similar calculations would be made for other income groups.) The final result, which is left for the reader to verify, is obtained by using the following percentages: low income at 15, 55, and 30, and high income at 18, 48, and 34. These yield 118 HBW, 327 HBO, and 221 NHB trips.

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Reading Assignment

Estimation of Trip Generation Rates for Residential Areas in Jordan

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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.

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Reading Assignment

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 HBO	Zero NHB	One HBO	One NHB	Two+ HBO	Two+ 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

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Reading Ass

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 HBW	Zero HBO	Zero NHB	One HBW	One HBO	One NHB	Two+ HBW	Two+ HBO	Two+ 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.

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Reading Assignment

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.

Reading Assignmentz

Part 2:

The following cross-classification data have been developed for Jeffersonville Transportation study area:

($) Income	*HH (%)* High	Med	Low	*Autos/HH (%)* 0	1	2	3	*Trip Rate/Auto* 0	1	2	3+	*Trips (%)* HBW	HBO	NHB
10	0	30	70	48	48	4	0	2.0	6.0	11.5	17.0	38	34	28
20	0	50	50	4	72	24	0	2.5	7.5	12.5	17.5	38	34	28
30	10	70	20	2	53	40	5	4.0	9.0	14.0	19.0	35	34	31
40	20	75	5	1	32	52	15	5.5	10.5	15.5	20.5	27	35	38
50	50	50	0	0	19	56	25	7.5	12.0	17.0	22.0	20	37	43
60	70	30	0	0	10	60	30	8.0	13.0	18.0	23.0	16	40	44

Develop the family of cross-classification curves and determine the number of trips produced (by purpose) for a traffic zone containing 500 houses with an average household income of $35,000. (Use high 55,000; medium 25,000; low 15,000)

Trip generation

by Trip types

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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*

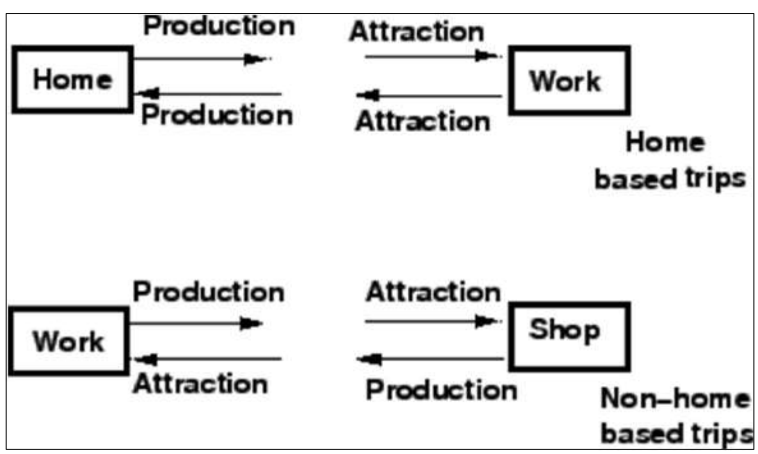


Image source: https://www.civil.iitb.ac.in/~vmtom/1100_LnTse/203_lnTse/plain/

100

100

Trip generation

Trip types

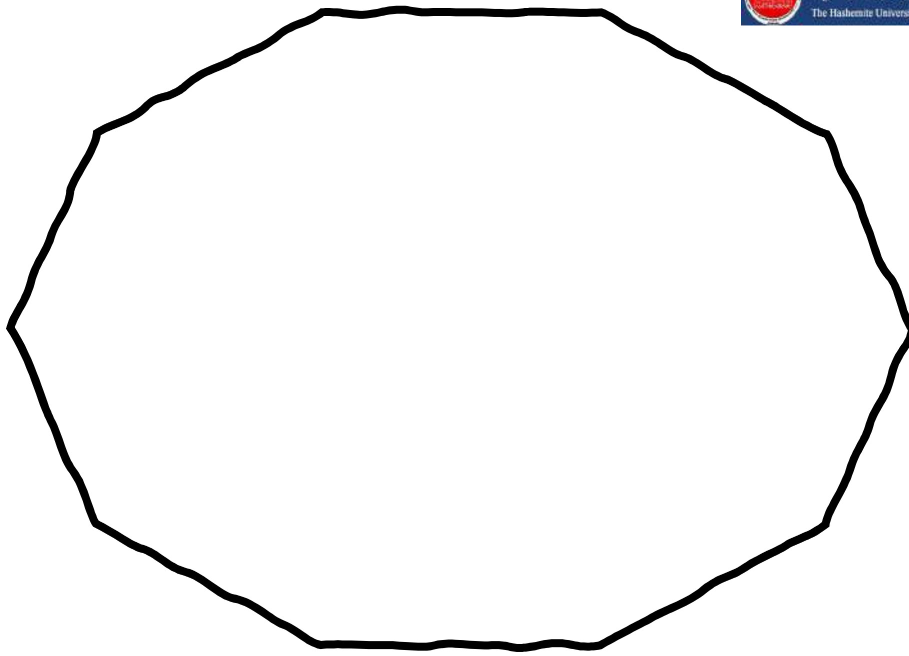
- Attracted (T_a) trips
  - T_a *is function with land use*
- Produced (T_p) trips?
  - T_p *is function with*
    - Population
    - Income
    - Household size
    - Number of household size
    - Vehicle owned

Trip generation

TRIP PURPOSE	MODEL TYPE	INDEPENDENT VARIABLES	REGRESSION	R^2
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

Example



Study area

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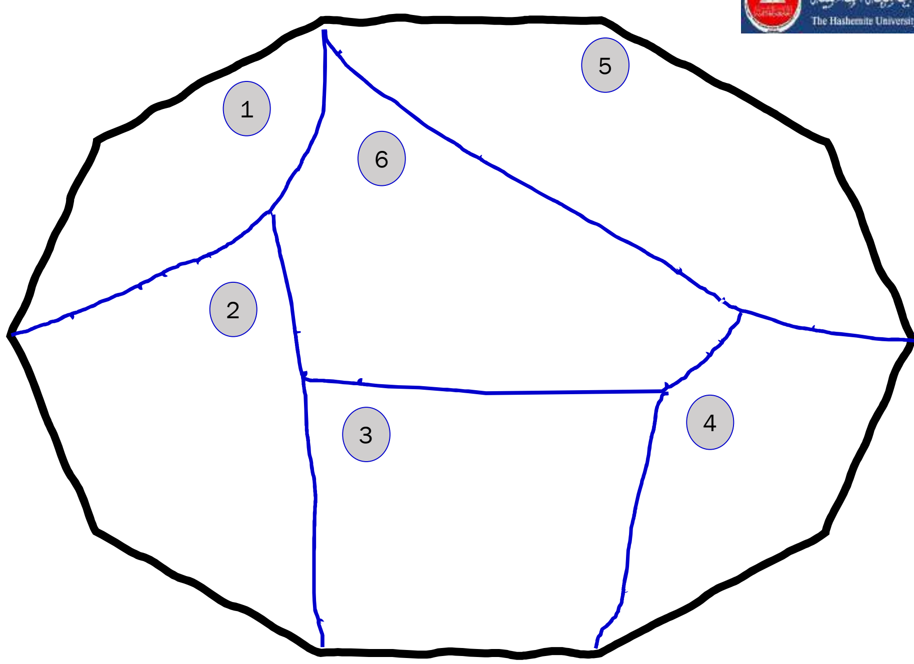
Example



Zoning

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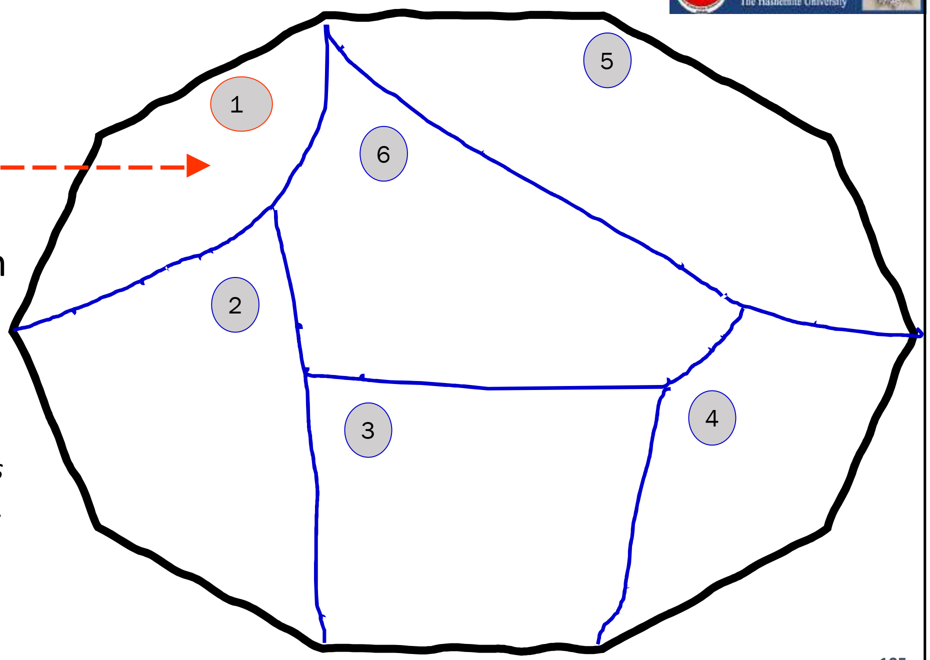
Example

Attracted trips

The land use within
Zone 1 are

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



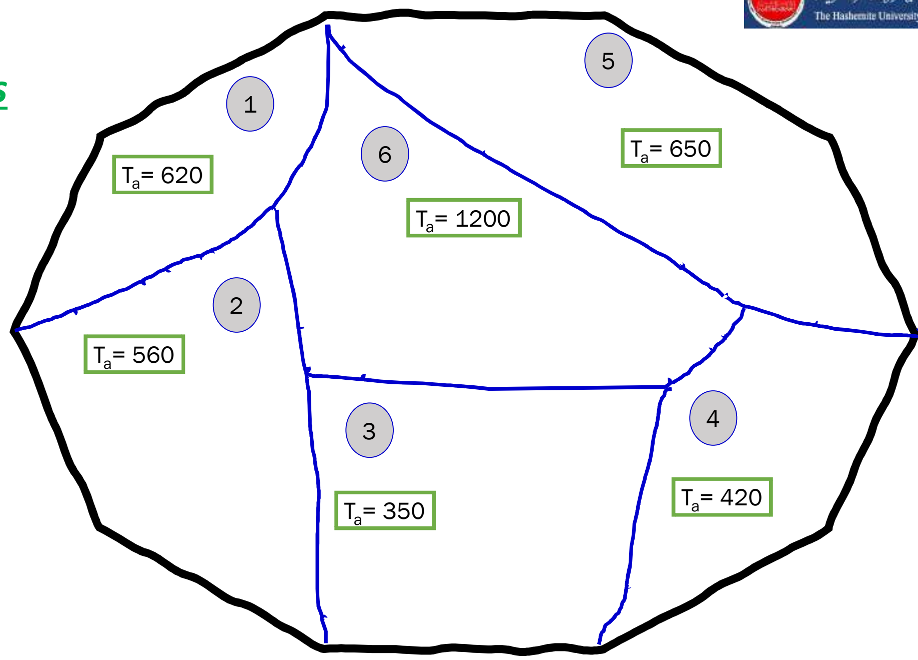
Example

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)			626

Example

Attracted trips



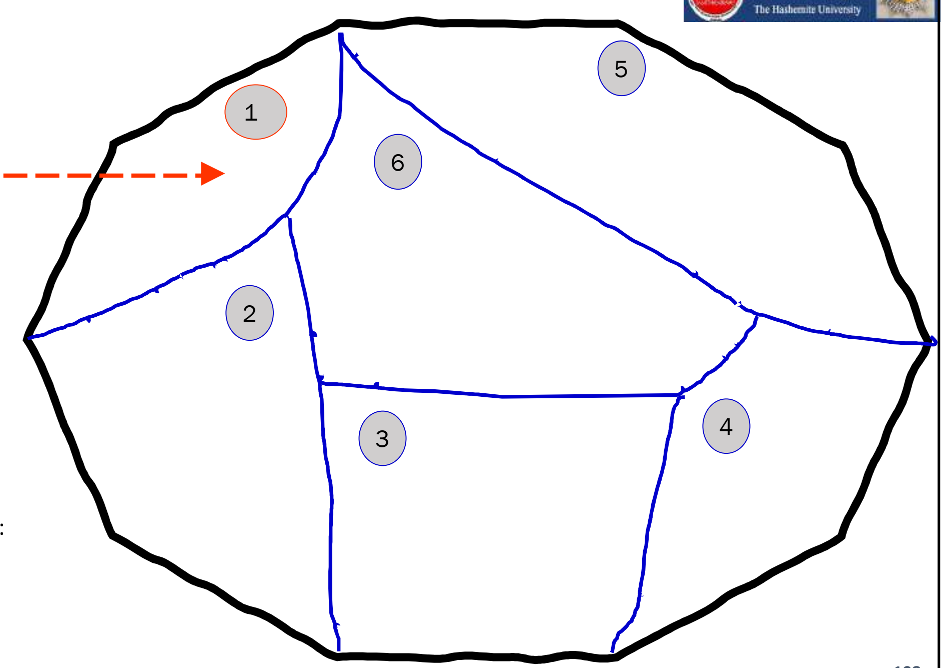
Example

Produced Trips

The land use within

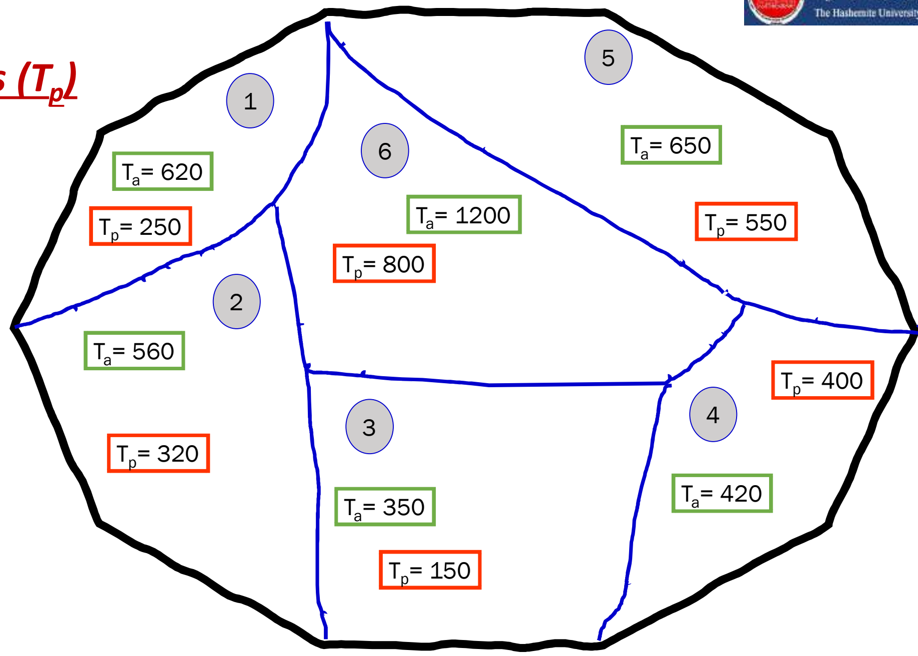
Zone 1 are

- *Number of dwelling units: 60*
- *Average income per dwelling unit: $44,000*
  - See example - 6 : Computing Trips Generated in a Suburban Zone



Example

Produced trips (T_p)



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

Balancing Trip Productions and Attraction

Example No.1 : Balancing the Home-based trips

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*

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

Balancing Trip Productions and Attraction

Solution of Example No.1

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

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

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

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

=(240*0.75)= 180

Balancing Trip Productions and Attraction

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

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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

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

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Balancing Trip Productions and Attraction

Solution of Example No.2

- $Trip\ correction\ factor = \frac{Total\ Unbalanced\ PRODUCTIONtrips}{Total\ Unbalanced\ attrachtion\ \ trips}$
- $Trip\ correction\ factor = \frac{600}{800} = 0.75$

Table 12.8b Balancing Non-Home-Based Trips

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

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

	Unbalanced NHB Trips		*Balanced NHB Trips*	
Zone	*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*0.75)= 180

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

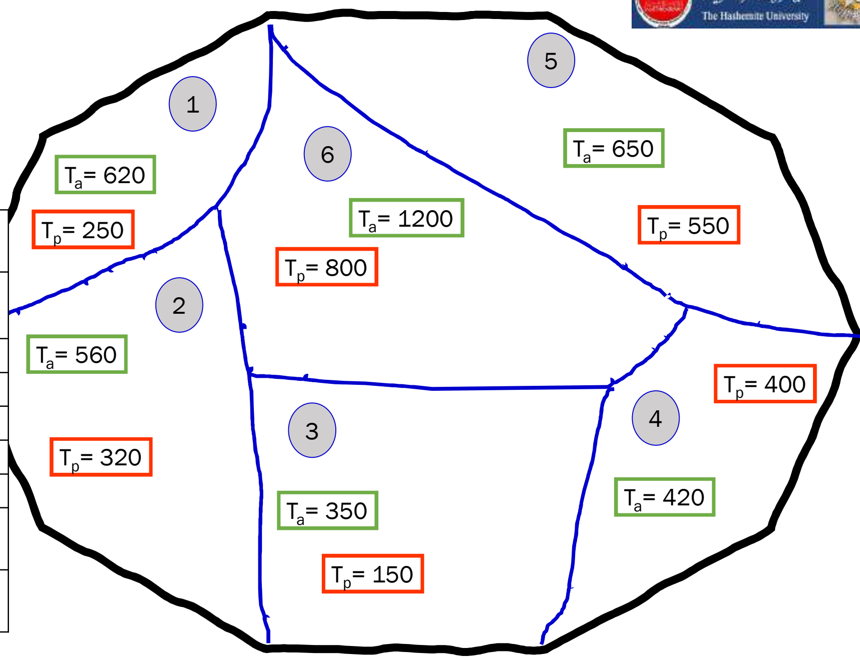
	Unbalanced NHB Trips		*Balanced NHB Trips*	
Zone	*NHB Productions*	*NHB Attractions*	*NHB Productions*	*NHB Attractions*
1	100	240	180	180
2	200	400	300	300
3	300	160	120	120
Total	600	800	600	600

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

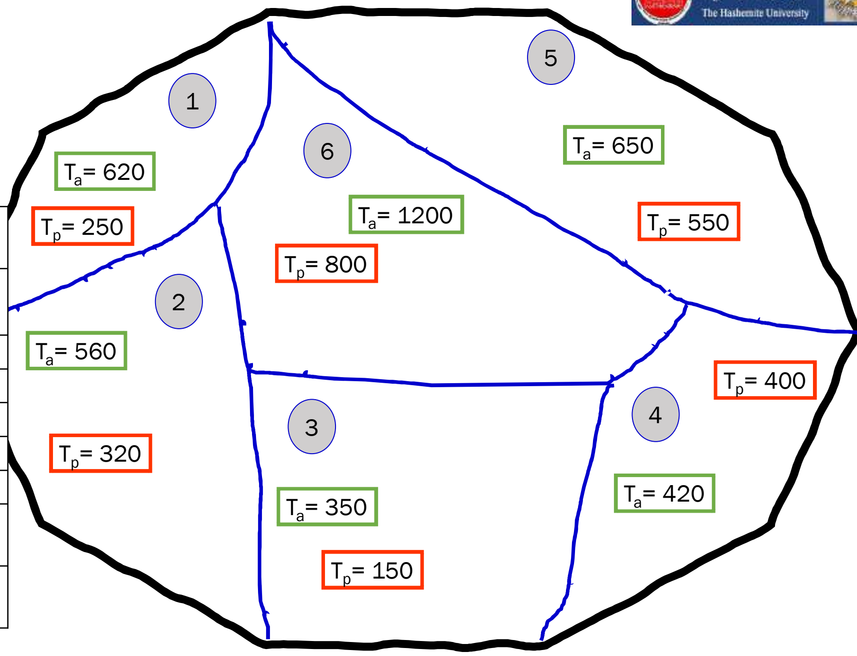
$$Trip\ correction\ factor = \frac{Total\ Unbalanced\ production\ trips}{Total\ Unbalanced\ attractions\ trips}$$

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

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	2470	3800	2470	2470

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



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TRANSPORTATION ENGINEERING AND PLANNING (110 401367)

Spring 2021-2022

Module No. 4

4.2 _ Trip Distribution

Dr. Hamza 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 tsransportation	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

2

Travel Forecasting Process

Trip Distribution

3

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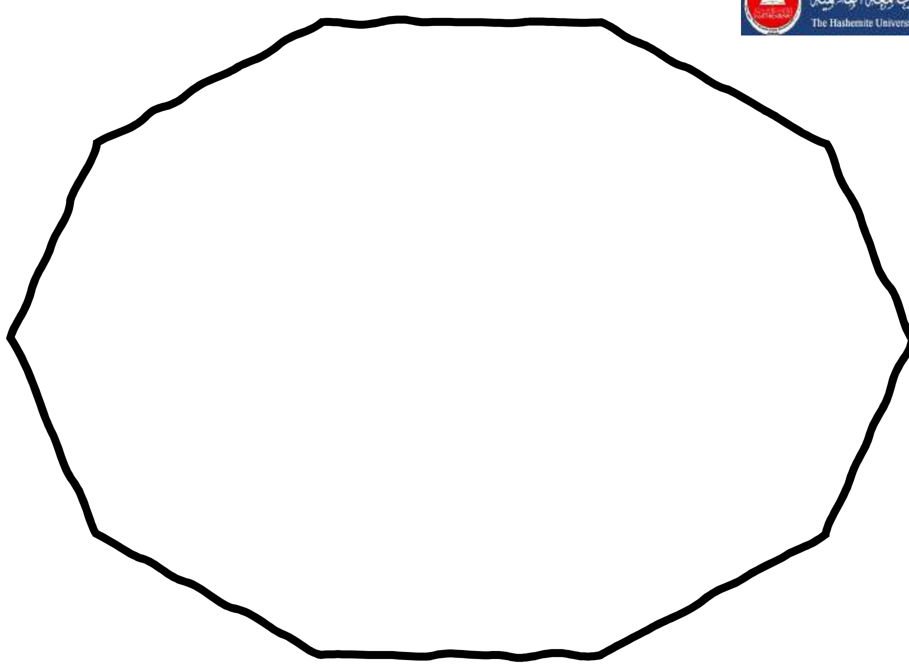
Review

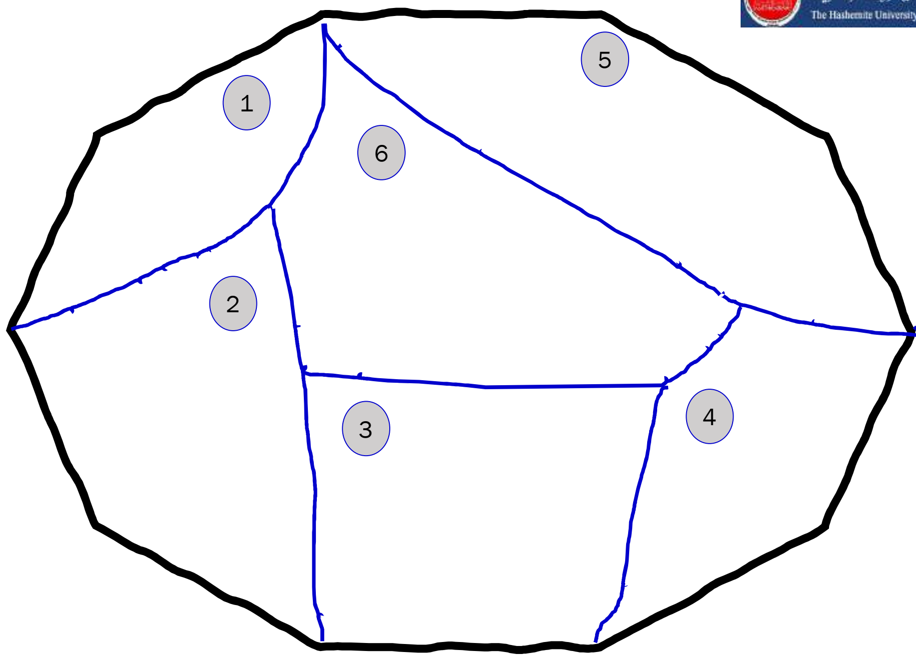


<u>Study area</u>

4

4

Review



Zoning

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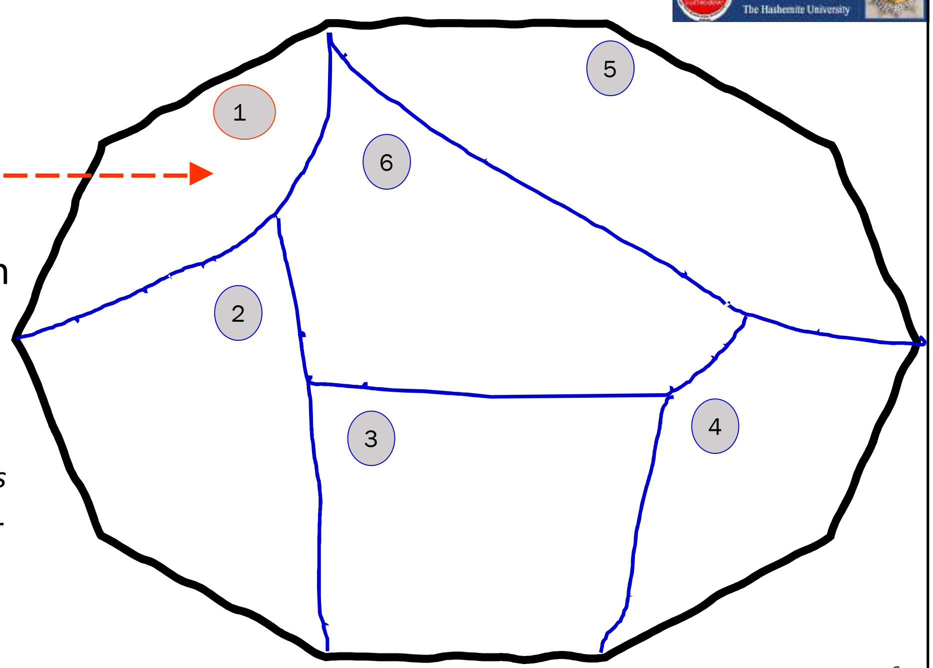
Review

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

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)			626

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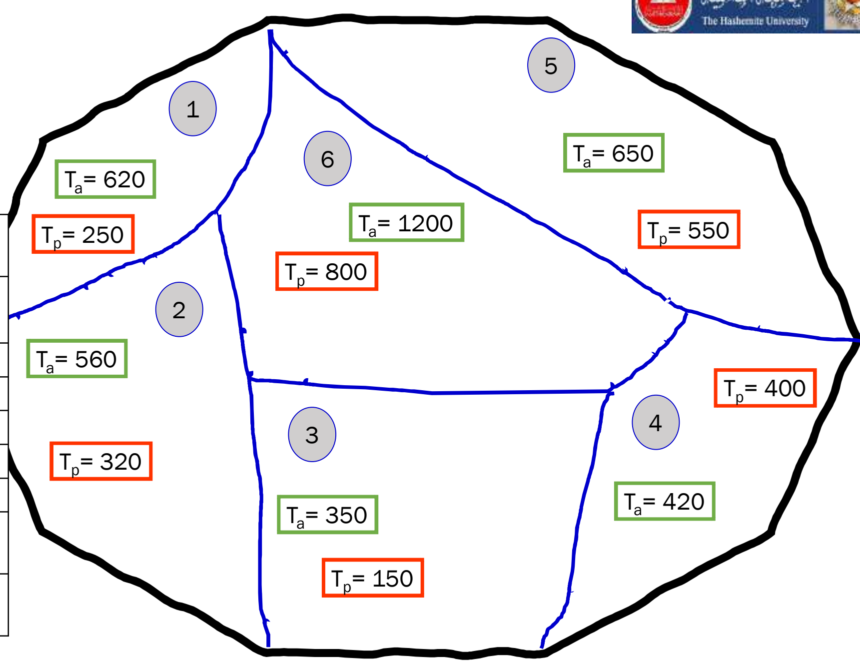
Review

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



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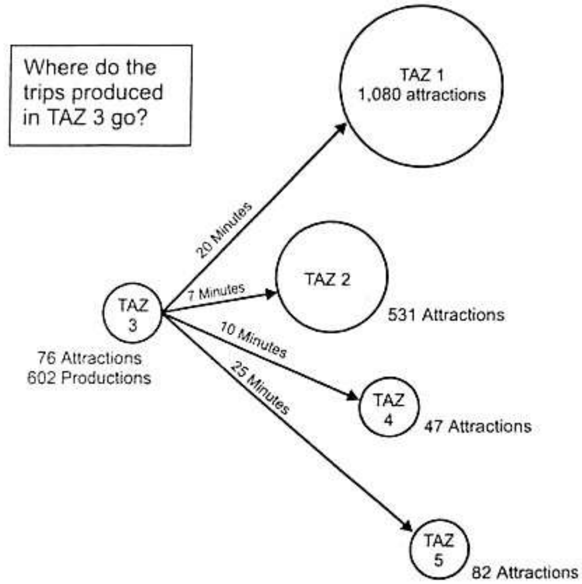
Review

Travel Forecasting Process

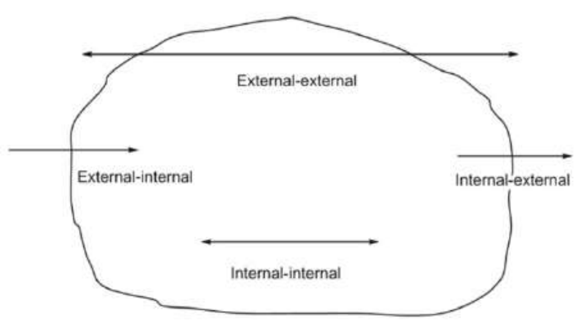
- Four-step process"
  - *Trip generation*
    - How many trips
  - *Trip distribution*
    - From where to where
  - *Modal choice*
    - On what mode
  - *Traffic assignment*
    - On what route

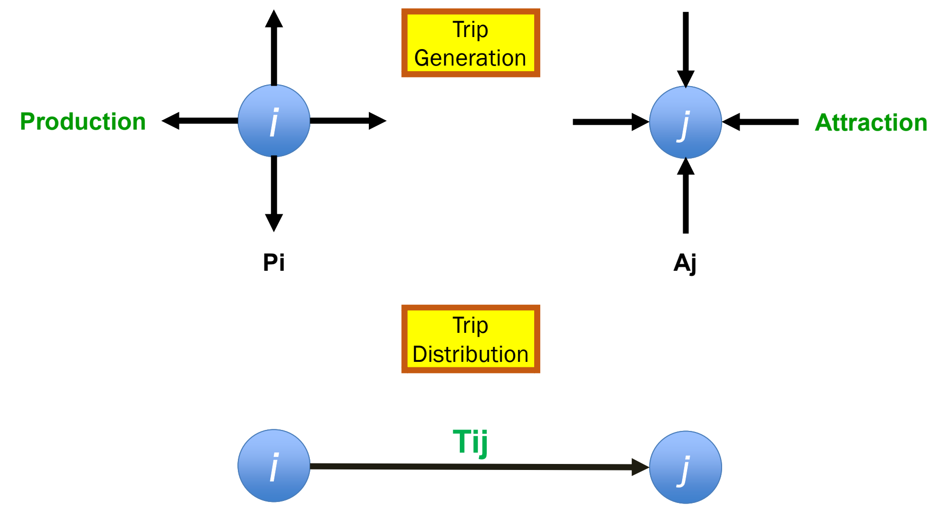


Trip Distribution

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





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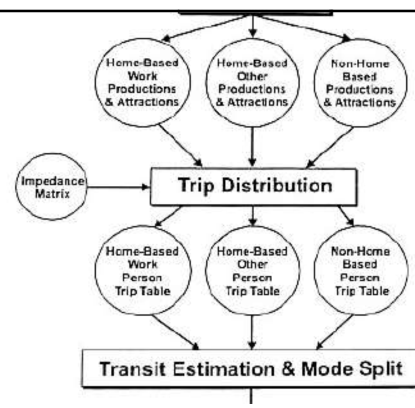
Trip Distribution

- 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	

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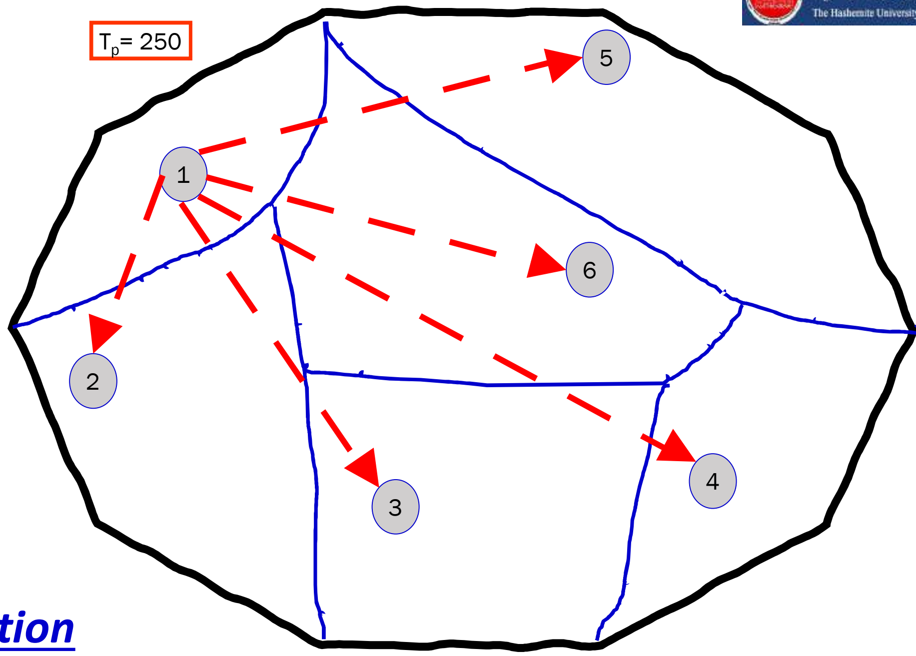
Example



Trip distribution

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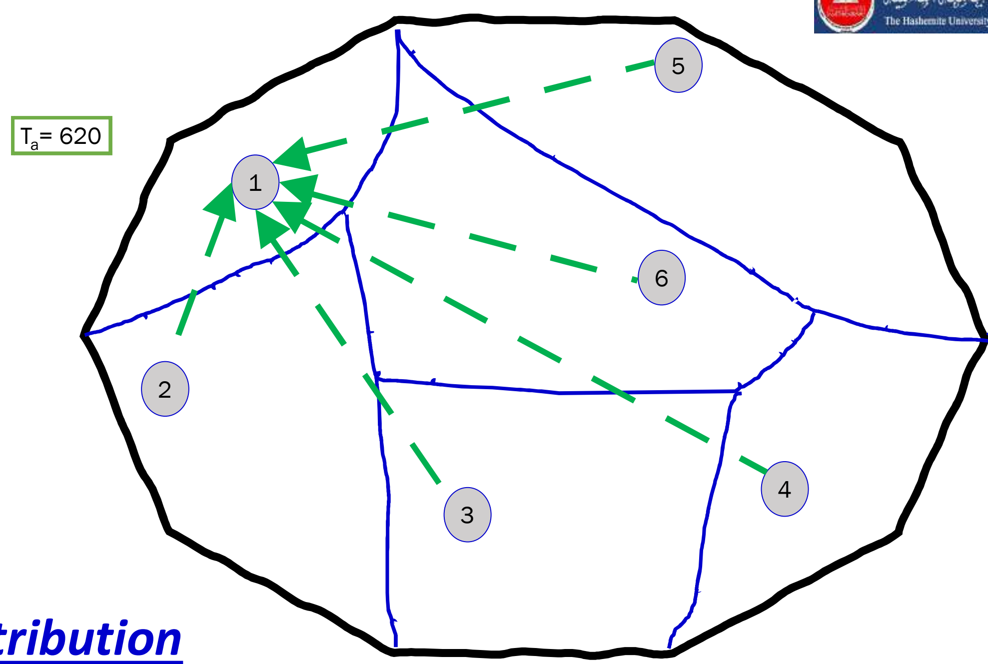
Example



Trip distribution

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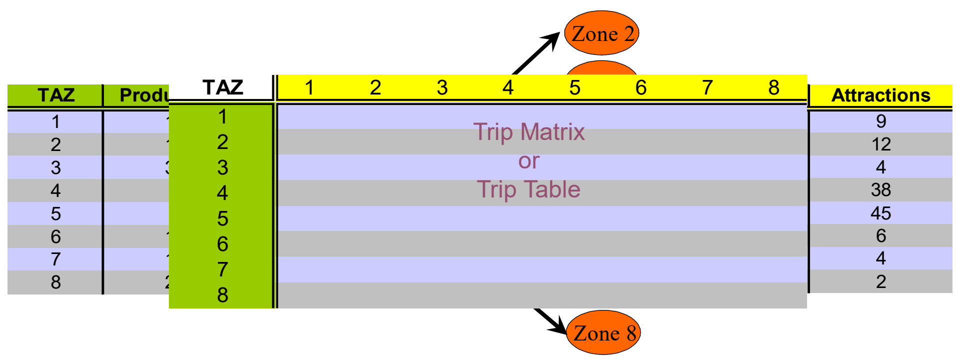
Trip Generation → Trip Distribution

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



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Basic Assumptions of Trip Distribution

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

Trip Distribution Lecture 8 Norman W. Garrick and Hamed Ahangari - ppt download (slideplayer.com)

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Trip Distribution

Methods

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

Trip Distribution Models

Gravity model

The Inspiration for the Gravity Model

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

$$F = k \frac{M_1 M_2}{r^2}$$

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

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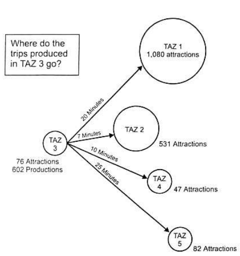
Gravity Model

Definition

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



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

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

Gravity Model Equation

$$\text{Trips}_{ij} = \text{Productions}_i \times \frac{\text{Attractions}_j \times FF_{ij} \times K_{ij}}{\Sigma\ \text{Attractions}_j \times FF_{ij} \times K_{ij}}$$

Where:

Trips_{ij}	Trips between TAZs i and j
Productions_i	Productions from TAZ i
Attractions_j	Attractions to TAZ j
Friction Factor (FF_{ij})	Friction factor for TAZs i and j
Socioeconomic factor (K_{ij})	Socioeconomic factor for TAZs i and j

i=production TAZ
j=attraction TAZ

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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 Pi for **all zones** must equal the sum of Aj 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*

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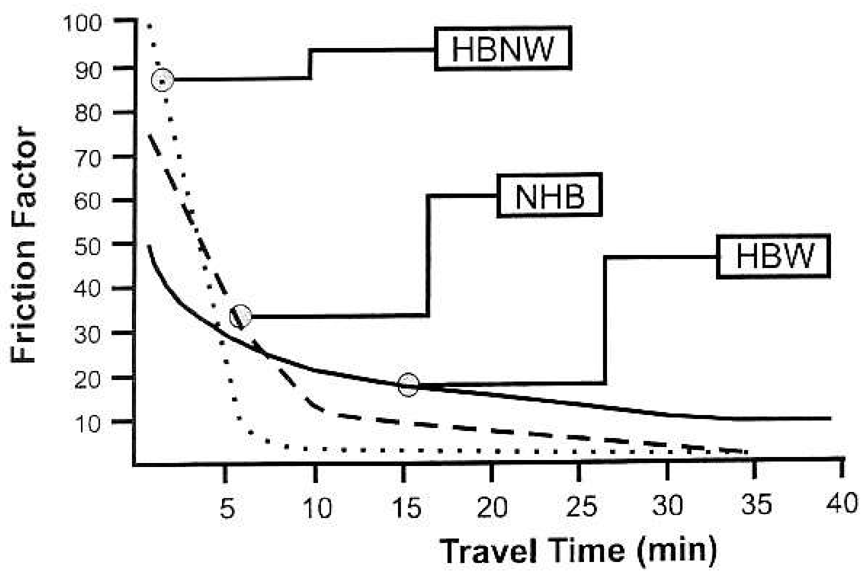
Trip Distribution

F values for calibration



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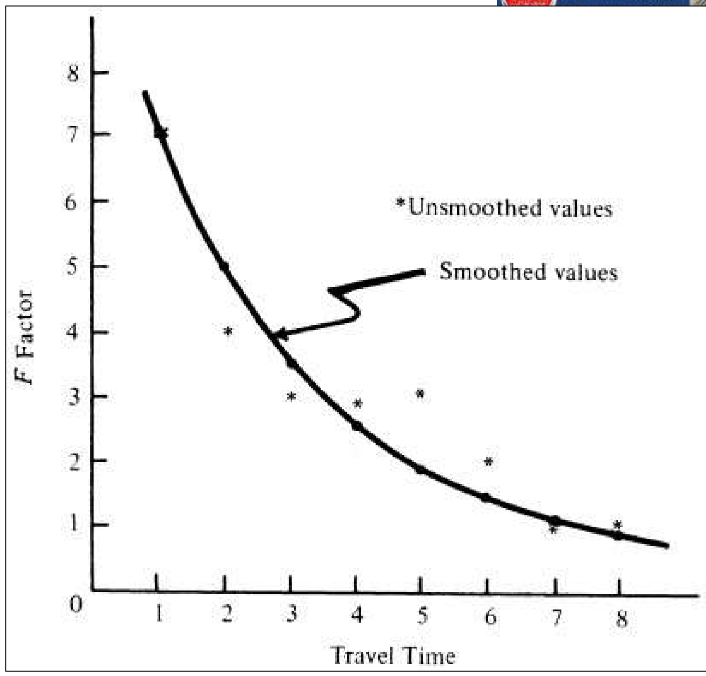
Trip Distribution

F values for calibration

- Figure 12.7 illustrates F values for calibrations of a gravity model. (

$$F = a \times b^{t} \times e^{-c}$$

where parameters a, b, and c are based on national data sources, such as NCHRP Report 365, or the formula may be calibrated using local data.



Gravity Model

Calibrating process for F factor

- After each distribution process is completed,
  - The percentage of trips in each trip length category produced by the gravity model is ***compared*** with the percentage of trips recorded in the O-D survey.
  - If the percentages **do not agree**, then
    - The F_{ij} factors that were used in the distribution process are **adjusted**
    - Another gravity model trip distribution is performed.
    - The calibration process is continued until the trip length percentages are in agreement.

Trip Distribution

Example No. 1

Calculate the Attractiveness of Each Zone

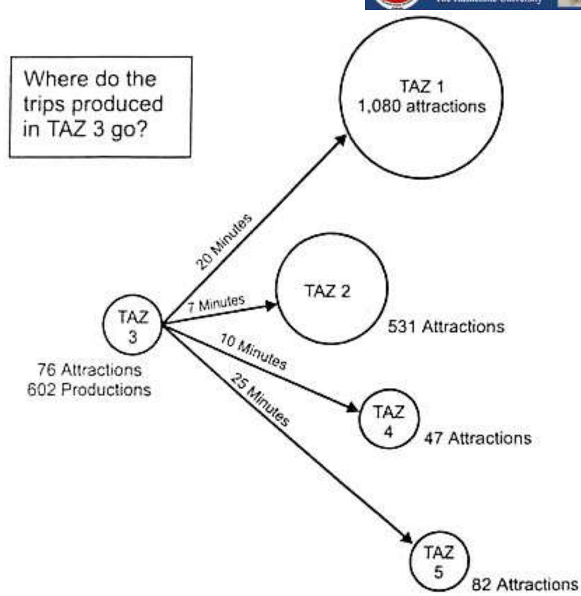
From Trip Generation:

HBW Productions and Attractions

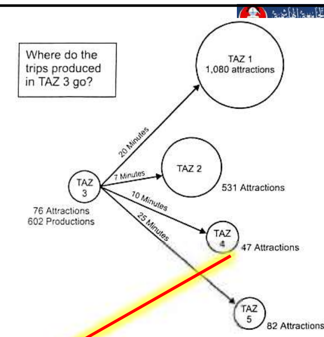
TAZ	Productions	Attractions
1	234	**1080**
2	76	**531**
3	**602**	**76**
4	432	**47**
5	472	**82**

HBW Friction Factors

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



Calculate the Attractiveness of Each Zone



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

i = production TAZ
j = attraction TAZ

Attraction TAZ→	1	2	3	4	5
# Attractions (A_j)	1,080	531	76	47	82
Friction Factor (FF_{ij})	6	29	45	18	4
Attractiveness (A_j * 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

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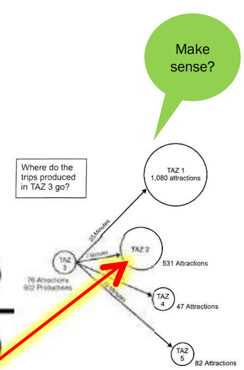
Calculate the Relative Attractiveness of Each Zone



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

Attraction TAZ→	1	2	3	4	5	Sum of Attractiveness
Attractiveness ($A_j \times FF_{ij}$)	6,480	15,399	3,420	846	328	26,473
Relative Attractiveness $\frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$	6,480/ 26,473 or 0.2448	0.5817	0.1292	0.0319	0.0124	1.0000

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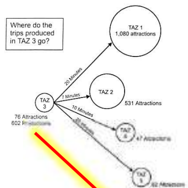
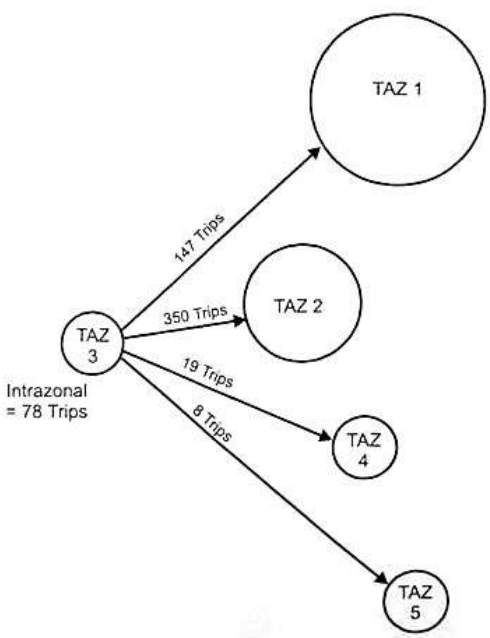
Distribute Productions to TAZs



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

TAZ	Productions from TAZ 3 $P_3 = 602$	Relative Attractiveness $\frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$	Distributed Trips $P_i \times \frac{(A_j \times FF_{ij})}{\sum (A_j \times FF_{ij})}$
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**
Total		**1.000**	**602**

First Iteration Distribution



HBW Trip Table
Attraction End

Production 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

Trip Distribution

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

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

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
Total	750	750

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

Orange cells are internal-internal green cell are internal-external

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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

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

F factor (F_{ij})

Zone	Zone 1	Zone 2	Zone 3
1	39	52	50
2	52	26	26
3	50	26	39

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

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

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

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

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

Solution of Example -1 (Example 12.4)

Use of Calibrated *F* Values and Iteration

Step -5: Solve

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

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

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

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

$$P_1 = 140$$

Make similar calculations for zones 2 and 3.

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

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

Zone	Balanced Trip	
	Production(P_i)	Attraction (A_i)
1	140	300
2	330	270
3	280	180
Total	750	750

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

i and j are zones number

n is total number of zones

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

T_{2-3} → $i=2$, $j=3$, $n=3$

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

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

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

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

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

$= 56.5 \approx 57$

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T_{2-3} → $i=2$, $j=3$, $n=3$

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

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

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

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

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

$= 56.5 \approx 57$

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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	144	68	68	280	280
Computed *A*	379	210	161	750	750
Given *A*	300	270	180	750	

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	144	68	68	280	280
Computed *A*	379	210	161	750	750
Given *A*	300	270	180	750	

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	144	68	68	280	280
Computed *A*	379	210	161	750	750
Given *A*	300	270	180	750	

Solution of Example -1 (Example 12.4)

- Step -6: Adjusted attraction trip factors

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

where

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

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

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

where

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

j is destination zone number
k is iteration number

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

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

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

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Solution of Example -1 (Example 12.4)

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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.

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

Zone	Balanced Trip		
	Production(P_i)	Attraction (A_j)	Adjusted Attraction (A_j) at k =2
1	140	300	237
2	330	270	347
3	280	180	201
Total	750	750	750

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

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

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

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.

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

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.

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	

Trip Distribution

Example No. 2 (Example 12.5) : Selecting Singly or Doubly Constrained Gravity Model Results

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.

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

Solution of Example -2 (Example 12.5)

Selecting Singly or Doubly Constrained Gravity Model Results

Table 12.14 Home-Based Shopping Productions and Attractions

Zone	*Productions*	*Attractions*
1	400	300
2	400	300
3	100	300
Total	900	900

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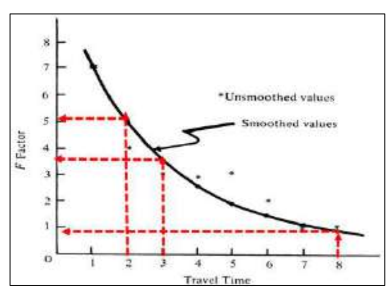
Solution of Example -2 (Example 12.5)

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



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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	59	29	12	100	100
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	33	33	33	100	100
Computed *A*	300	300	300	900	900
Given *A*	300	300	300	900	

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.

Trip Distribution Models

Growth Factor Model

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Growth Factor Assumptions

- Future travel pattern **would be the same as** the existing pattern
  - *distribution of future trips from an origin is a proportion of the present trip distribution*
- The growth factor models allow us to adjust future interchanges
- These models are is used when the available data is only
  - The origins and destinations between each zone for the current or base year.
  - The trip generation values for each zone for the future year.
- These models are used primarily to distribute trips between zones in the study area and zones in cities external to the study area.
- It cannot be used to forecast traffic between zones where no traffic currently exists.
- The only measure of travel friction is the amount of current travel.
  - *Cannot reflect changes in travel time between zones, as does the gravity model*

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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*

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Growth Factor Models

- The goal is then to estimate the matrix at some point in the future
  - *For example, what would the trip matrix look like in 2 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)

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Some of the More Popular Growth Factor Models

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

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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 τ = 1.2 (growth rate), then…

Trip Matrix, t (2013)

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

$T_{ij} = \tau\, t_{ij}$
$= (1.2)(5)$
$= 6$

Trip Matrix, T (2018)

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

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Growth Factor Models

Fratar method

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

- 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**

i is origin zone number
j is destination zone number

x are all zones in the study area except the origin zone i

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Trip Distribution

Example No. 3 (Example 12.6) :

Forecasting Trips Using the Fratar Model

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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.

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

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

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

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Present Trips between zone i and zone j (t_{ij})

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

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)*
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

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Growth Factor Models

Fratar method

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

- 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**

i is origin zone number
j is destination zone number

x are all zones in the study area except the origin zone i

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.

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

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

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

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

Similar calculations yield

$$\overline{T}_{AC} = 141 \qquad \overline{T}_{AD} = 124 \qquad \overline{T}_{BC} = 372 \qquad \overline{T}_{CD} = 430$$

⇒ Find the trips between Zone A and Zone B

step

① Trips from Zone A to Zone B

i = origin Zone ⇒ $i = A$

j = Distination Zone ⇒ $j = B$

x = All Zones except the origin Zone ⇒ $x = B, C,$ and D

$$\Rightarrow T_{ij} = t_i G_i * \frac{t_{ij} G_j}{\sum_x t_{ix} G_x}$$

$$\rightarrow T_{AB} = (t_A G_A) * \frac{t_{AB} G_B}{\sum_{x=B}^{x=D} t_{Ax} G_x}$$

$$\sum_{x=B}^{x=D} t_{Ax} G_x = \underbrace{t_{AB} G_B}_{\substack{i=A \\ x=B}} + \underbrace{t_{AC} G_C}_{\substack{i=A \\ x=C}} + \underbrace{t_{AD} G_D}_{\substack{i=A \\ x=D}}$$

$T_{AB} = \ldots$

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$$\rightarrow T_{AB} = (t_A G_A) * \frac{t_{AB} G_B}{\sum_{x=B}^{x=D} t_{Ax} G_x}$$

$$\sum_{x=B}^{x=D} t_{Ax} G_x = \underbrace{t_{AB} G_B}_{\substack{i=A \\ x=B}} + \underbrace{t_{AC} G_C}_{\substack{i=A \\ x=C}} + \underbrace{t_{AD} G_D}_{\substack{i=A \\ x=D}}$$

$$T_{AB} = t_A G_A * \frac{t_{AB} G_B}{t_{AB} G_B + t_{AC} G_C + t_{AD} G_D}$$

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

$$\Rightarrow \boxed{T_{AB} = 446}$$

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step

② Trips from Zone B to Zone A

$\dot{i}$ = origin Zone ⇒ $\dot{i} = B$

$\dot{j}$ = Distination Zone ⇒ $\dot{j} = A$

x = All Zones except the origin zone → $x = A$, C, and D

$$\Rightarrow T_{BA} = t_B G_B * \frac{t_{BA} G_A}{\sum_{x=A}^{x=D} t_{Bx} G_x}$$

$$\hookrightarrow = \underbrace{t_{BA}}_{\substack{i=B \\ x=A}} G_A + \underbrace{t_{BC}}_{\substack{i=A \\ x=C}} G_C + \underbrace{t_{BD}}_{\substack{i=B \\ x=D}} G_D$$

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$$\Rightarrow T_{BA} = t_B G_B * \frac{t_{BA} G_A}{\sum_{x=A}^{x=D} t_{Bx} G_x}$$

$$\hookrightarrow = \underbrace{t_{BA}}_{\substack{i=B \\ x=A}} G_A + \underbrace{t_{BC}}_{\substack{i=A \\ x=C}} G_C + \underbrace{t_{BD}}_{\substack{i=B \\ x=D}} G_D$$

$$T_{BA} = t_B G_B * \frac{t_{BA} G_A}{t_{BA} G_A + t_{BC} G_C + t_{BD} G_D}$$

$$= (700 * 1.1) * \frac{400 * 1.2}{400 \times 1.2 + (300 * 1.4) + (\cancel{0 * 1.3})}$$ Zero

$$= (700 * 1.1) * \frac{400 * 1.2}{400 * 1.2 + 300 * 1.4} = 446$$

$$\Rightarrow T_{BA} = 446$$

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step (3) Average trips between Zone A and Zone B ($\overline{T_{AB}}$)

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

$$\Rightarrow \boxed{\overline{T_{AB}} = 428}$$

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

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

Solution of Example No. 3 (Example 12.6) :

Forecasting Trips Using the Fratar Model

generation in zone A is estimated as 693 trips, whereas the actual value is 720 trips. Similarly, the estimate for zone B is 800 trips, whereas the actual value is 770 trips.

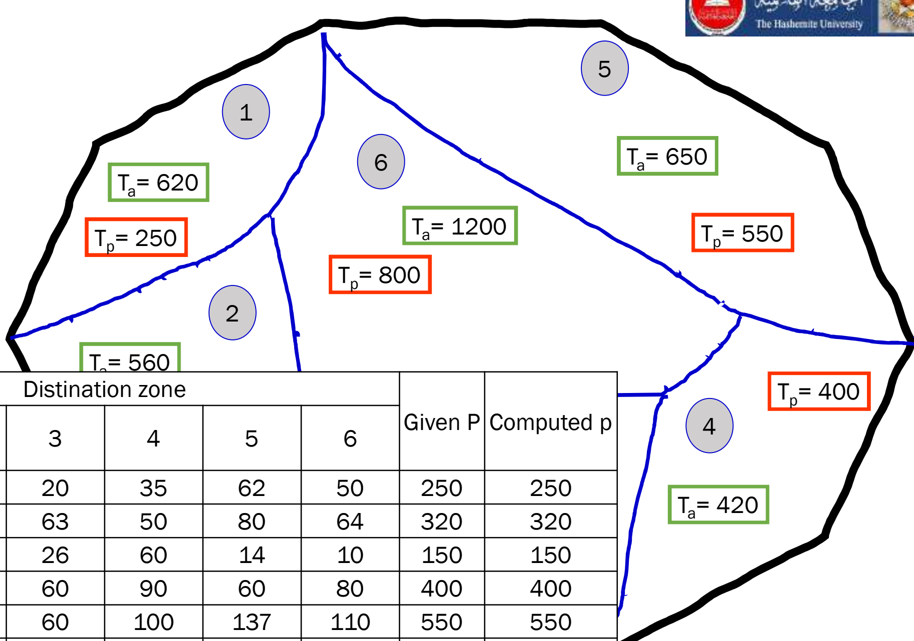
Proceed with a second iteration in which the input data are the numbers of trips between zones as previously calculated. Also, new growth factors are computed as the ratio of the trip generation expected to occur in five years and the trip generation estimated in the preceding calculation. The values are given in Table 12.20.

The calculations for the second iteration are left to the reader to complete and the process can be repeated as many times as needed until the estimate and actual trip generation values are close in agreement.

Table 12.20 Growth Factors for Second Iteration

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

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 (110 401367)

Spring 2021-2022

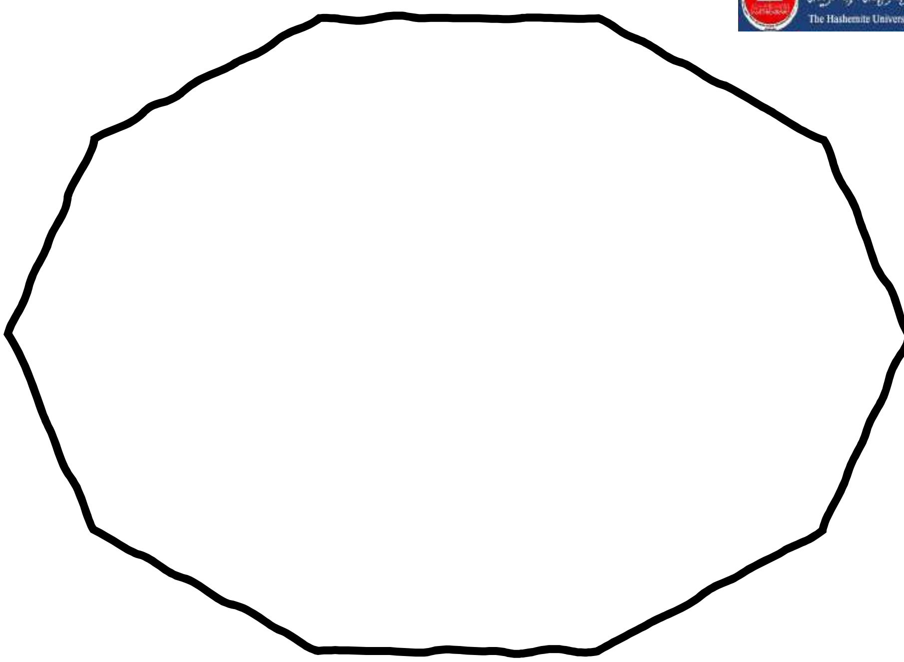
Module No. 4

4.3_ Mode Choice

Dr. Hamza Alkuime

1

Review

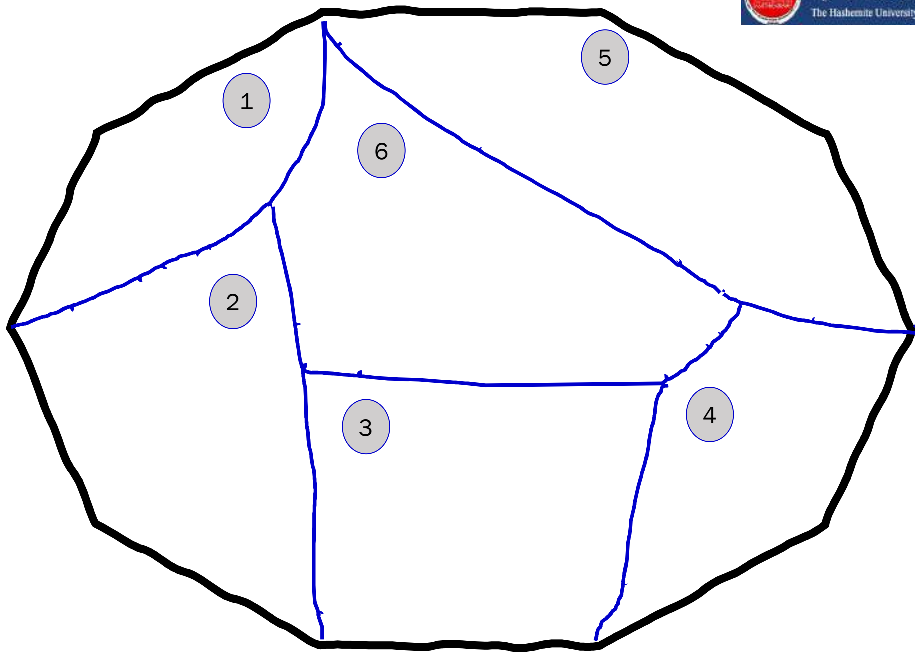


Study area

2

2

Review



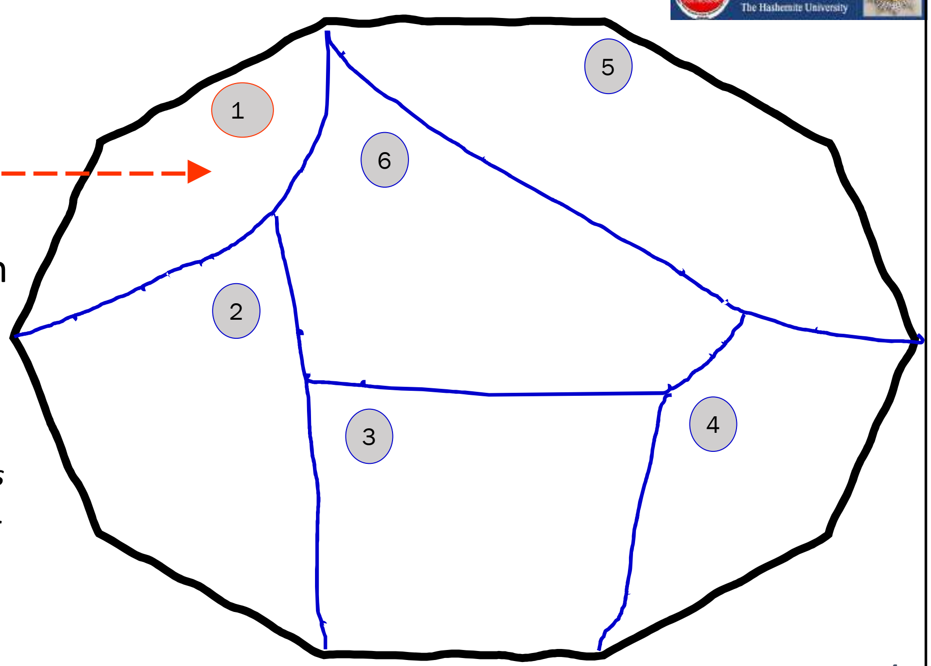
Zoning

Review

Attracted trips

The land use within
Zone 1 are

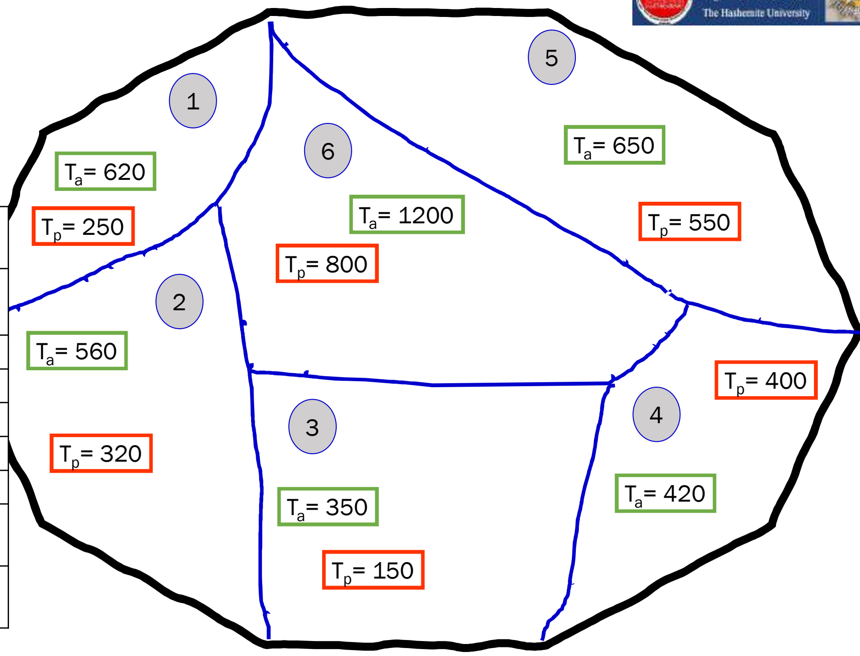
- *120 office space*
- *500 factory*
- *50 educational seats*
- *100 shopping center*



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



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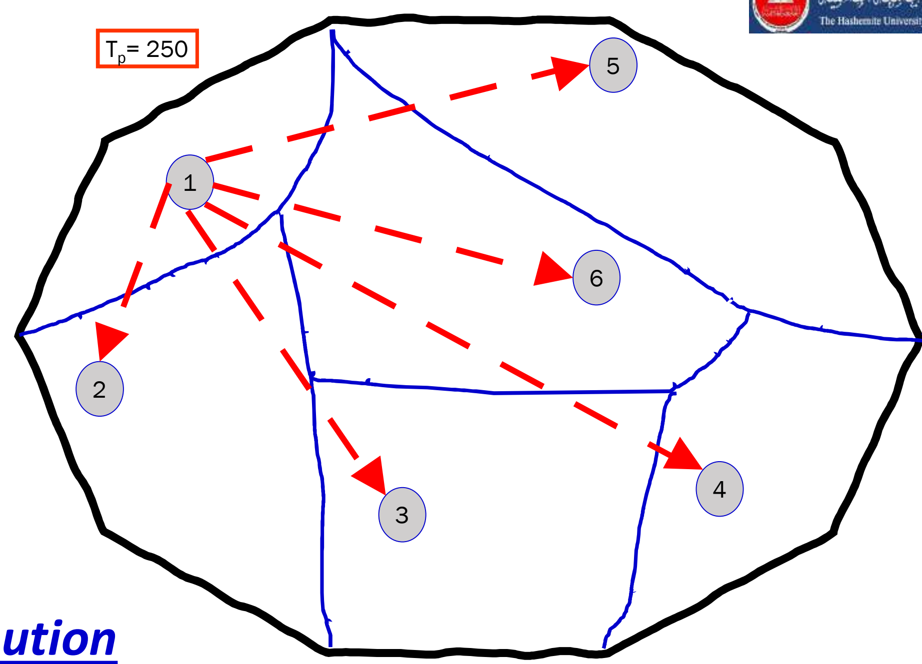
Review

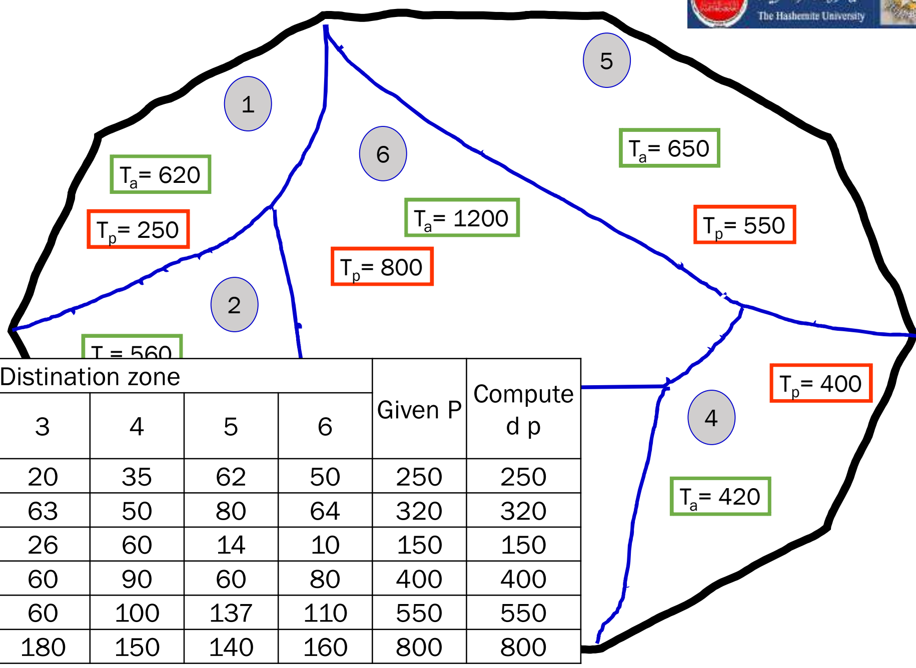


Trip distribution

6

6

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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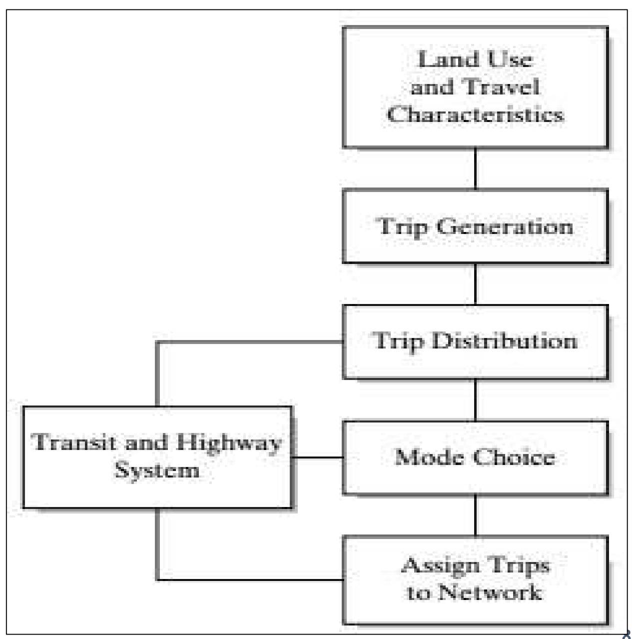
Review

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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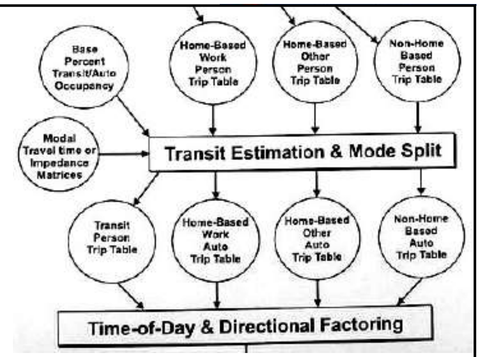
Mode Split

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:
  - *Trip characteristics*
    - length, time of day, purpose, …etc.
  - *Trip maker characteristics*
    - Income, auto ownership, employment, …etc.
  - *Transportation system characteristics*
    - Accessibility, parking, travel time, …etc.



Mode Choice

- Goal
  - *What modes these trips are taking ?*
  - *What influences the choice of mode ?*
    - Path that minimizes travel cost, time, distance, speed
- Inputs
  - *Origin- destination matrix*
- Output
  - *Mode wise Origin- destination matrix*

Generated trips

Origin zone	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%*

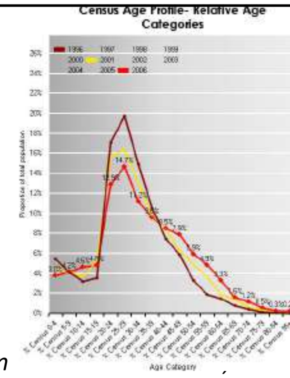
Trips by Car (41% of trip generated)

Origin zone	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

Trips by Bus (58% of trip generated)

Origin zone	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

Factors Affecting Mode Split



- ❑ Person/household characteristics
  - ❑ *Auto availability, income, HH size, life cycle*
- ❑ Trip characteristics
  - ❑ *Purpose, chaining, time of departure, OD, length*
- ❑ Land use characteristics
  - ❑ *Sidewalk/ped facilities, mix of uses at both ends, distance to transit, parking an density at both ends*
- ❑ Service characteristics
  - ❑ *Facility design (HOV, bikes), frequency, congestion, cost (parking, tolls, fares, out-of-pocket costs), stop spacing*

https://web.engr.uky.edu/~rsouley/CE%20451/LECTURES/Transit/Transit.ppt

12

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*

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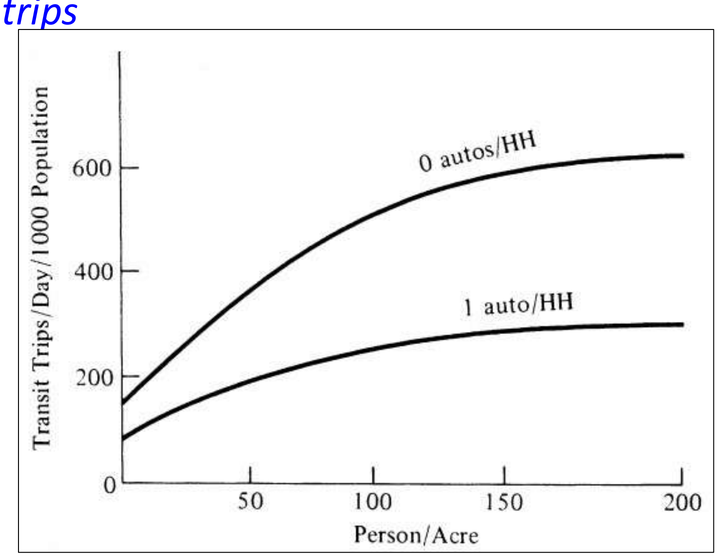
Mode Choice Models

1. Direct Generation of transit trips

Mode Choice

Direct Generation of transit trips

- Transit trips can be generated directly, by estimating either
  - *Total person trips*
  - *Total auto driver trips*
- This method assumes that the attributes of the system are not relevant.
- Factors such as travel time, cost, and convenience are not considered.



Mode Choice

Example No. 1 (Example 12.7): Estimating Mode Choice by Direct Trip Generation

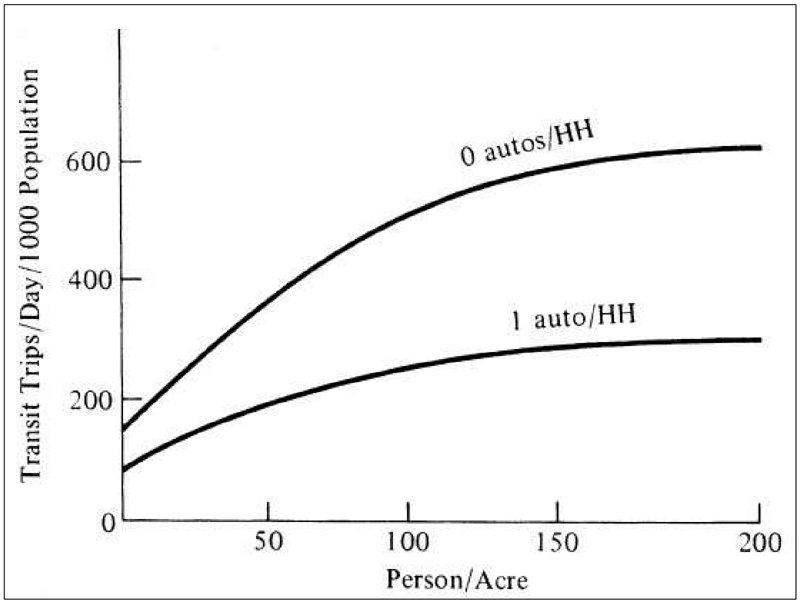
Example No.1 (Example 12.7):

Estimating Mode Choice by Direct Trip Generation

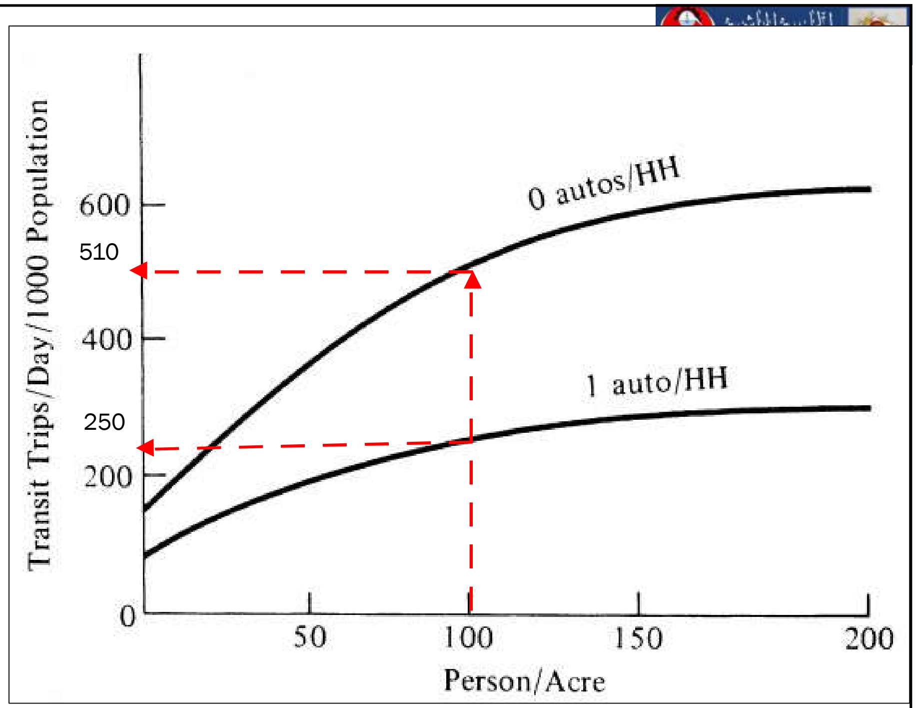
- Determine the number of transcit trips per day in a zone which has
  - ***5000 people*** *living on 50 acres.*
  - *Auto ownership is*
    - 40% of zero autos per household
    - 60% of one auto per household

Mode Choice

Direct Generation of transit trips



Solution of Example No. 1 (Example 12.7):



Solution of Example No. 1 (Example 12.7):

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

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

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

1020 + 750 = 1770 transit trips per day

Mode Choice Models

2.Trip End Models

Trip End Models

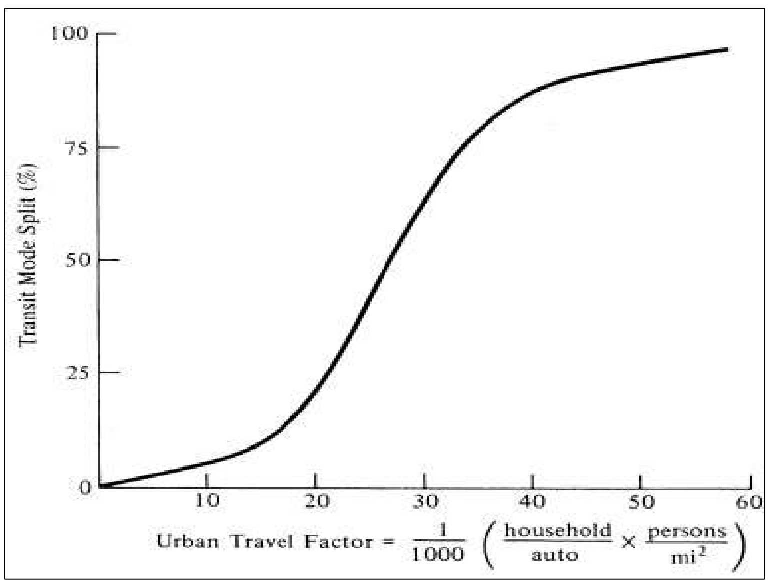
Definition

- To determine the % of total person or auto trips that will use a mode
- Estimates are made **prior** to the trip distribution phase based on:
  - *land-use or socioeconomic characteristics of the zone.*
- This method **does not** incorporate the quality of service.

Trip End Models

Procedures

1. Generate total person trip productions and attractions by trip purpose.
   - *Determined from trip generation step*
2. Compute the urban travel factor (UTF)
   - $UTF = \frac{1}{1000} \times \left(\frac{Houdhold}{auto}\right) \times \left(\frac{Person}{mi^2}\right)$
3. Determine the percentage of these trips by transit using a mode choice curve.
4. Apply auto occupancy factors.
5. Distribute transit and auto trips separately
   - *Using trip distribution process*



Trip End Models

Example No.1 (Example 12.8): Estimating Trip Productions by Transit

Trip End Models

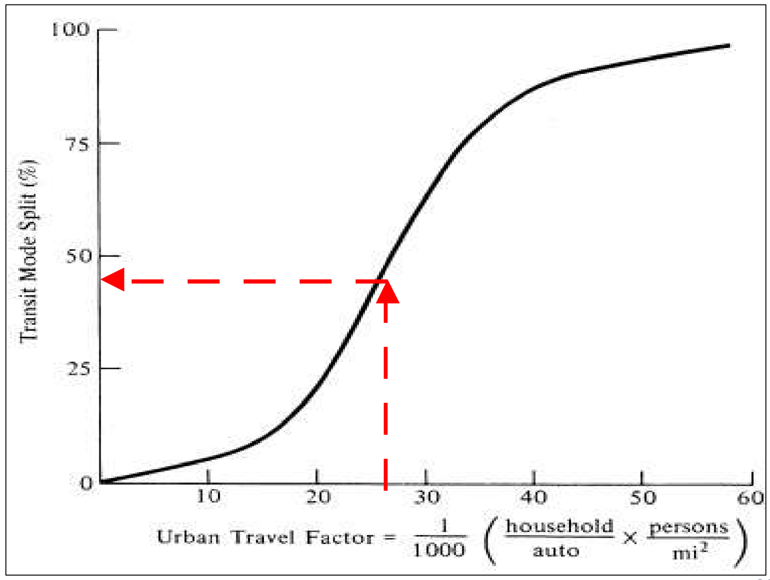
Example No. 1 (Example 12.8): : Estimating Trip Productions by Transit

- 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.

Trip End Models

Solution of Example No.1 (Example 12.8)

- Compute the urban travel factor (UTF)
  - $UTF = \frac{1}{1000} \times \left(\frac{Houdhold}{auto}\right) \times \left(\frac{Person}{mi^2}\right)$
  - $UTF = \frac{1}{1000} \times (1.8) \times (15000) =$ *27.0*
- Transit mode split = 45%.



Mode Choice Models

3. Trip Interchange Models

Mode Choice

Trip Interchange Models

- In this method estimates are made **after** the trip distribution
- In this method, system level-of-service variables are considered, including:
  - *Relative travel time*
  - *Relative travel cost*
  - *Economic status of the trip maker*
  - *Relative travel service.*
- An example of this procedure is illustrated using the **QRS** method which takes account of service parameters in estimating mode choice.

Trip Interchange Models

QRS method

- The QRS method is based on the following relationship

$$\mathrm{MS}_a = \frac{(I_{ijt})^b}{(I_{ija})^b + (I_{ijt})^b} \times 100$$

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

Trip Interchange Models

QRS method

$$MS_a = \frac{(I_{ijt})^b}{(I_{ija})^b + (I_{ijt})^b} \times 100$$

i is origin zone number
j is destination zone number
t for transit mode
a for auto mode

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

- MS_t = proportion of trips between zone *i* and zone *j* ***using transit***
- MS_a = proportion of trips between zone *i* and zone *j* ***using auto***
- *b* = an exponent,
  - *which depends on trip purpose*

Trip Interchange Models

QRS method

$$MS_a = \frac{(I_{ijt})^b}{(I_{ija})^b + (I_{ijt})^b} \times 100$$

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

- I_{ijm} = a value referred to as the *impedance* of travel of mode *m*, between zone *i* and zone *j*
  - *It is a measure of the total cost of the trip.*
- $Impedance\ (I) = \ (in\ vehicle\ time\ [mintue]) + \ (2.5\ x\ excess\ time\ [min]) + \ (3\ x \frac{trip\ cost\ [\$]}{income\ earned/min})$

i is origin zone number
j is destination zone number
m is travel of mode
t for transit mode
a for auto mode

Trip Interchange Models

QRS method

$$Impedance\ (I) = \ (in\ vehicle\ time\ [mintue]) + \ (2.5\ x\ excess\ time\ [min]) + \ (3\ x \frac{trip\ cost\ [\$\ ]}{income\ earned/min})$$

- The impedance value
  - *Determined for each zone pair*
  - *Represents a measure of the expenditure required to make the trip by either auto or transit*
- In-vehicle time
  - *is time spent traveling in the vehicle*
- Excess time
  - *is time spent traveling but not in the vehicle, including waiting for the train or bus and walking to the station.*
- Assume that the time worked per year is 120,000 min

QRS method

Data needed

- Distance between zones by auto and transit
- Transit fare
- Out-of-pocket auto cost
- Parking cost
- Highway and transit speed
- Exponent values, b
- Median income,
- Excess time,
  - *includes the time required to walk to a transit vehicle and time waiting or transferring.*
  - *Assume that the time worked per year is 120,000 min.*

QRS method

Example No. 1 (Example 12.9):
Computing Mode Choice Using the QRS Model

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*

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

QRS method

*Solution of Example No. 1 (*Example 12.9) :

Solution: Use Eq. 12.6.

$$MS_a = \frac{I^b_{ija}}{I^b_{ijt} + I^b_{ija}}$$

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

$$= 20 + 12.5 + 33.75$$

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

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

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

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

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

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QRS method

*Solution of Example No.1 (*Example 12.9) :

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

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$\dot{i}$ = origin Zone = Zone S ⇒ $\dot{i} = S$ a ⇒ Auto
$\dot{j}$ = Distination Zone ⇒ Zone D ⇒ $\dot{j} = D$ t ⇒ transit

Step 1:- Find the impedance terms for travelling by Auto (a) and transit (t).

① In-vehicle time

(1-1) by Auto = $\frac{\text{Distance travelled [Table 12.21]}}{\text{Speed}}$

$$= \frac{10\ mi}{30\ \frac{mi}{hr}} = 10\ mi * \frac{1}{30}\ \frac{hr}{mi} * \frac{60\ min}{1\ hr}$$

$$= \frac{10 \times 60}{30} = \underline{20\ min.}$$

(1-2) by transit = $\frac{\text{Distance travelled}}{\text{speed}} = \frac{8\ mi}{20\ \frac{mi}{hr}} = 8\ mi * \frac{1}{20}\ \frac{hr}{mi} * \frac{60\ min}{1\ hr}$

$$= \frac{8}{20} \times 60 = \underline{24\ min}$$

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② Excess time. [From Table 12.21]

↳ by Auto 5 min

by transit 8 min.

③ Trip cost [Table 12.21]

by Auto = $0.75\$ + 0.15\ \frac{\$}{mi} * 10\ mi = 0.75 + 0.15 = 2.25\ \$$

by transit = $0.1\ \frac{\$}{mi} * 8\ mi = 0.8\ \$$

④ income earn / min

$$= \frac{24000}{120000\ [\text{assumed}]\ (min)} = \frac{24}{120}\ \frac{\$}{min} = 0.2\ \$/min.$$

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⇒ Summary

	in-vehicle time (min)	Excess time (min)	Trip cost ($).	incom/min
by Auto	20	5	2.25	0.2
by transit	24	8	0.8	0.2

⇒ Step 2 Find the impedance for each mode

$I_{ija} = I_{SDa}$ = in-vehicle time + 2.5 excess time + 3 * $\frac{\text{trip cost}}{\text{incom/min}}$ → by Auto

by Auto $= 20 + 2.5 * 5 + 3 * \frac{2.25}{0.2} = 20 + 12.5 + 33.75 = 66.25$ equivalent min

$I_{ijt} = I_{SDt}$ = in-vehicle time + 2.5 excess time + 3 × $\frac{\text{trip cost}}{\text{incom/min}}$

by transit $= 24 + 2.5 \times 8 + 3 \times \frac{0.8}{0.2} = 24 + 20 + 12 = 56$ equivalent min

44
40

40

⇒ $I_{SDa} = 66.25$, $I_{SDt} = 56$, $b = 2$ [given]

→ Step 3 Find M_{Sa} and M_{SD}

$$\Rightarrow M_{sa} = \frac{I_{ija}^{b}}{I_{ijt}^{b} + I_{ija}} * 100 = \frac{I_{SDa}^{b}}{I_{SDt}^{2} + I_{SDa}} * 100 = \frac{(66.25)^2}{(56)^2 + (66.25)^2} = \frac{4389}{3136 + 4389} * 100$$

$\Rightarrow M_{sa} = 0.58 \times 100 = 58\%$

$\Rightarrow M_{st} = 1 - M_{sa} = 1 - 0.58 = 41.6\%$

$\Rightarrow M_{sa} = 58.4\%$
$M_{st} = 41.6\%$

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Mode Choice Models

Alternative approach : Logit Models

Mode Choice

Logit Models

- An alternative approach used in transportation demand analysis is to consider the relative utility of each mode as a summation of each modal attribute.

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

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

Mode Choice

Logit Models

- The choice of a mode is expressed as a probability distribution.
- If two modes, **auto (*A*)** and **transit (*T*)**, are being considered,
  - *the probability of selecting the auto mode A can be written as*

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

Logit Models

*Example No.1 (*Example 12.10) : Use of Logit Model to Compute Mode Choice

Logit Models

Example 12.10 : Use of Logit Model to Compute Mode Choice

The utility functions for auto and transit are as follows.

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

where

T_1 = total travel time (minutes)
T_2 = waiting time (minutes)
C = cost (cents)

The travel characteristics between two zones are as follows:

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

Mode Choice

Solution of Example No.1

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

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

$$U_A = -0.46 - (0.35 \times 20) - (0.08 \times 8) - (0.005 \times 320) = -9.70$$
$$U_B = -0.07 - (0.35 \times 30) - (0.08 \times 6) - (0.005 \times 100) = -11.55$$

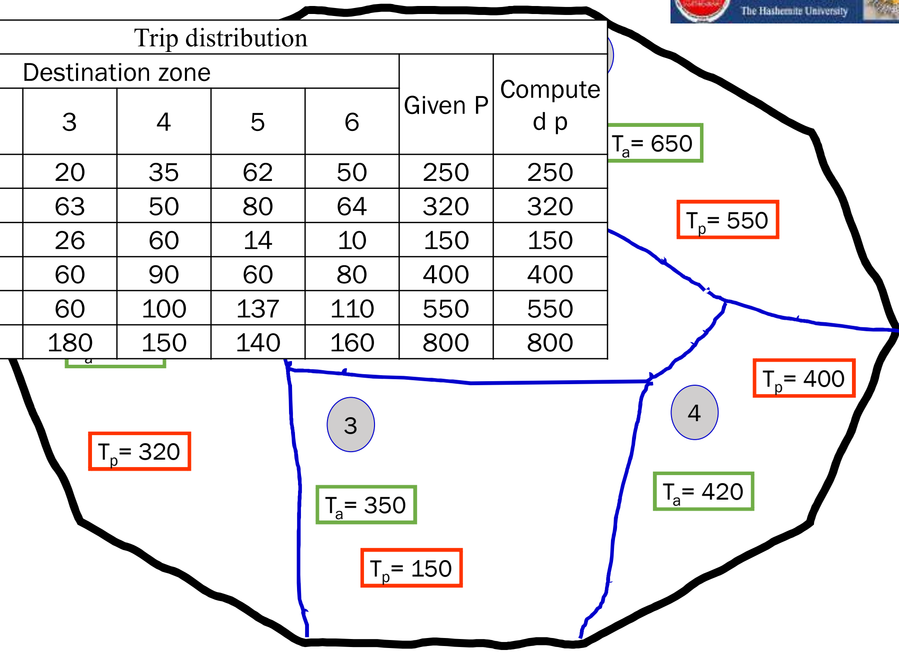
Using Eq.12.9 yields

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

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

Example

Origin zone	Trip distribution							
	Destination 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



Mode Choice

- *42 % by car*
- *58% by bus*

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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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TRANSPORTATION ENGINEERING AND PLANNING (110 401367)

Spring 2021-2022

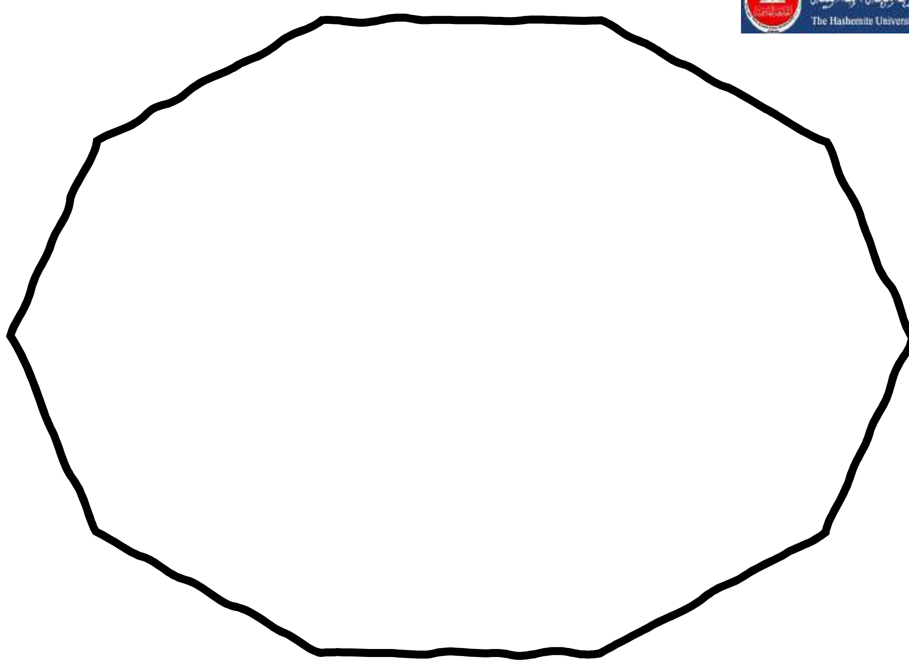
Module No. 4

4.4_ Traffic Assignment

Dr. Hamza Alkuime

1

Review

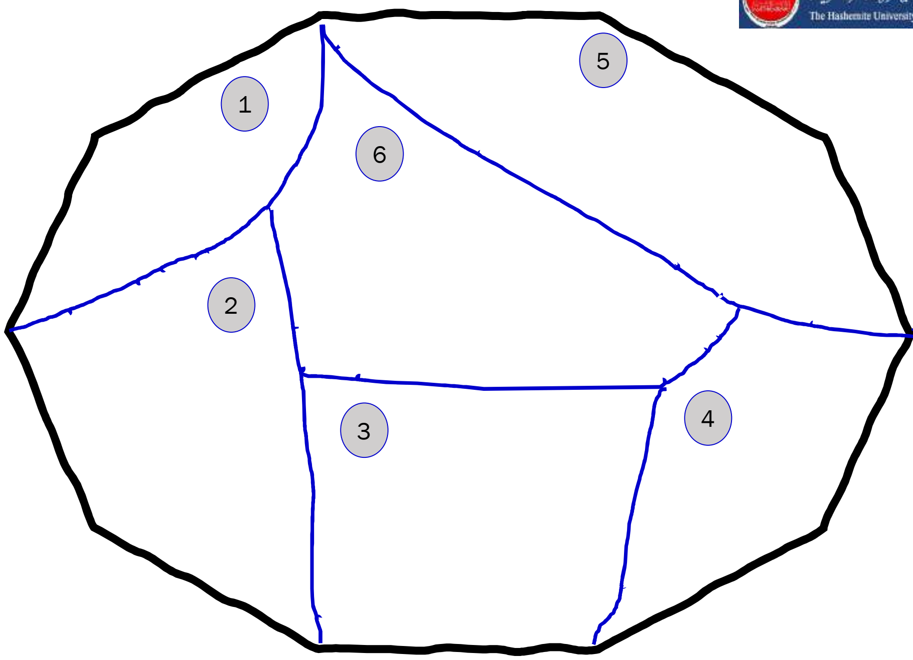


Study area

2

2

Review



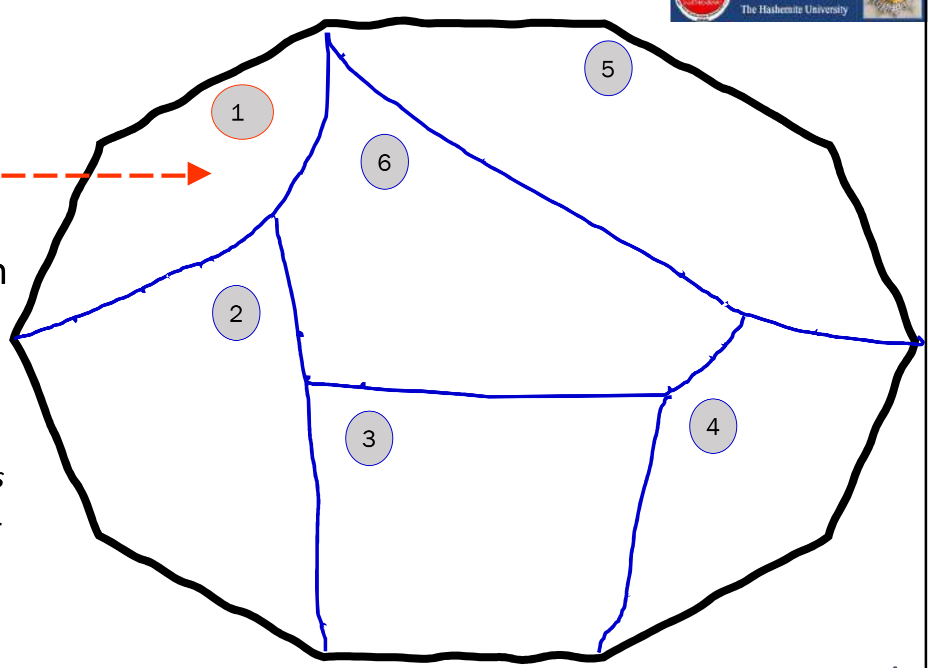
Zoning

Review

Attracted trips

The land use within Zone 1 are

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



Review

Balanced Trip Productions and Attractions

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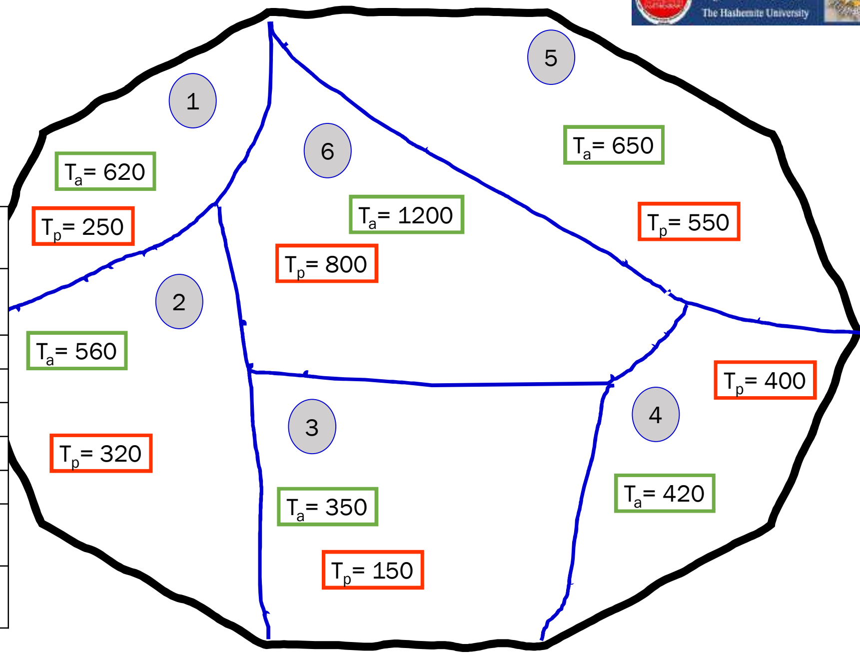
Total trips	2470	2470



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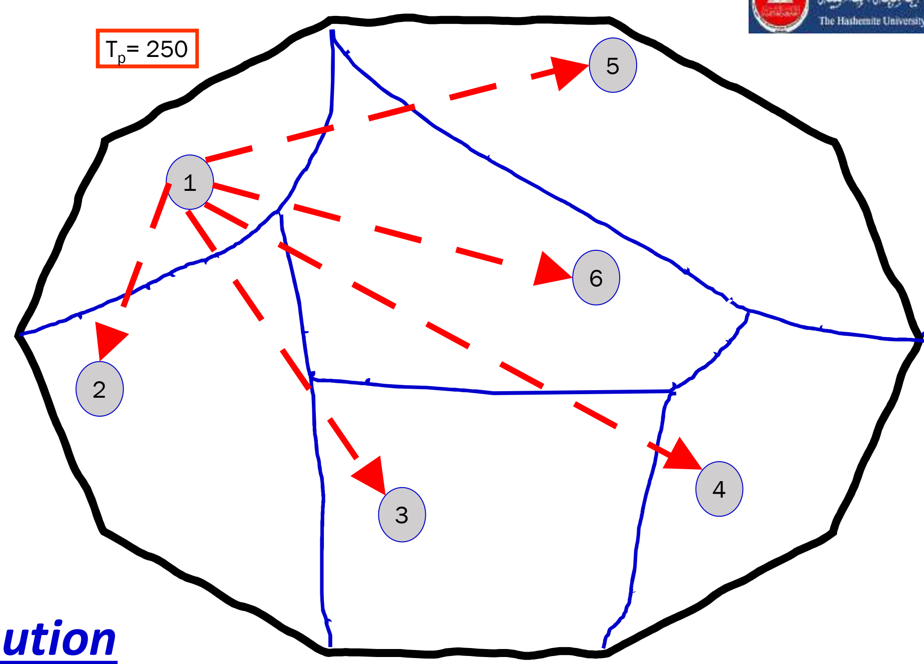
Review



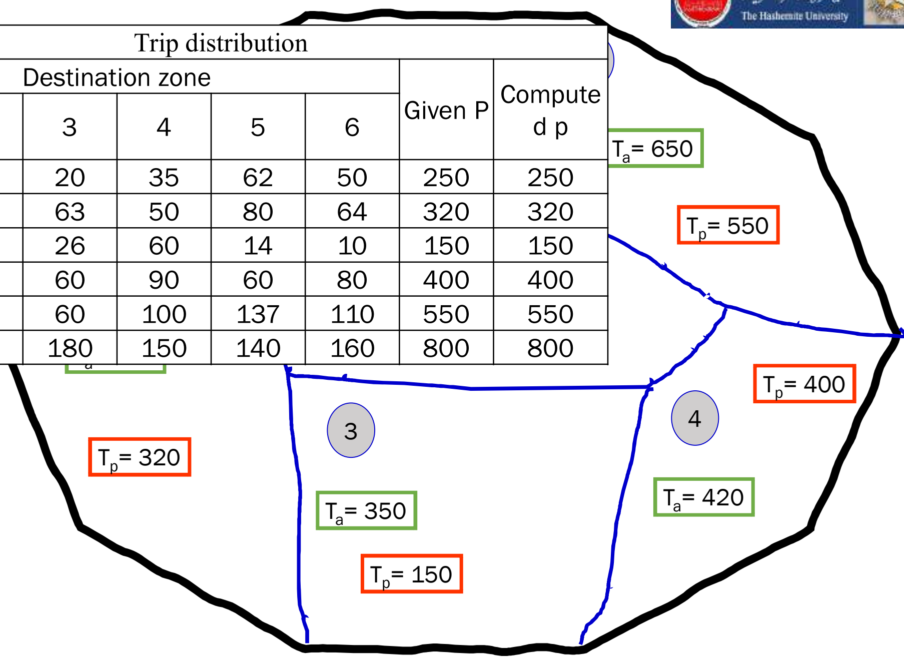
Trip distribution

6

6

Example

	Trip distribution							
Origin zone	Destination 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



- Model split
  - *42 % by car*
  - *58% by bus*

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

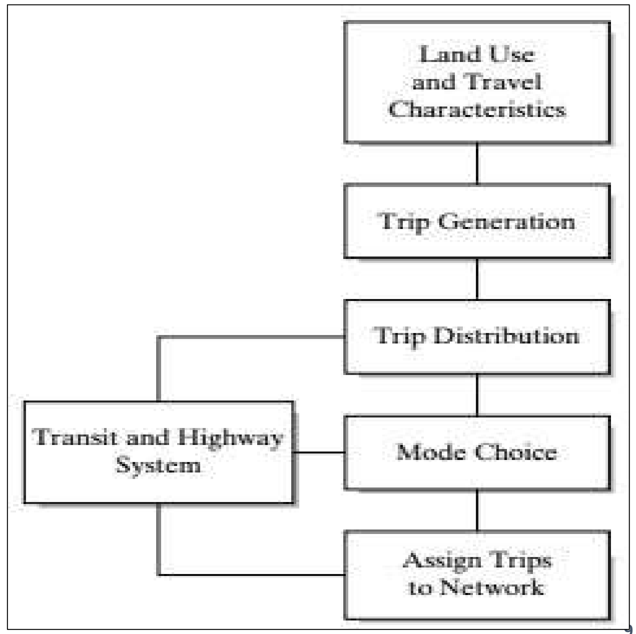
Origin zone	*Trips by Bus (58% of trip generated)*					
	Distination zone					
	1	2	3	4	5	6
1	37	12	12	20	36	29
2	24	13	37	29	46	37
3	10	13	15	35	8	6
4	23	41	35	52	35	46
5	37	46	35	58	79	64
6	52	46	104	87	81	93

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



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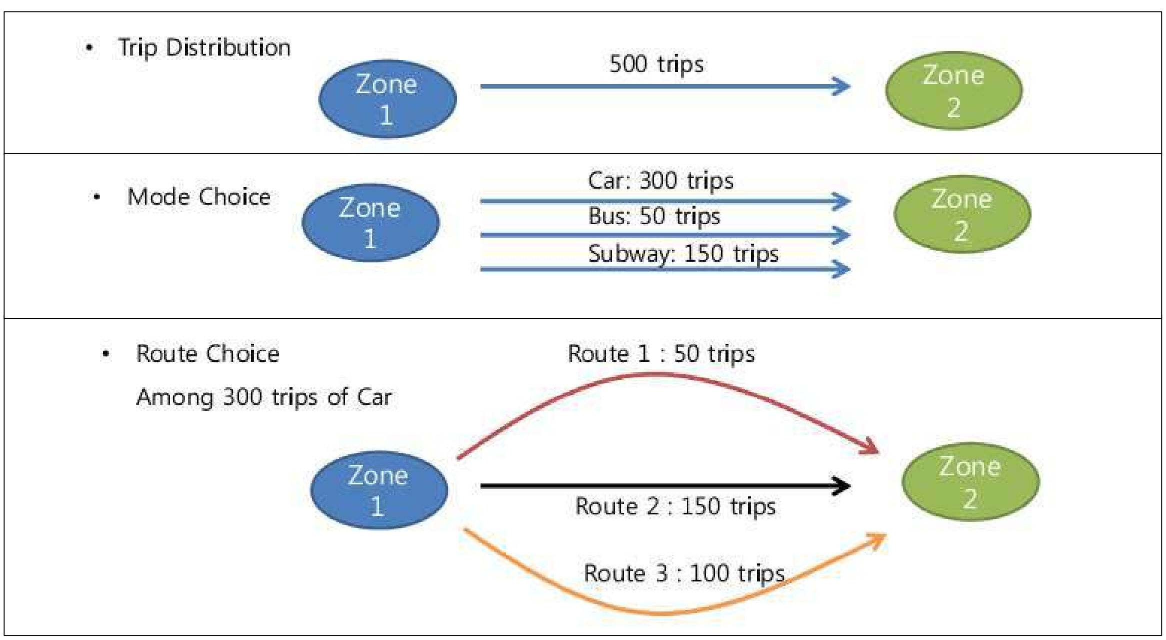
Traffic Assignment (Rout choice)



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Traffic assignment

- Goal
  - *What path or route will a person choose?*
  - *What influences the choice of route?*
    - Path that minimizes travel cost, time, distance, speed
- Inputs
  - *Origin- destination matrix (trip table)*
- Output
  - *Path table*
  - *Used to*
    - Determine the actual street and highway routes that will be used
    - The number of automobiles and buses trips that can be expected on each highway segment

Traffic assignment

Data needed

- Number of trips that will be made from one zone to another
  - *Determined in the trip distribution step*
- Available highway or transit routes between zones
- How long it will take to travel on each route
- A decision rule (or algorithm) that explains how motorists or transit users select a route
- External trips that were not considered in the previous trip generation and distribution steps

Traffic assignment

Approaches

- Three basic approaches can be used for traffic assignment purposes:
  1. *Diversion curves*
  2. *Minimum time path (all-or-nothing) assignment*
     - Commonly used
     - Generally, produces accurate results
     - Adequately demonstrates the basic principles involved
  3. *Minimum time path with capacity restraint*

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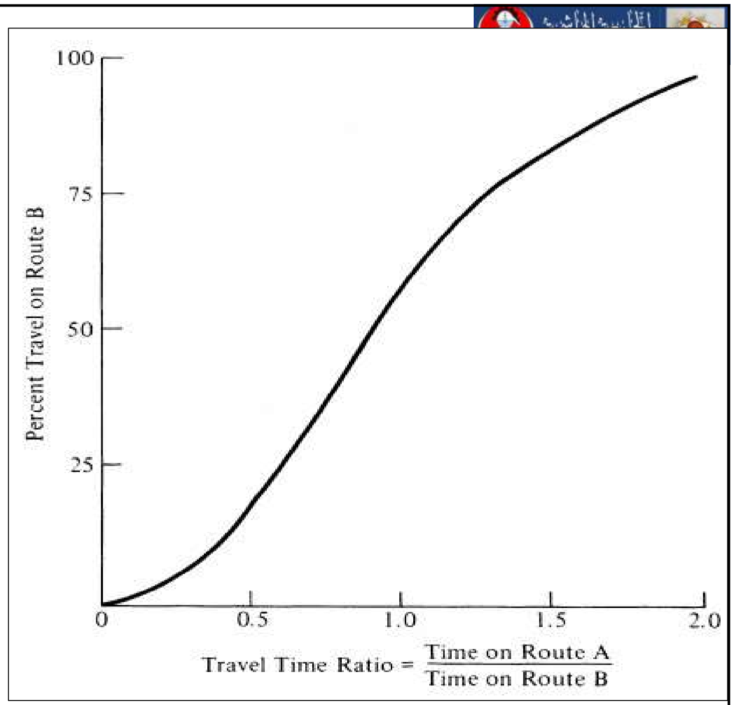
Traffic assignment

1. Diversion curves

- Travel Time Ratio versus Percentage of Travel on Route *B*



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Traffic assignment

2. Minimum time path (all-or-nothing) Algorithm

- Assumption
  - *The traveler will always select the route that represents minimum travel time between any O-D pair.*
  - *This method assigns all trips to those **links** that comprise the shortest time path between the two zones.*

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Traffic assignment

Minimum time path (all-or-nothing) assignment

- In this method,
  - *All trips are assigned on the shortest route which is **the minimum** travel time or cost between zones*
- To determine which route that will be,
  - It is necessary to find the shortest route from the zone of origin to all other destination zones.
  - The results can be depicted as a tree, referred to as a skim tree

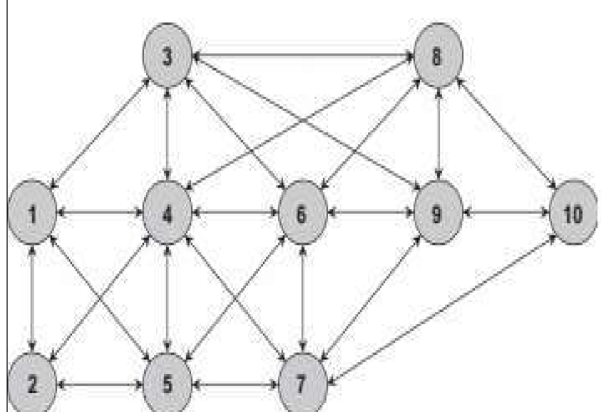

Figure 2.13 Simple network for assignment illustration.

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Traffic assignment

Skim tree

- Nodes
  - *Each zone is represented by a node in the network which represents the **entire area being examined**.*
- Links
  - *Zones are interconnected by links,*
    - which represent the physical characteristics of the road segments and facilities of the transportation network
- Path
  - *Represented through a series of links, each with its own set of attributes and characteristics*
  - These attributes can include
    - length, speed limit, travel time, capacity, functional classification, and a host of other variables used to describe the characteristics and expected performance of the link
  - *The link attributes are translated to the path through a process **called skimming***

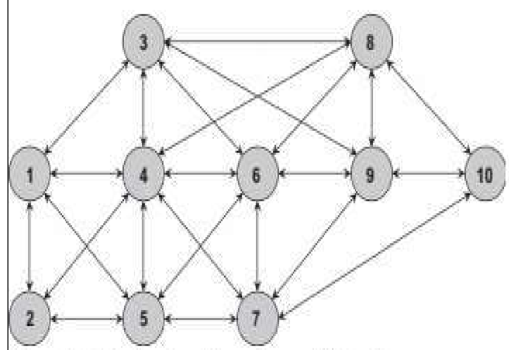


Figure 2.13 Simple network for assignment illustration.

The problem is finding the minimum-travel-time paths connecting each O-D pair for a given set of link travel time

Traffic assignment

Skim tree

- If evaluating a trip with
  - *origin in zone 1*
  - *destination in zone 4*
- The path is represented
  - A. 1→ 4
  - B. 1 → 3-3 → 4
  - C. 1 → 5-5 → 4
  - D. 1 → 2-2 → 4
  - E. 1→ 2-2 → 5-5 → 4
- Therefore,
  - *The decision of which path drivers will take becomes a function of the attributes of each path,*
  - *which, in turn, are estimated from the aggregated attributes of each link sequence*

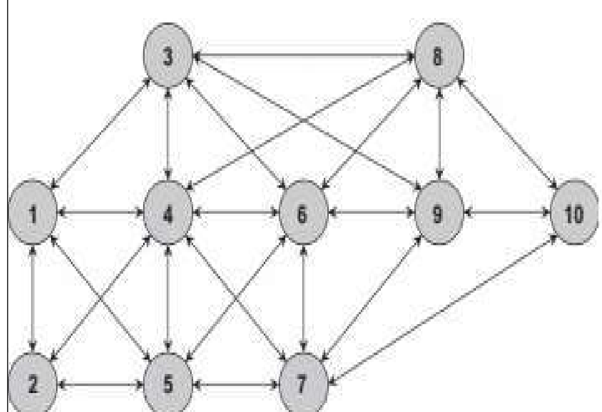


Figure 2.13 Simple network for assignment illustration.

Traffic assignment

Skim tree

- If evaluating a trip with
  - *origin in zone 1*
  - *destination in zone 4*
- The path is represented
  - A. 1→ 4
  - B. 1 → 3-3 → 4
  - C. 1 → 5-5 → 4
  - D. 1 → 2-2 → 4
  - E. 1→ 2-2 → 5-5 → 4

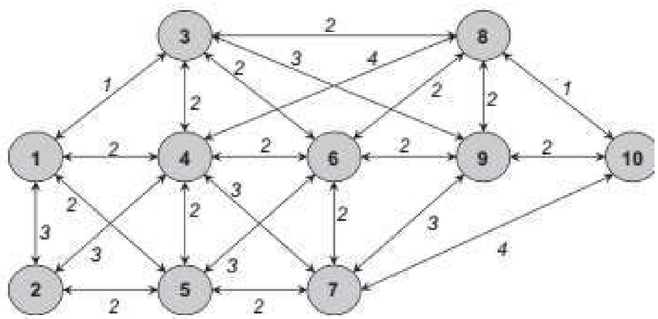


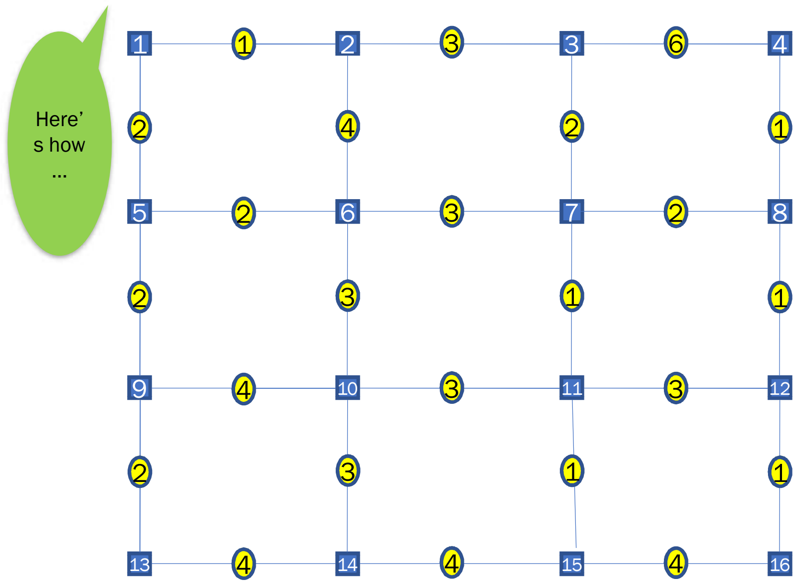
Figure 2.14 Simple assignment network with link travel times.

- Figure 2.14 amends the previous example by adding link travel times (in minutes) for each zone-to-zone connection
  - *It appears that link 1 → 4 is indeed the shortest travel time between zones 1 and 4 at 2 min*

Skim Tree

Example No. 1

Find the shortest path from node 1 to all other nodes (from Garber and Hoel)



Yellow numbers 3 represent link travel times in minutes

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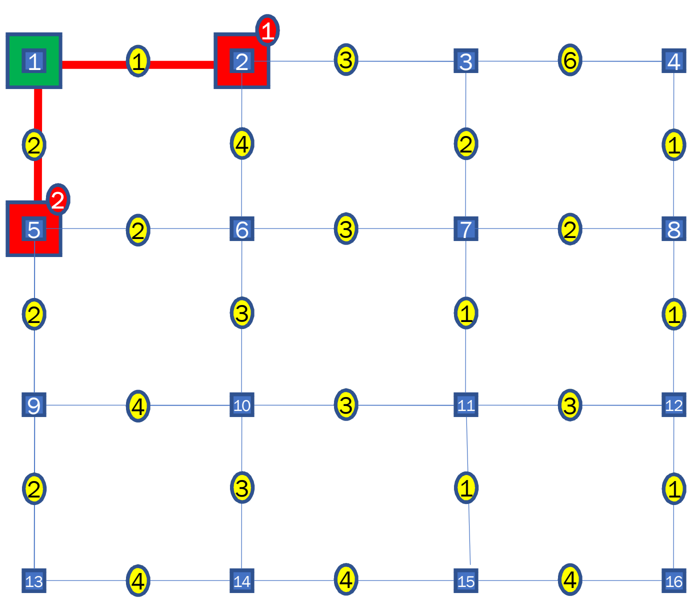
STEP 1



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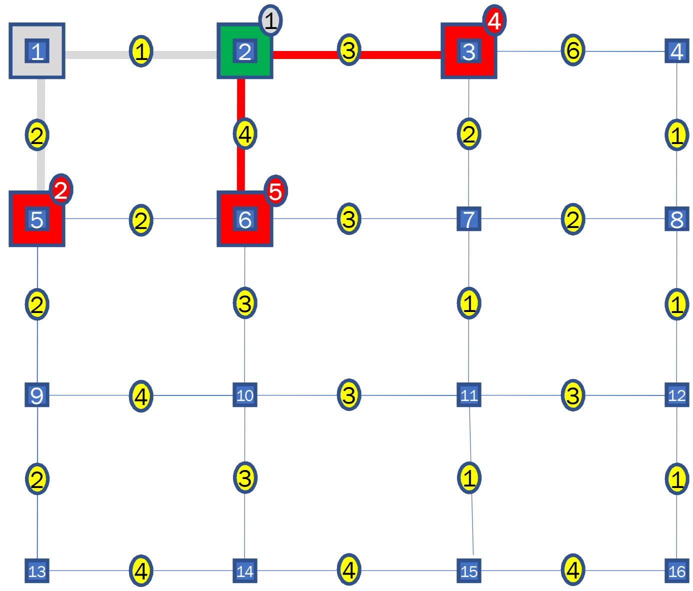
STEP 2



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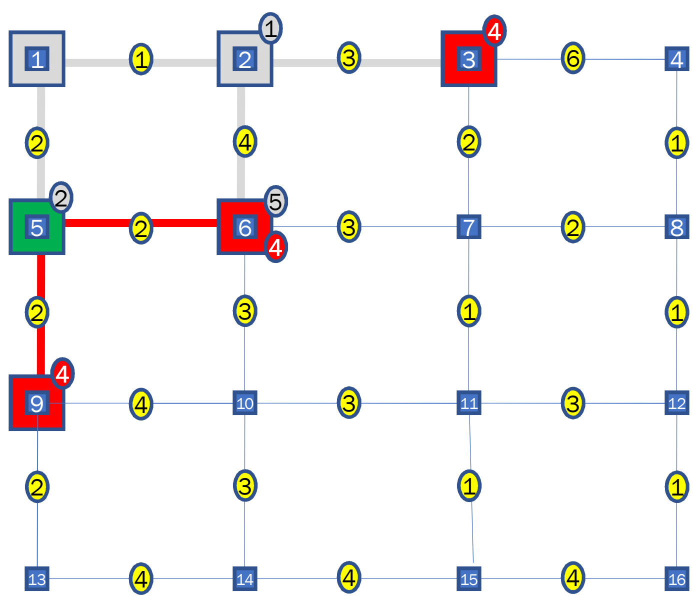
STEP 3



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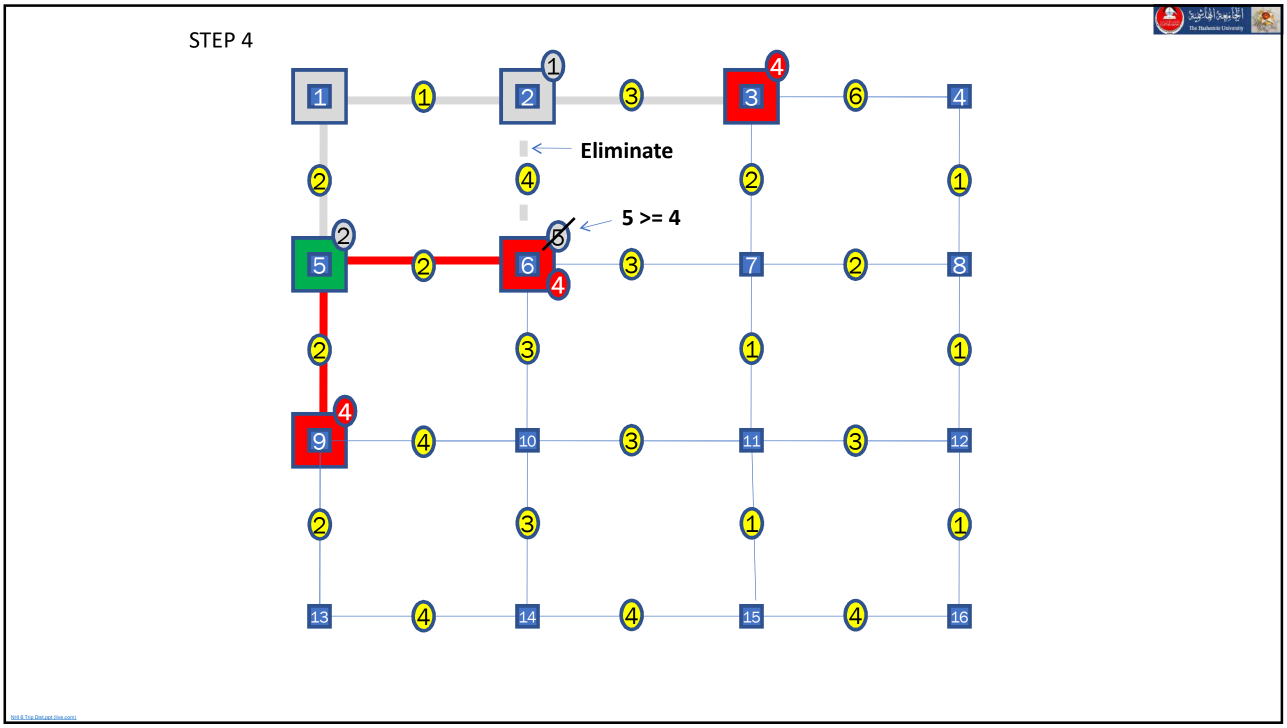

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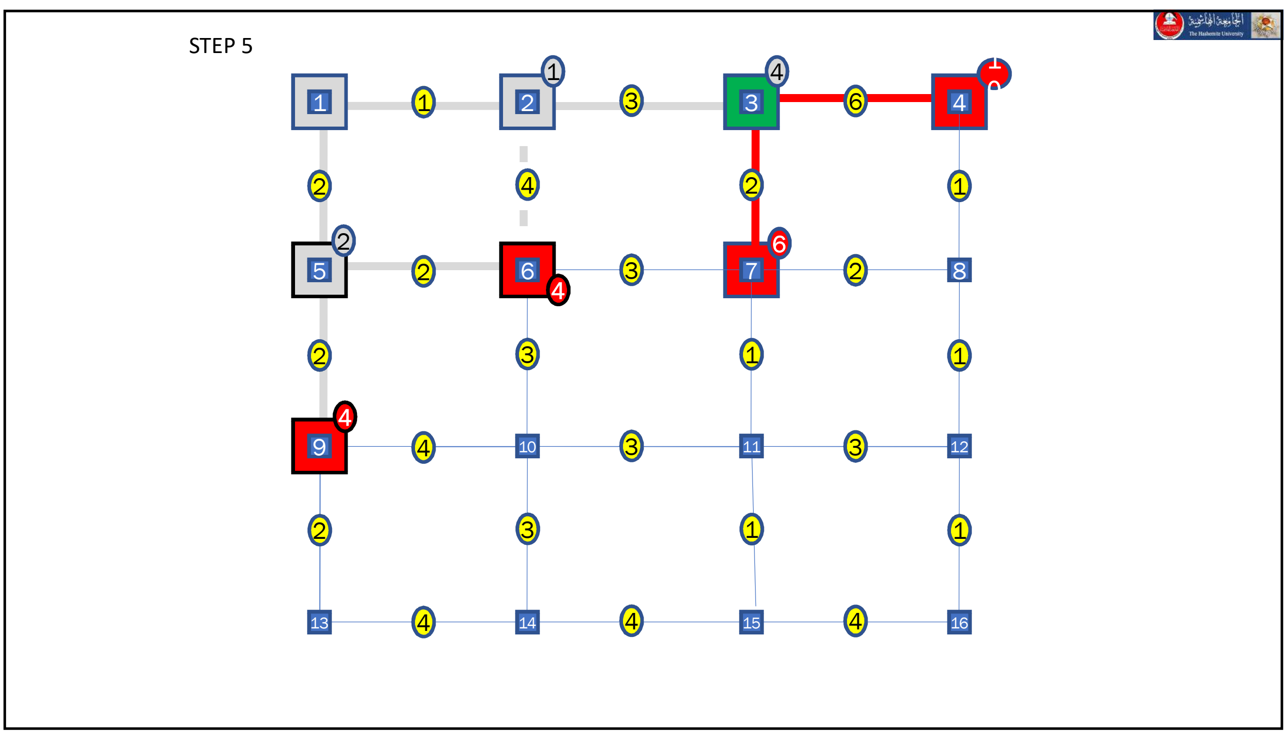

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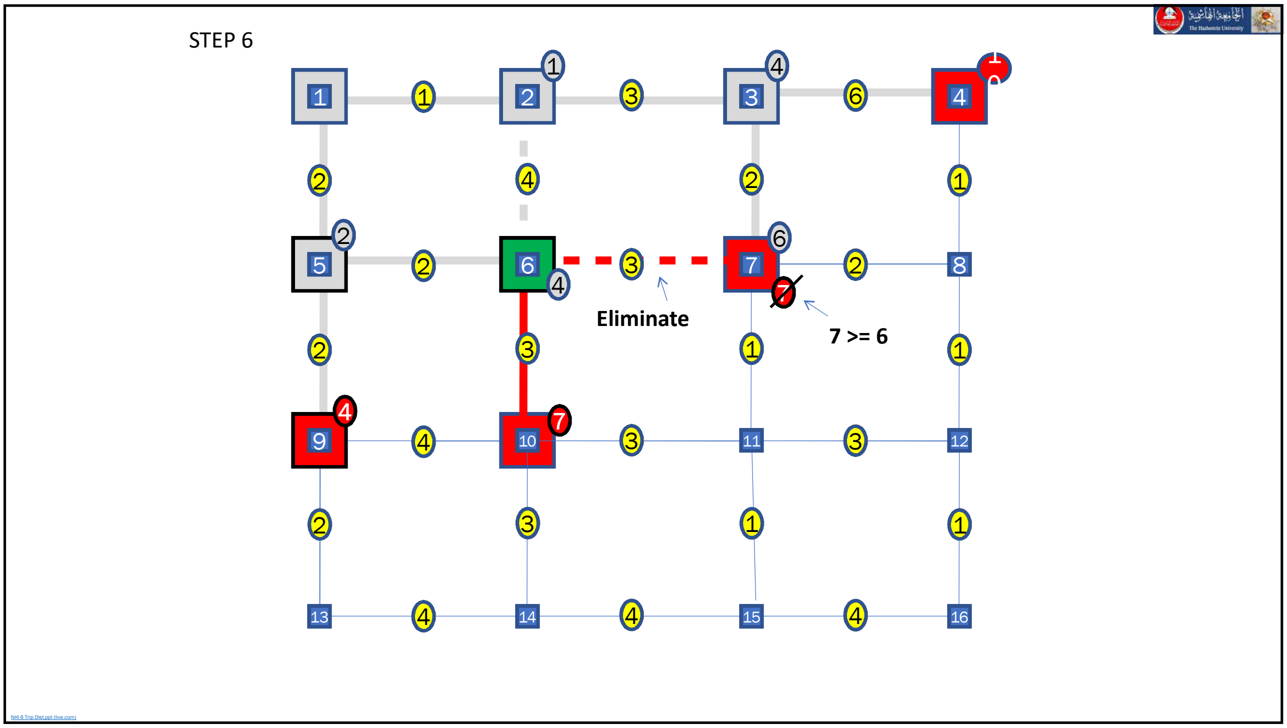

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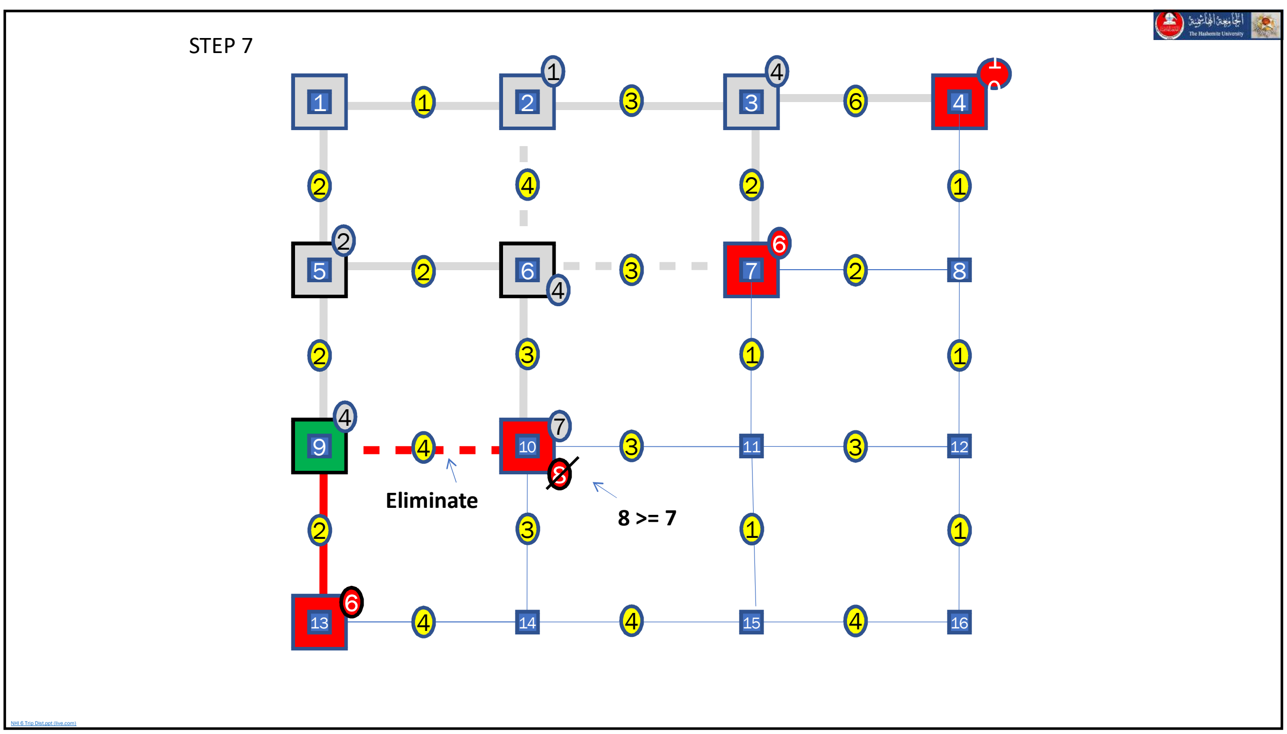

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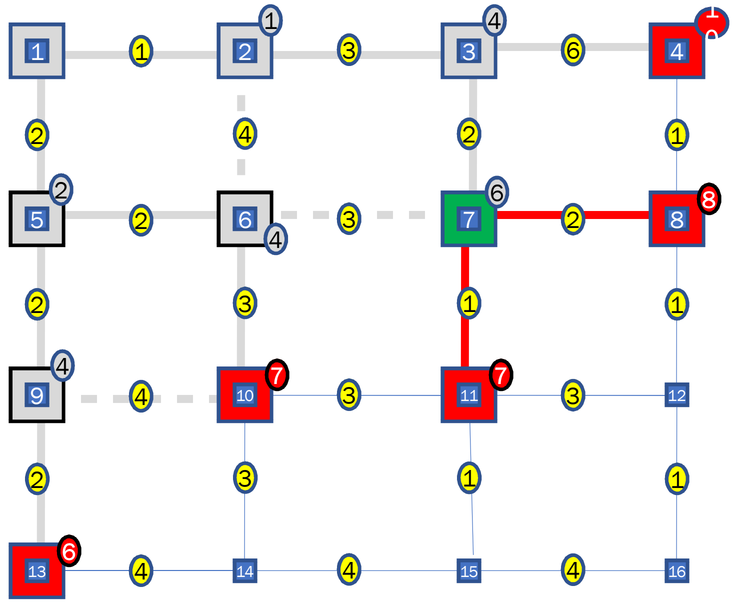
STEP 8



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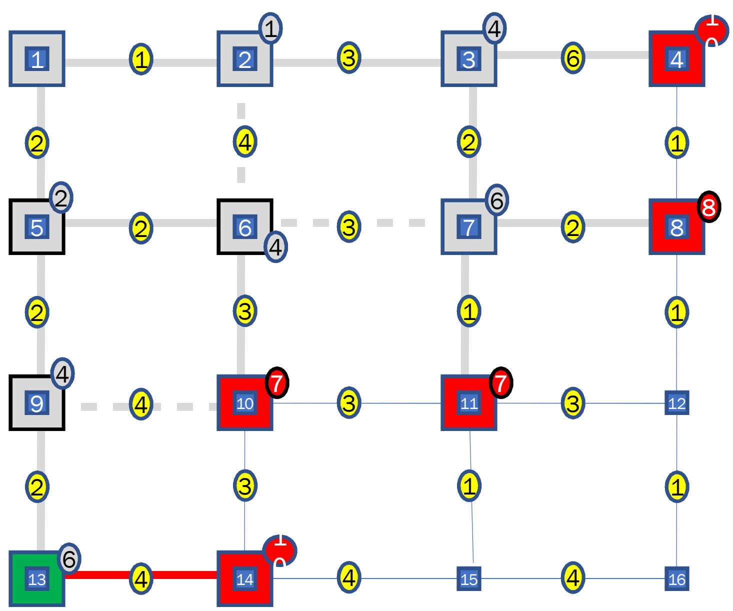
STEP 9



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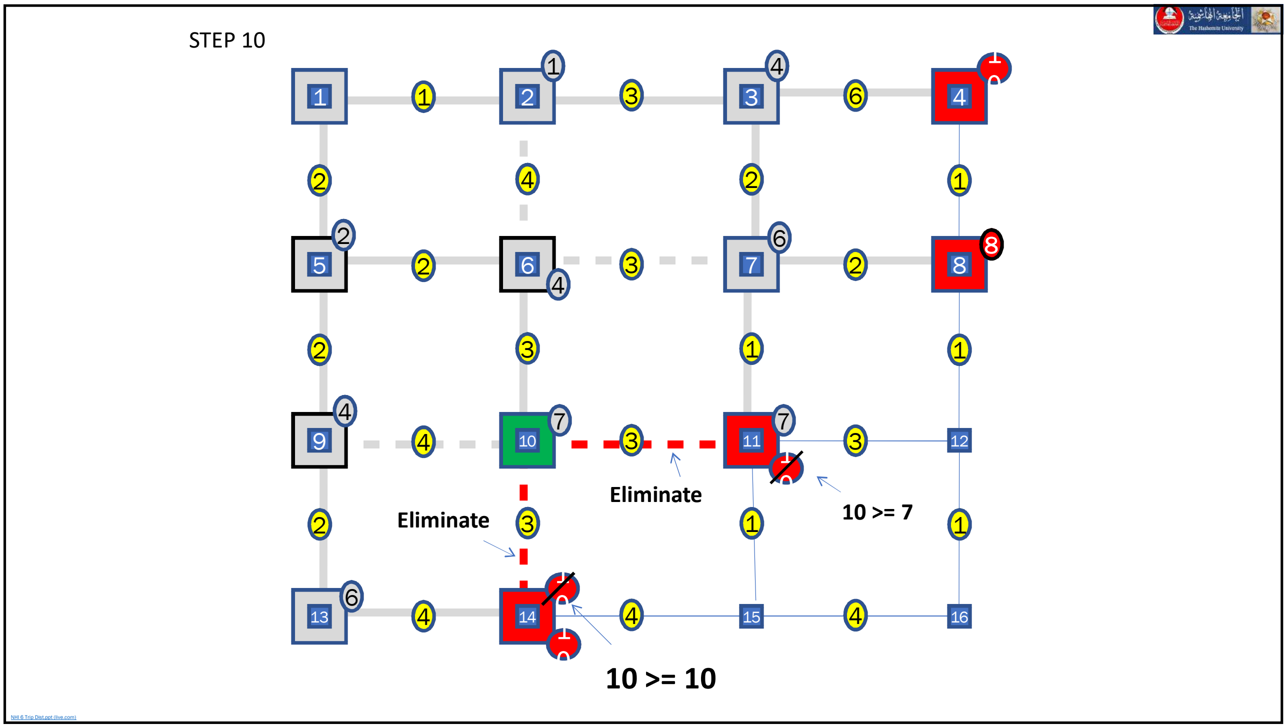

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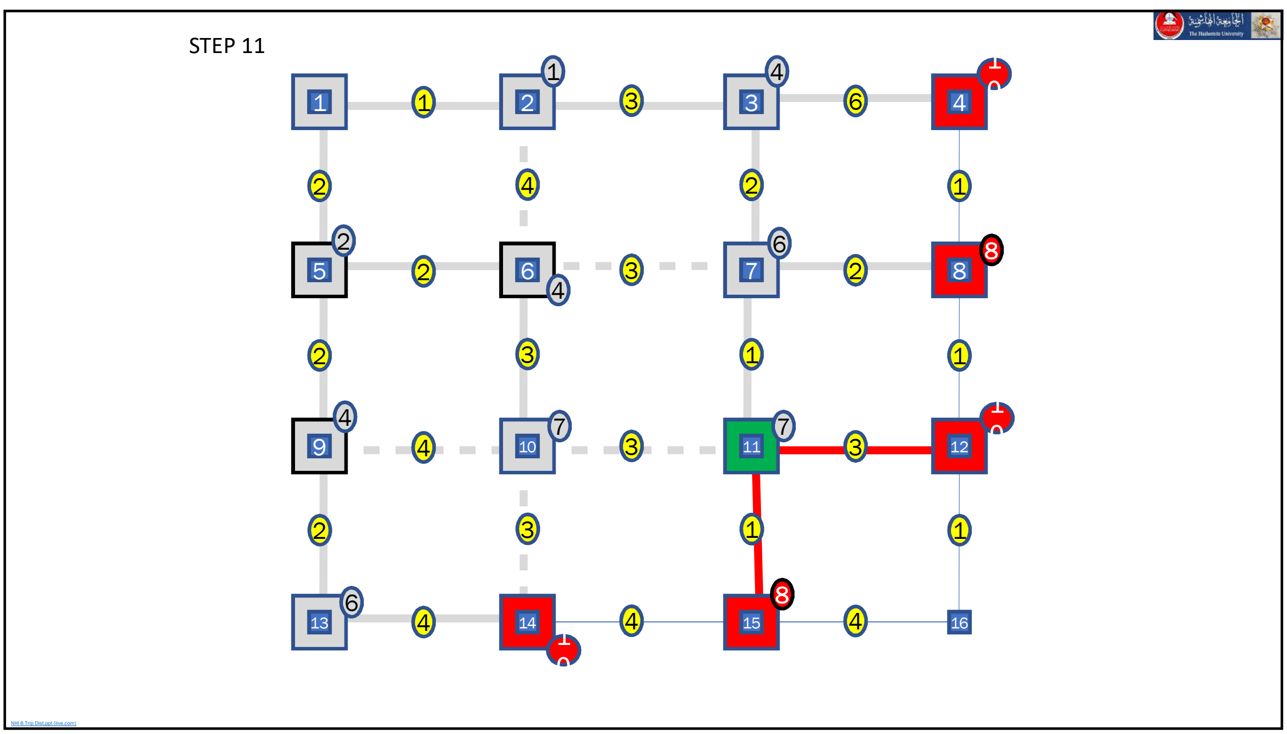

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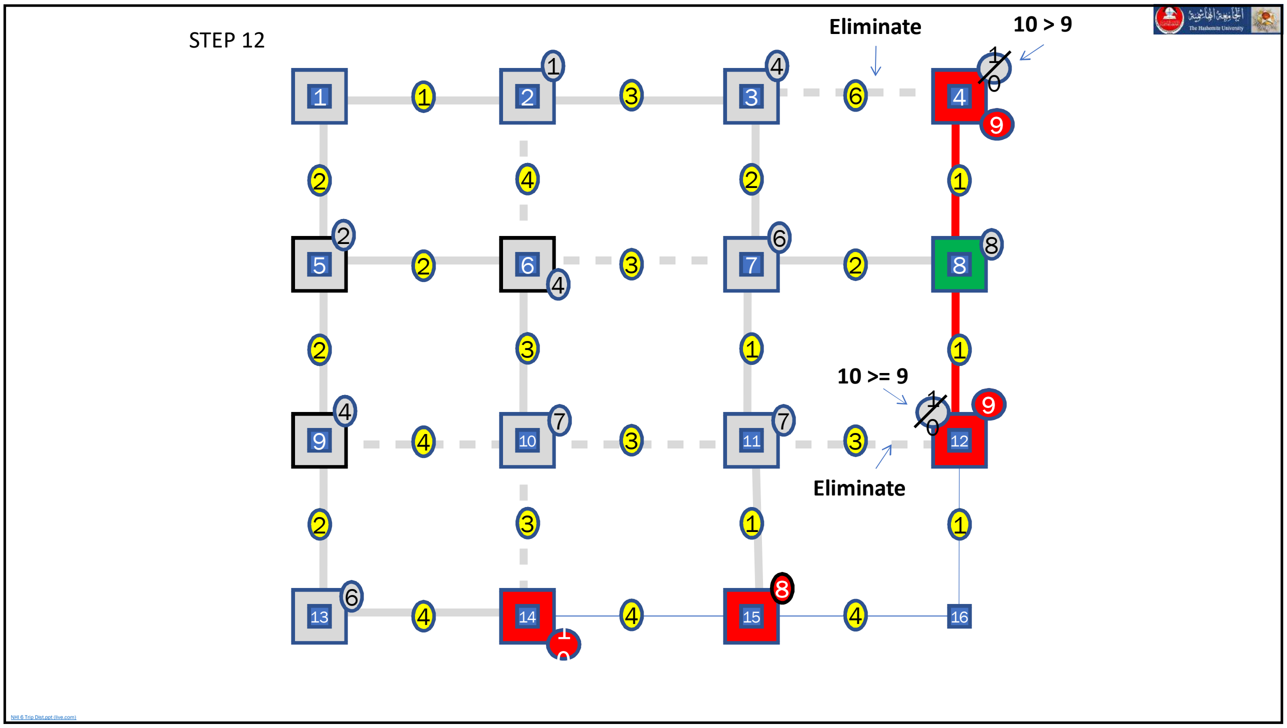

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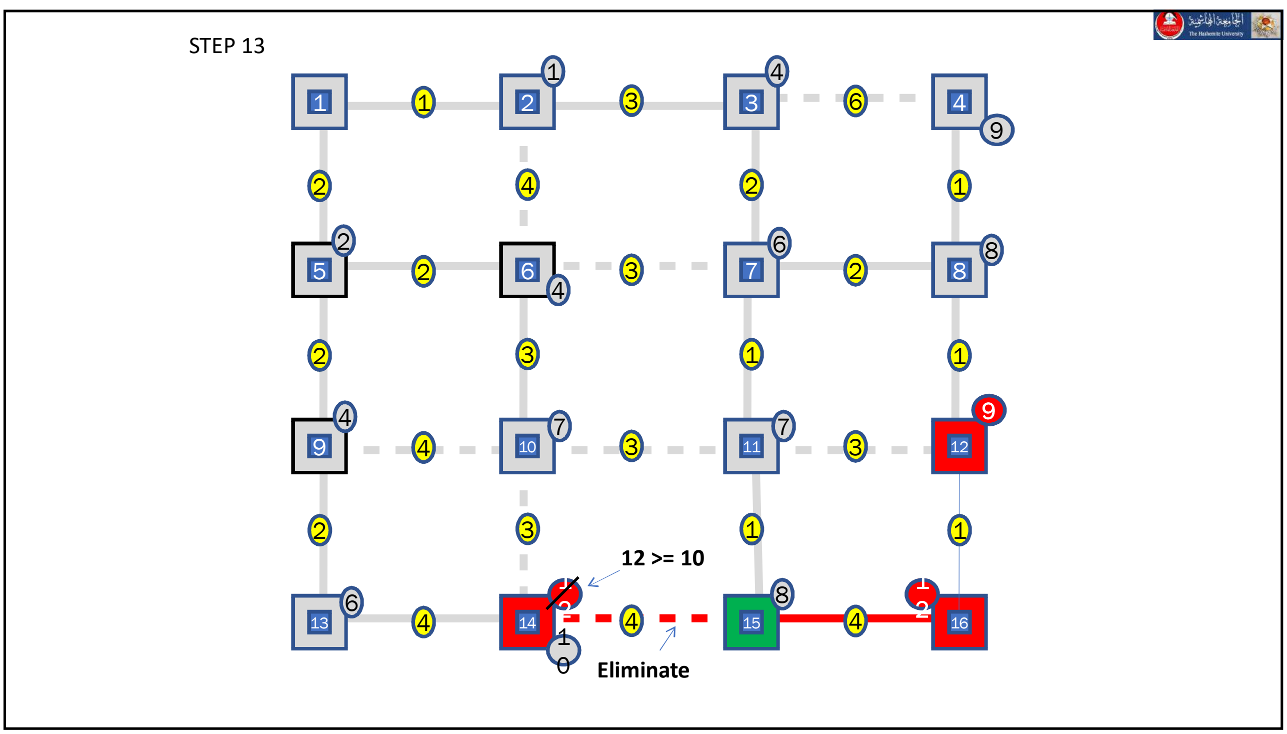

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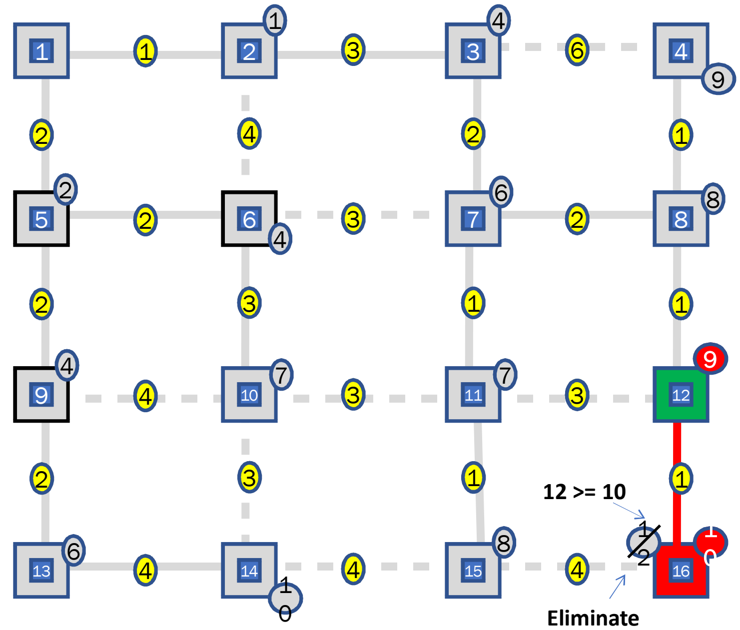
STEP 14



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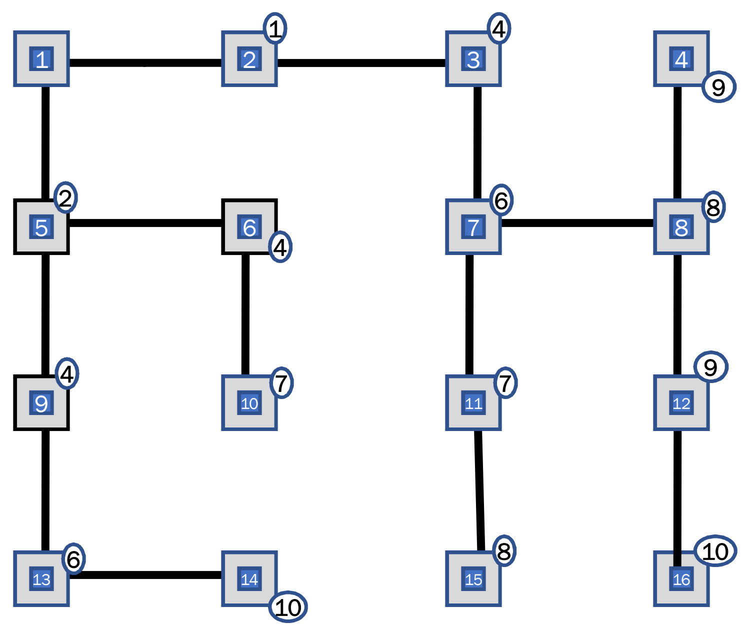
FINAL



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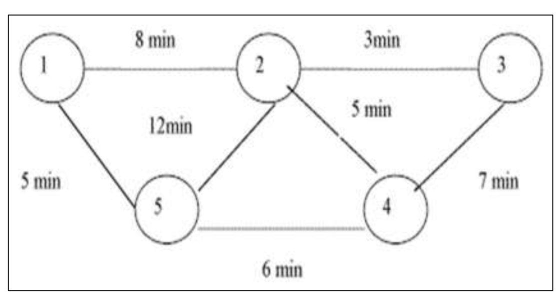
Skim tree

*Example No. 2 (*Example 12.10) : Using of Skim tree

Example No. 1 (Example 12.10) : Using of Skim tree

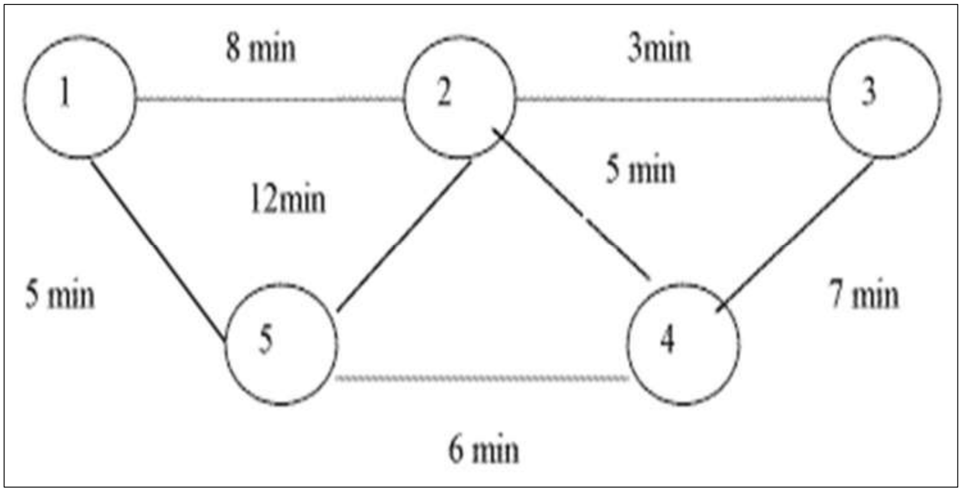
1. Assign the vehicle trips shown in the O-D trip table to the network shown in Figure below using the all-or-nothing assignment technique.
2. Make a list of the links in the network and indicate the volume assigned to each.
3. Calculate the total vehicle minutes of travel.
4. Show the minimum path and 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	-



Example No.1 (Example 12.10) : Using of Skim tree

Travel time between zones



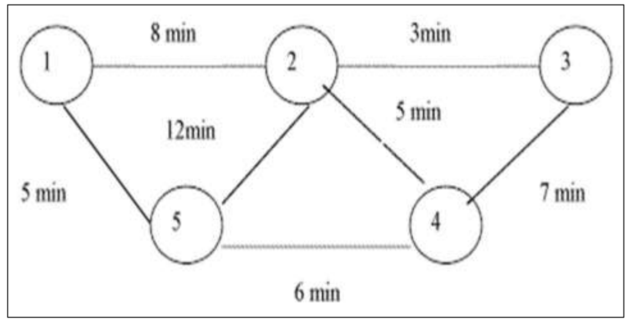
Solution of Example No.1 (Example 12.10) : Using of Skim tree

- Steps:
  - *Step 1: Find the <u>shortest paths</u> 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***
    - **<u>from O-D matrix</u>**
  - *Step 4: Find* total trips (volume) *on* ***<u>each link</u>***
  - *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*

Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 1: *Find the shortest paths between zones*

Nodes		Shortest	Path
From	To	Path	ID
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		

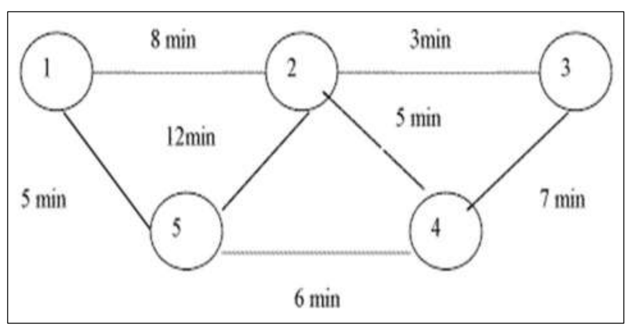


shortest path = The path with minimum cumulative travel time

Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 1: *Find the shortest paths between zones*

Nodes		Shortest	Path
From	To	Path	ID
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

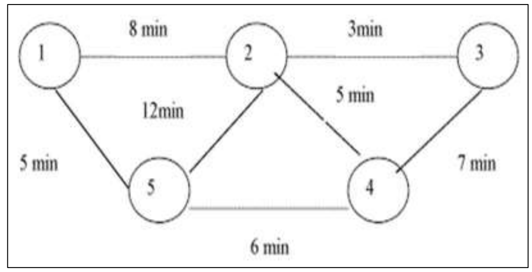


shortest path = The path with minimum cumulative travel time

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 From	Nodes To	Shortest Path	Path ID	Cumlative Travel Time (min)
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	

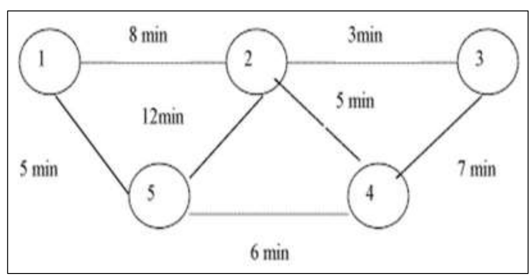


shortest path = The path with minimum cumulative travel time

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 From	Nodes To	Shortest Path	Path ID	Cumlative Travel Time (min)
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

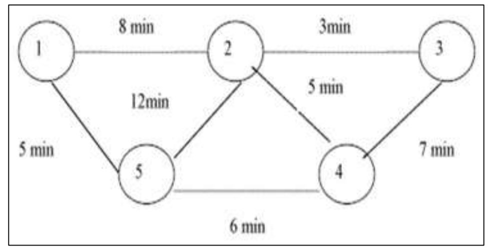


shortest path = The path with minimum cumulative travel time

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 From	Nodes To	Shortest Path	Path ID	Cumlative Travel Time (min)	Traffic volume on shortest paths
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	-

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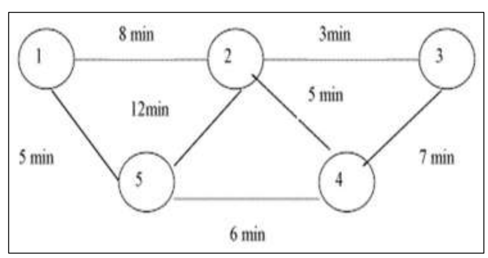
Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 3: Find traffic volumes (or estimated trips) for shortest paths **between zones** ***(from O-D matrix)***

Nodes From	Nodes To	Shortest Path	Path ID	Cumlative Travel Time (min)	Traffic volume on shortest paths
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



	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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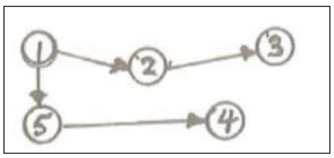
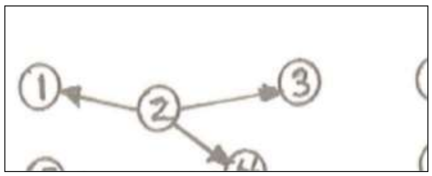
Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 4: Find total trips (volume) *on* ***each link***

Link	Used in Paths with ID	Cumulative trips on link
1-2		
2-1		





Nodes From	Nodes To	Shortest Path	Path ID	Estimated trips between zones
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

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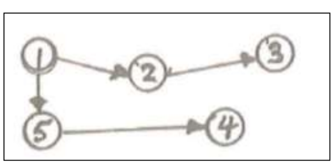
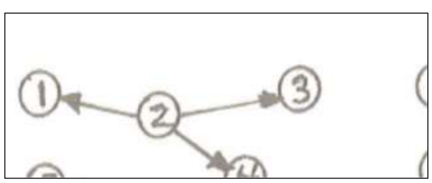
Solution of Example No.1 (Example 12.10) : Using of Skim tree

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 From	Nodes To	Shortest Path	Path ID	Estimated trips between zones
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

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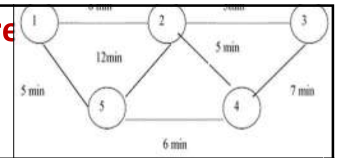
Solution of Example No.1 (Example 12.10) : Using of Skim tre

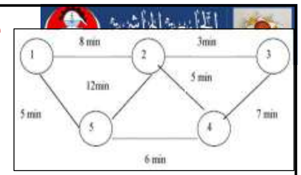


Step 4: Find total trips (volume) *on each link (Cont.)*

Selected Link	Used in Paths with ID	Culmlative 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 From	Nodes To	Shortest Path	Path ID	Cumlative Travel Time (min)	Traffic volume on shortest paths
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

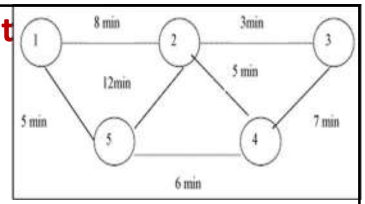
Solution of Example No.1 (Example 12.10) : Using of Skim tree



Step 4: Find total trips (volume) *on each link (Cont.)*

Selected Link	Used in Paths with ID	Colmlative trips on link	Link travel time (min [from
1-2	1, 2	=100+100=200	8
2-1	5, 9	=400+200=600	8
1-5	3, 4	=200+150=350	5
5-1	3	450	5
2-5	0	0	5
5-2	0	0	12
2-3	3,6	=200+200=400	3
3-2	9,10	300	3
2-4	7,8	600	5
4-2	14,18,	250	5
3-4	12,	250	7
4-3	19	350	7
4-5	8,12,13,16	1300	6
5-4	18,19,20	700	6

Solution of Example No.1 (Example 12.10) : Using of Skim t



Step 5: Find total vehicle minutes of travel *on each*

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	
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

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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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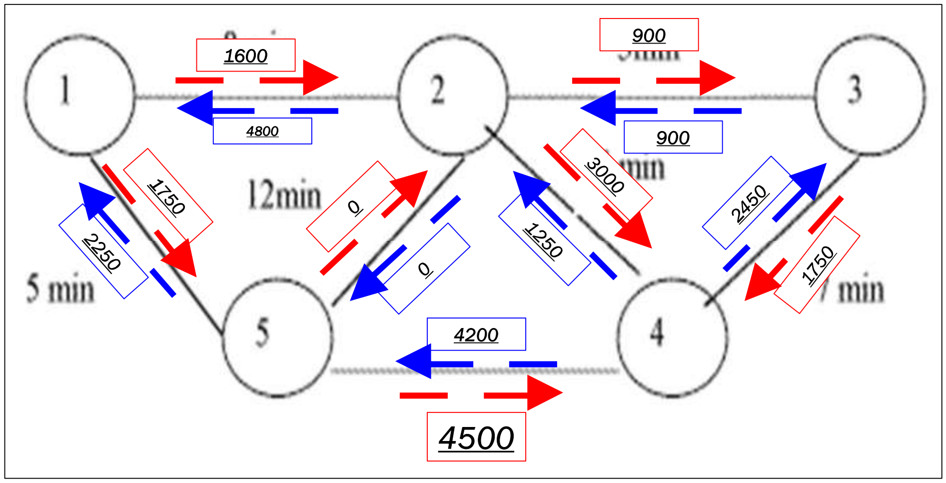
Solution of Example No.1 (Example 12.10) : Using of Skim tree

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



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	

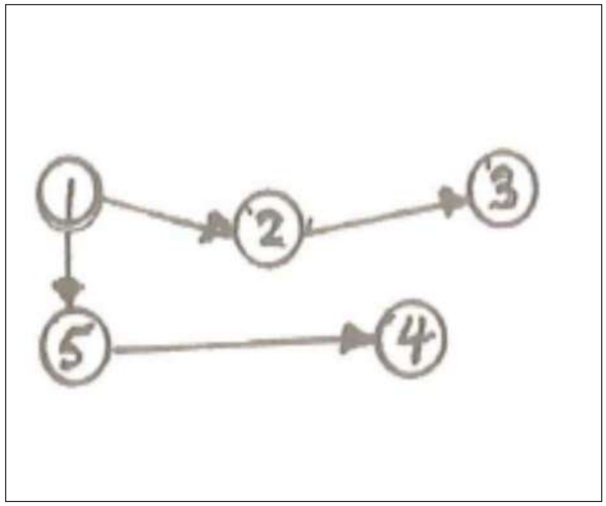
	Trips between Zones					
From/to	1	2	3	4	5	Total
1	-	100	100	200	150	
2	400	-	200	100	500	
3	200	100	-	100	150	
4	250	150	300	-	400	
5	200	100	50	350	-	

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

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		
1	2	1-2	1
	3	1-2,2-3	2
	4	1-5,5-4	3
	5	1-5	4



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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		
2	1	2-1	5
	3	2-3	6
	4	2-4	7
	5	2-4,4-5	8

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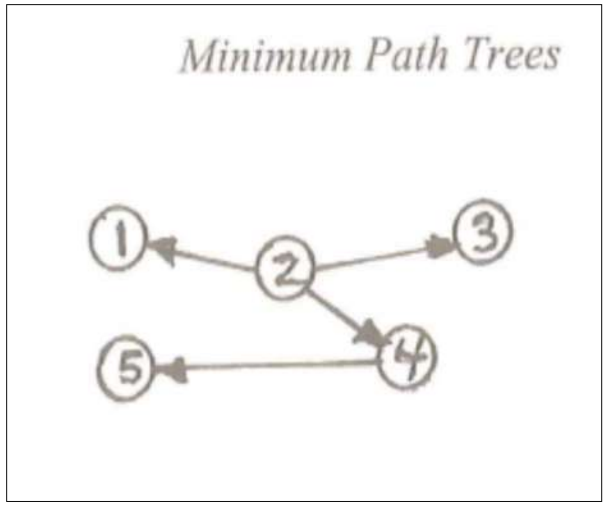
Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 7: Draw the minimum path (skim trees) at each node (cont.)

Nodes		Shortest Path	Path ID
From	To		
2	1	2-1	5
	3	2-3	6
	4	2-4	7
	5	2-4,4-5	8



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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		
3	1	3-2,2-1	9
	2	3-2	10
	4	3-4	11
	5	3-4,4-5	12

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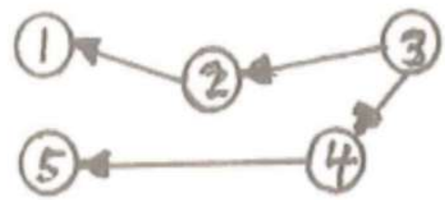
Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 7: Draw the minimum path (skim trees) at each node (cont.)

Nodes		Shortest Path	Path ID
From	To		
3	1	3-2,2-1	9
	2	3-2	10
	4	3-4	11
	5	3-4,4-5	12



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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		
4	1	4-5,5-1	13
	2	4-2	14
	3	4-3	15
	5	4-5	16

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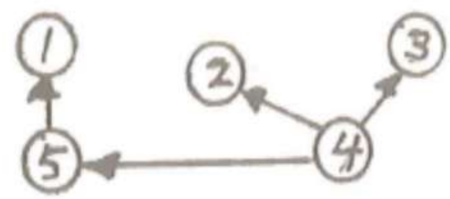
Solution of Example No.1 (Example 12.10) : Using of Skim tree

Step 7: Draw the minimum path (skim trees) at each node (cont.)

Nodes		Shortest Path	Path ID
From	To		
4	1	4-5,5-1	13
	2	4-2	14
	3	4-	15
	5	4-5	16



Solution of Example No.1 (Example 12.10) : Using of Skim tree

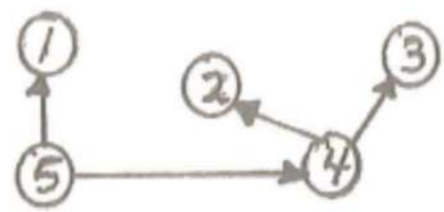
Step 7: Draw the minimum path (skim trees) at each node (cont.)

Nodes		Shortest Path	Path ID
From	To		
5	1	5-1	17
	2	5-4,4-2	18
	3	5-4,4-3	19
	4	5-4	20

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		
5	1	5-1	17
	2	5-4,4-2	18
	3	5-4,4-3	19
	4	5-4	20



What Next

- The process of calculating the travel demand for an urban transportation system is now completed.
- The results of this work will be used to
  - *Determine where improvements will be needed in the system*
  - *Make economic evaluations of project priority*
  - *Assist in the geometric and pavement design phases*

Transportation Engineering and Planning (110 401367)

Fall 2021-2022

Module No. 3

3.1 _ Foundations of Engineering Economy

Dr. Hamza Alkuime

1

Major Topics To Be Covered

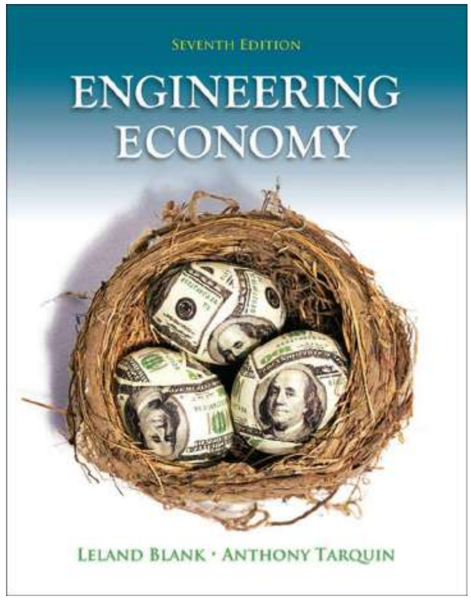
Topics	No. of Weeks	Contact hours*
1. Introduction to transportation systems	1/3	1
2. Transportation planning	1	3
3. Demand forecasting using 4 steps modeling	4	12
4. Engineering economy in transportation	3	9
5. Evaluation of transportation alternatives	2	6
6. Urban mass transit systems	3 2/3	11
7. Airports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

2

Engineering Economy

References

- Leland Blank and Anthony Tarquin, ***Engineering Economy***, 7th Edition,. McGraw-Hill, 2005



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Engineering Economy

Definition

- It deals with the concepts and techniques of analysis useful in evaluating the worth of systems, products, and services in relation to their costs

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Engineering Economy

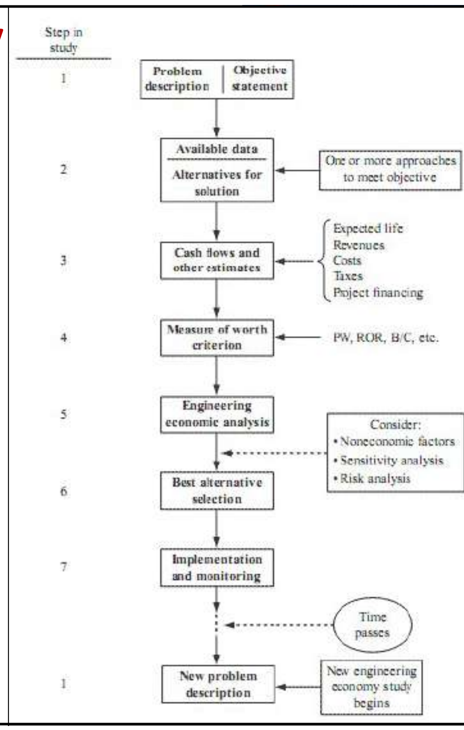
Importance

It is used to answer many different questions

- ***Which engineering projects are worthwhile?***
  - Has the civil engineer shown that constructing a new road is worth developing?
- ***Which engineering projects should have a higher priority?***
  - Has the civil engineer shown which transit improvement projects should be funded with the available budget?
- ***How should the engineering projects be designed?***
  - Has civil engineer chosen the best alignment for the proposed roadway?

Performing an Engineering Economy

1. Identify and understand the problem; identify 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; consider noneconomic factors; use sensitivity analysis as needed.
6. Select the best alternative.
7. Implement the solution and monitor the results.



Engineering Economy

Terminology and Symbols

- *t* = time
  - *stated in periods; years, months, days*
- *P* = value or amount of money at a time designated as the present or time = 0.
  - *Also P is referred to as present worth (PW), present value (PV), net present value (NPV), discounted cash flow (DCF), and capitalized cost (CC);*
  - *monetary units, such as dollars*
- *F* = value or amount of money at some future time.
  - *Also F is called future worth (FW) and future value (FV);*
  - *dollar*

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Terminology and Symbols

- *A* = **series** of consecutive, equal, end-of-period amounts of money.
  - *Also A is called the annual worth (AW) and equivalent uniform annual worth (EUAW);*
  - *dollars per year, euros per month*
- *i* = interest rate per time period
  - *percent per year, percent per month*
- *n* = number of interest periods
  - *years, months, days*

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Terminology and Symbols

Notes

- The symbols *P* and *F* represent one-time occurrences:
- *A* always
  - *represents a uniform amount*
  - *occurs with the same value in each interest period for a specified number of periods*
- The interest rate *i* is expressed in percent per interest period,
  - *for example, 12% per year.*
- In general, every problem will involve
  - At least **four** of the symbols *P*, *F*, *A*, *n*, and *i*,
    - At least **three** of them estimated or known

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Terminology and Symbols

Example 1.6

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Terminology and Symbols

Example 1.6

- Today, Julie borrowed \$5000 to purchase furniture for her new house.
- She can repay the loan in either of the two ways described below.
  - *a*) Five equal annual installments with interest based on 5% per year.
  - (*b*) One payment 3 years from now with interest based on 7% per year.
  - *Determine the engineering economy symbols and their value for each option:*

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Terminology and Symbols

Solution of Example 1.6

Solution

(*a*) The repayment schedule requires an equivalent annual amount A, which is unknown.

$$P = \$5000 \qquad i = 5\% \text{ per year} \qquad n = 5 \text{ years} \qquad A = ?$$

(*b*) Repayment requires a single future amount F, which is unknown.

$$P = \$5000 \qquad i = 7\% \text{ per year} \qquad n = 3 \text{ years} \qquad F = ?$$

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Engineering Economy

Basic Concepts

- Cash flow
- Interest Rate and Time value of money
- Equivalence technique

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Cash Flow

Definition

- Cash flows are the amounts of money
  - *Estimated for future projects*
  - *Observed for project events that have taken place*
- All cash flows occur during specific time periods,
  - such as 1 month, every 6 months, or 1 year.
  - Annual is the most common time period.
- For example,
  - a payment of $10,000 once every year in December for 5 years is a series of 5 outgoing cash flows.

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Cash Flow
Cash inflows

- **Cash inflows**
  - *are the receipts, revenues, incomes, and savings generated by project and business activity.*
  - *A **plus sign** indicates a cash inflow*

Cash Inflow Estimates

- Income: JD150,000 per year from sales of solar-powered watches
- Savings: JD24,500 tax savings from capital loss on equipment salvage
- Receipt: JD750,000 received on large business loan plus accrued interest
- Savings: JD150,000 per year saved by installing more efficient air conditioning
- Revenue: JD50,000 to JD75,000 per month in sales for extended battery life iPhones

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Cash Flow
Cash outflows

- **Cash outflows**
  - Are costs, disbursements, expenses, and taxes caused by projects and business Cash flow activity.
  - A **negative or minus sign** indicates a cash outflow.

Cash Outflow Estimates

- Operating costs: JD230,000 per year annual operating costs for software services
- First cost: JD800,000 next year to purchase replacement equipment
- Expense: JD20,000 per year for loan interest payment to bank
- Initial cost: JD1 to JD1.2 million in capital expenditures for a water recycling unit

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Engineering Economy

Net cash flow

$$\text{Net cash flow} = \text{cash inflows} - \text{cash outflows}$$
$$\text{NCF} = R - D$$

- Where:
  - *NCF is net cash flow*
  - *R is receipts*
  - *D is disbursements.*

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Engineering Economy

Categories of Cash Flows

- The expenses and receipts due to **engineering projects** usually fall into one of the following categories:
  1. *First cost (Capital):*
     - expense to build or to buy and install
  2. *Operations and maintenance (O&M):*
     - annual expense, such as electricity, labor, and minor repairs
  3. *Salvage value:*
     - receipt at project termination for sale or transfer of the equipment (can be a salvage cost)
  4. *Revenues:*
     - annual receipts due to sale of products or services
  5. *Overhaul:*
     - major capital expenditure that occurs during the asset's life

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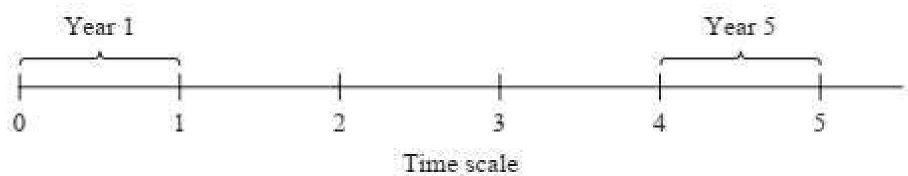
Cash Flow

Cash Flow diagrams (CFD)

- It is a graphical representation of cash flows drawn on the *y* axis with a time scale on the *x* axis
- The diagram includes
  - *what is known*
  - *what is estimated*
  - *what is needed*

Figure 1–4
A typical cash flow time scale for 5 years.



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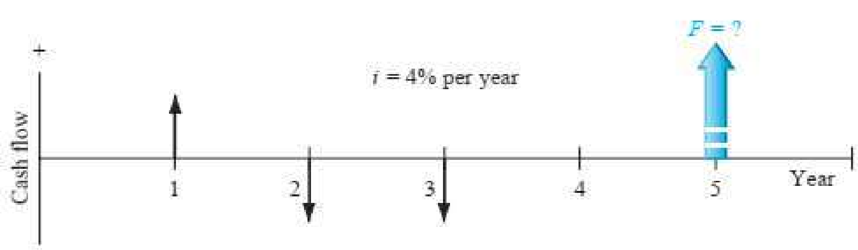
Cash Flow

Cash Flow diagrams (CFD)

- The direction of the arrows on the diagram is important
  - *to differentiate income from outgo.*
    - A vertical arrow pointing up indicates a positive cash flow.
    - A down-pointing arrow indicates a negative cash flow

Figure 1–5
Example of positive and negative cash flows.



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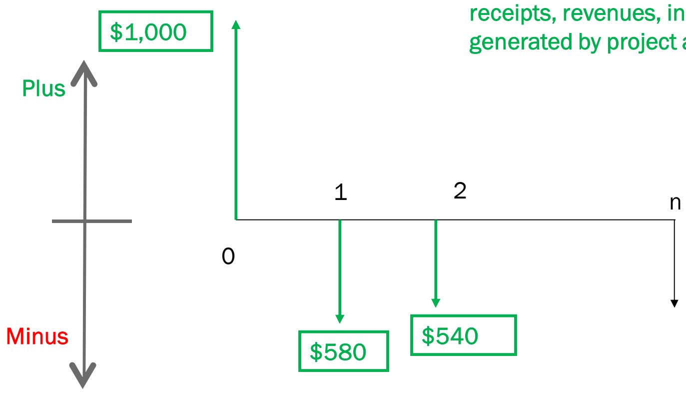
Cash Flow

Cash Flow Diagram

Cash inflow:

receipts, revenues, incomes, and savings generated by project and business activity.



Cash outflow:

costs, disbursements, expenses, and taxes caused by projects and business Cash flow activity.

Cash Flow Diagram

Example 1.8

Cash Flow Diagram

Example -1.8

- 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, or 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

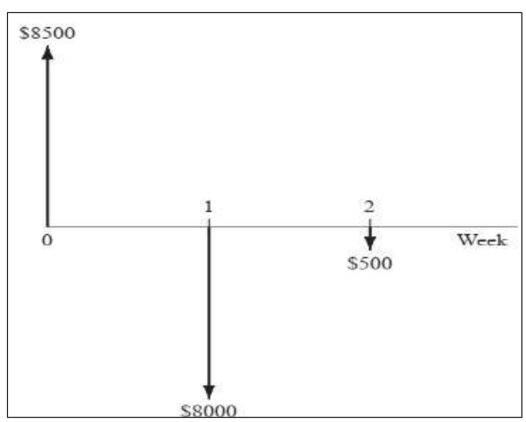
Cash flows from perspective of borrower for loan and purchases

Cash Flow Diagram

Solution of Example -1.8

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.

Cash Flow Diagram

Example 1.9

Cash Flow Diagram

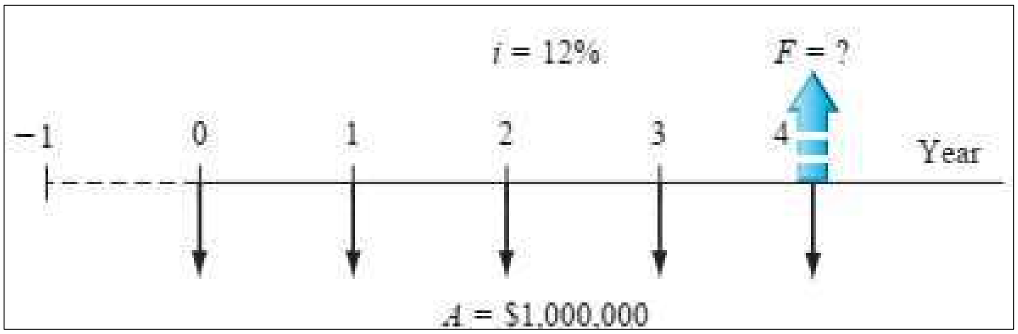
Example 1.9

- Each year Exxon-Mobil expends large amounts of funds for mechanical safety features throughout its worldwide operations.
- Carla Ramos, a lead engineer for Mexico and Central American operations, plans expenditures of $1 million *now* and each of the next 4 years just for the improvement of field-based pressure-release valves.
- Construct the cash flow diagram to find the equivalent value of these expenditures at the end of year 4, using a cost of capital estimate for safety-related funds of 12% per year

Cash Flow Diagram

Solution of Example 1.9

- Each year Exxon-Mobil expends large amounts of funds for mechanical safety features throughout its worldwide operations. Carla Ramos, a lead engineer for Mexico and Central American operations, plans expenditures of $1 million now and each of the next 4 years just for the improvement of field-based pressure-release valves. Construct the cash flow diagram to find the equivalent value of these expenditures at the end of year 4, using a cost of capital estimate for safety-related funds of 12% per year



Cash Flow Diagram

Example 1.10

Cash Flow Diagram

Example 1.10

- An electrical engineer wants to deposit an amount *P* now such that she can withdraw an equal annual amount of ***A1* $2000** per year for the **first 5 years, starting 1 year after the deposit,** and a different annual withdrawal of ***A2* $3000** per year **for the following 3 years.**
- How would the cash flow diagram appear if ***i* 8.5% per year**?

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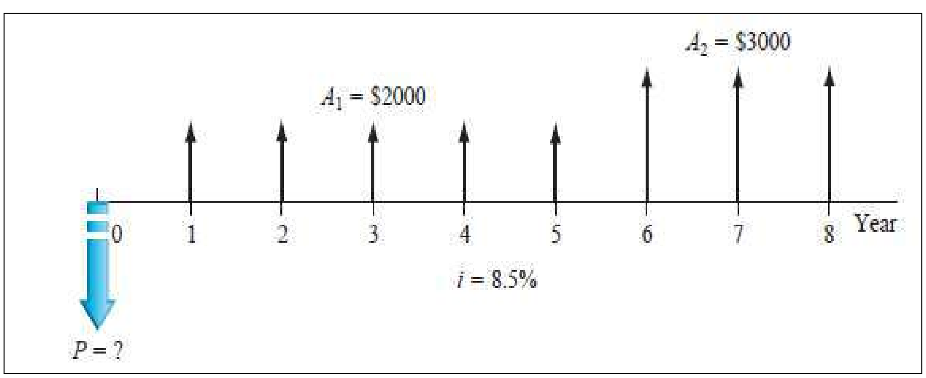
Cash Flow Diagram

Solution of Example 1.10

- An electrical engineer wants to deposit an amount *P* now such that she can withdraw an equal annual amount of ***A1* $2000** per year for the **first 5 years, starting 1 year after the deposit,** and a different annual withdrawal of ***A2* $3000** per year **for the following 3 years.** How would the cash flow diagram appear if ***i* 8.5% per year**?



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Cash Flow Diagram

Example 1.11

Cash Flow Diagram

Example 1.11

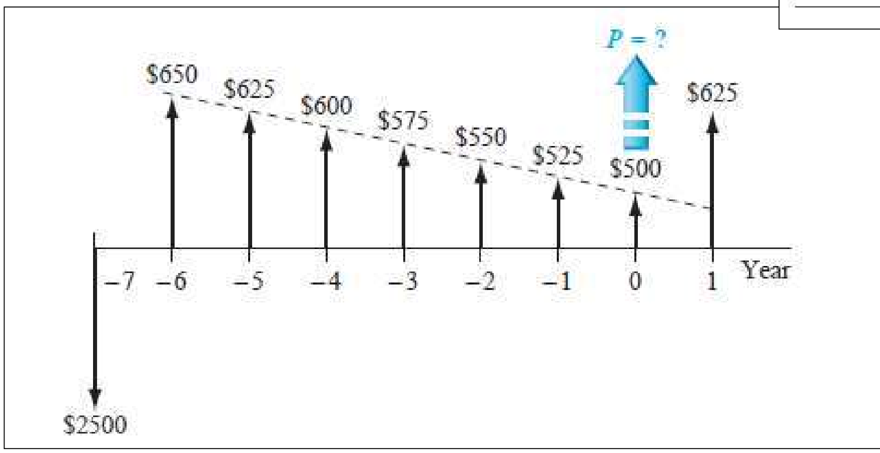
- A rental company **spent $2500 on a new air compressor 7 years ago**.
  - *The **annual rental income from the compressor has been $750**.*
  - *The **$100 spent on maintenance the first year** has **increased each year by $25**.*
  - *The company plans **to sell the compressor at the end of next year** for **$150**.*
- Construct the cash flow diagram from the *company's* **perspective** and indicate where the present worth now is located.

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

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



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Interest Rate and Rate of Return

- Interest is the manifestation of the time value of money.
- Computationally, interest is
  - *The difference between an ending amount of money and the beginning amount.*
  - *If the difference is zero or negative, there is* ***no*** *interest.*
- There are always two perspectives to an amount of interest
  - *Interest paid*
  - *Interest earned*

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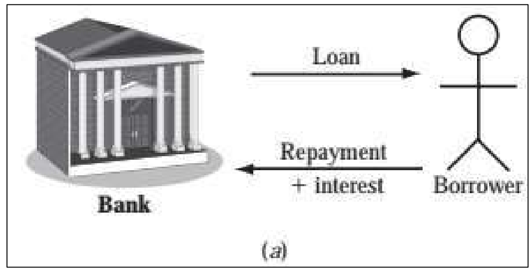
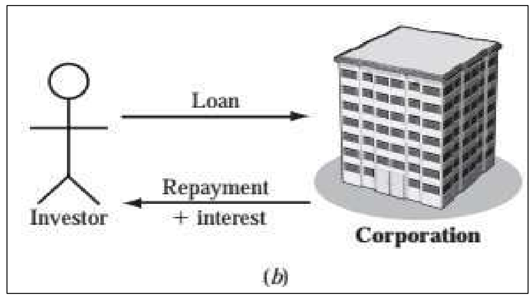
Interest Rate and Rate of Return

- **Interest is paid**
  - When a person or organization borrowed money (obtained a loan) and repays a larger amount over time.
- **Interest is earned**
  - When a person or organization saved, invested, or lent money and obtains a return of a larger amount over time





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Interest Rate and Rate of Return

Interest paid

- **Interest paid** on borrowed funds (a loan) is determined using the original amount, also called the *principal*,

$$\text{Interest} = \text{amount owed now} - \text{principal} \qquad [1.1]$$

- **Interest rate**
  - *When interest paid over a specific time unit is expressed as a percentage of the principal, the result is called the **interest rate***
  - *The time unit of the rate is called the **interest period.***

$$\text{Interest rate (\%)} = \frac{\text{interest accrued per time unit}}{\text{principal}} \times 100\% \qquad [1.2]$$

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Interest Rate and Rate of Return

Interest earned

- **Interest earned**
  - *Is the final amount minus the initial amount, or principal.*
  - $$\text{Interest earned} = \text{total amount now} - \text{principal} \qquad [1.3]$$
- **Rate of return (ROR)** (Or **return on investment [ROI]**)
  - Interest earned over a specific period of time is expressed as a percentage of the original amount
  - The time unit for rate of return is called the **interest period,**
  - The most common period is 1 year

$$\text{Rate of return (\%)} = \frac{\text{interest accrued per time unit}}{\text{principal}} \times 100\% \qquad [1.4]$$

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Interest Rate and Rate of Return

Example 1.3

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Interest Rate and Rate of Return

Example 1.3

- An employee at LaserKinetics.com borrows $10,000 on May 1 and must repay a total of $10,700 exactly 1 year later.
- Determine the interest amount and the interest rate paid.

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Interest Rate and Rate of Return

Solution of Example 1.3

Solution

The perspective here is that of the borrower since $10,700 repays a loan. Apply Equation [1.1] to determine the interest paid.

$$\text{Interest paid} = \$10{,}700 - 10{,}000 = \$700$$

Equation [1.2] determines the interest rate paid for 1 year.

$$\text{Percent interest rate} = \frac{\$700}{\$10{,}000} \times 100\% = 7\% \text{ per year}$$

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Interest Rate and Rate of Return

Example 1.4

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Interest Rate and Rate of Return

Example 1.4

- Stereophonics, Inc., plans to borrow $20,000 from a bank for 1 year at 9% interest for new recording equipment.
- Compute the interest and the total amount due after 1 year.

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Interest Rate and Rate of Return

Solution of Example 1.4

(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.

$$\text{Total due} = \$20{,}000 + 1800 = \$21{,}800$$

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Interest Rate and Rate of Return

Example 1.5

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Interest Rate and Rate of Return

Example 1.5

- (*a*) Calculate the amount deposited 1 year ago to have $1000 now at an interest rate of 5% per year.
- (*b*) Calculate the amount of interest earned during this time period.

Interest Rate and Rate of Return

Solution of Example 1.5

(*a*) The total amount accrued ($1000) is the sum of the original deposit and the earned interest. If X is the original deposit,

$$\text{Total accrued} = \text{deposit} + \text{deposit(interest rate)}$$

$$\$1000 = X + X(0.05) = X(1 + 0.05) = 1.05X$$

The original deposit is

$$X = \frac{1000}{1.05} = \$952.38$$

(*b*) Apply Equation [1.3] to determine the interest earned.

$$\text{Interest} = \$1000 - 952.38 = \$47.62$$

Interest Rate and Rate of Return

Inflation

- Inflation represents a decrease in the value of a given currency.
  - *That is, $10 now will not purchase the same amount of gasoline for your car (or most other things) as $10 did 10 years ago.*
- The changing value of the currency **affects** market interest rates
- In simple terms, interest rates **reflect** two things: a so-called real rate of return *plus* the expected inflation rate.
  - *The real rate of return allows the investor to purchase more than he or she could have purchased before the investment*
  - *while inflation raises the real rate to the market rate that we use on a daily basis*

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Economic Equivalence

Definition

- is a **combination** of **interest rate** and **time value of money** to **determine** the different amounts of money at different points in time that are equal in economic value.

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Economic Equivalence

Interest rate

- Definitions
  - *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
  - *Two types of Interest*
    - Simple interest
    - Compound interest

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Economic Equivalence

Simple interest

- 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.

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Economic Equivalence

Simple interest

- The total interest, **I**, earned or paid may be computed using the formula below.

Simple interest = (principal)(number of periods)(interest rate) [1.7]

$$I = Pni$$

P = principal amount lent or borrowed

N = number of interest periods (e.g., years)

i = interest rate per interest period

- **The total amount repaid at the end of *N* interest periods is *P + I*.**

Simple interest

Example 1.14

Simple interest

Example 1.14

- Greentree Financing lent an engineering company $100,000 to retrofit an environmentally unfriendly building.
- The loan is for 3 years at 10% per year simple interest.
- How much money will the firm repay at the end of 3 years?

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Simple interest

Solution of Example 1.14

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.

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Economic Equivalence

Compound interest

- Interest that is computed on
  - *The original unpaid debt (principle)*
  - *The unpaid interest (interest on top of interest !!!)*
- In most financial and economic analyses
  - *we use **compound interest***

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Economic Equivalence

Compound interest

In mathematical terms, the interest I_t for time period t may be calculated using the relation.

$$I_t = \left(P + \sum_{j=1}^{j=t-1} I_j \right)(i) \qquad [1.9]$$

I_t = *interest for time period t*

P = principal amount lent or borrowed

t = time period

i = interest rate per interest period

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Economic Equivalence

Future Value of a Loan With Compound Interest

$$\text{Total due after } n \text{ years} = \text{principal}(1 + \text{interest rate})^{n \text{ years}} = P(1+i)^n \quad [1.10]$$

I_t = interest for time period t

P = principal amount lent or borrowed

t = time period

i = interest rate per interest period

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Economic Equivalence

Example 1.15

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Economic Equivalence

Example 1.15

- Assume an engineering company borrows $100,000 at 10% per year <u>compound interest</u> and will pay the principal and all the interest after 3 years.
- Compute the annual interest and total amount due after 3 years.
- Graph the interest and total owed for each year,
- Compare with simple interest

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Economic Equivalence

Solution of Example 1.15

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

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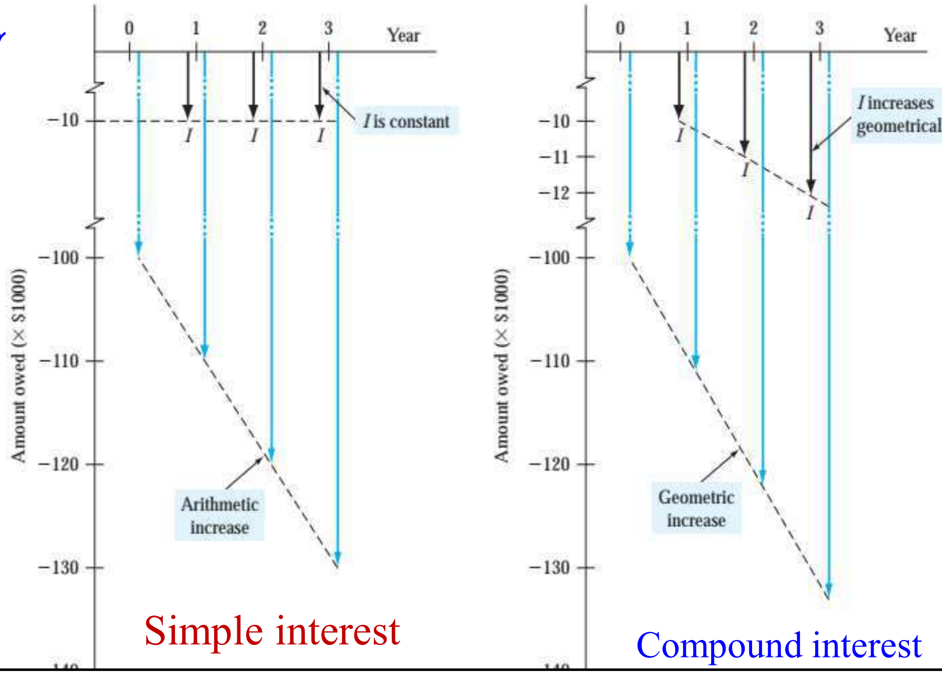
Economic Equivalence

Solution of Exam

- **An extra**
- **$133,100 – 130,000 = $3100 in interest is due for thecompounded interest loan**



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Engineering Economy

Terminology and Symbols

- *t* = time
  - *stated in periods; years, months, days*
- *P* = value or amount of money at a time designated as the present or time = 0.
  - *Also P is referred to as present worth (PW), present value (PV), net present value (NPV), discounted cash flow (DCF), and capitalized cost (CC);*
  - *monetary units, such as dollars*
- *F* = value or amount of money at some future time.
  - *Also F is called future worth (FW) and future value (FV);*
  - *dollar*

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Terminology and Symbols

- A = **series** of consecutive, equal, end-of-period amounts of money.
  - *Also A is called the annual worth (AW) and equivalent uniform annual worth (EUAW);*
  - *dollars per year, euros per month*
- i = interest rate per time period
  - *percent per year, percent per month*
- n = number of interest periods
  - *years, months, days*

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Notes

- In general, every problem will involve
  - At least **four** of the symbols P, F, A, n, and i,
    - At least **three** of them estimated or known

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Notation for Calculating a Present Value

- We can apply compound interest formulas to "move" cash flows along the cash flow diagram.
- Using the standard notation, we find that a **present amount, P**, can **grow into a future amount, F**, in **N time periods** at **interest rate i** according to the formula below:
  - $F = P(1 + i)^N$
  - $P = \frac{F}{(1+i)^N}$ *is the* ***single payment present worth factor***.
- Functional notation:

  P=F(P/F,i,n) P=5000(P/F,6%,10)

  - *Interpretation of (P/F, i, n):*
    - a present sum P, given a future sum F, n interest periods hence at an interest rate i per interest period
    - Obtained from interest tables

Interest tables

8%	TABLE 13 Discrete Cash Flow: Compound Interest F					
	Single Payments		Uniform Series Payments			
n	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	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

(F/P, 8%, 6)= 1.5869

Notation for Calculating a Present Value

- It is common to use standard notation for interest factors.
  - *We can use these to find economically equivalent values at different points in time.*
- **single payment compound amount factor**.

$$(1+i)^N = (F/P, i, N)$$

  - *The term on the right is read "F given P at i % interest per period for N interest periods."*
- ***single payment present worth factor***

$$(1+i)^{-N} = (P/F, i, N)$$

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Notation for Calculating a Present Value

Examples

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?

$$P = \$3,000(P/F, 6\%, 7) = \$3,000(0.6651) = \$1,995$$

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Notation for Calculating a Present Value

Example 2.2

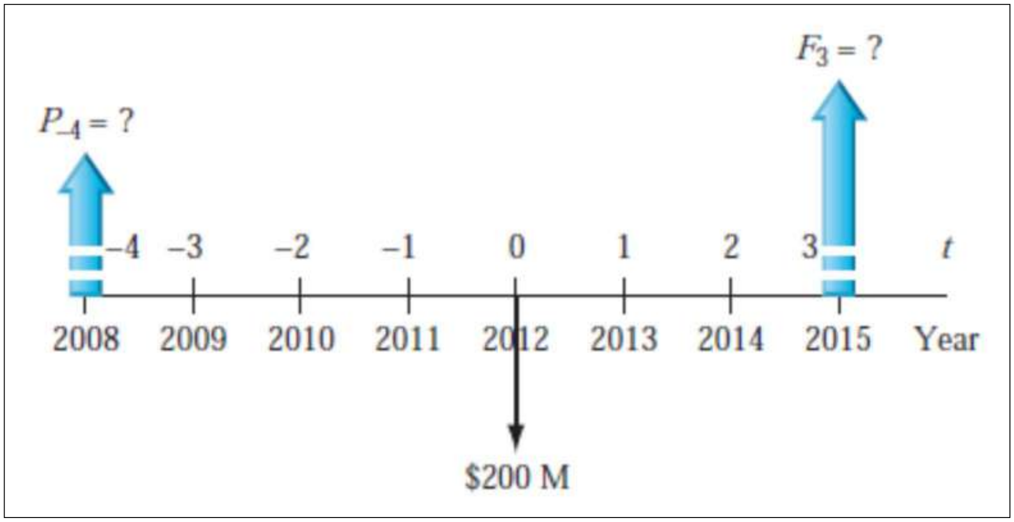
Notation for Calculating a Present Value

Example 2.2

- A Cement factory 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 plant is built in 2015**.*
  - *(b) The equivalent investment needed had the plant **been constructed in the year 2008.***

Notation for Calculating a Present Value

Solution of Example 2.2



Notation for Calculating a Present Value

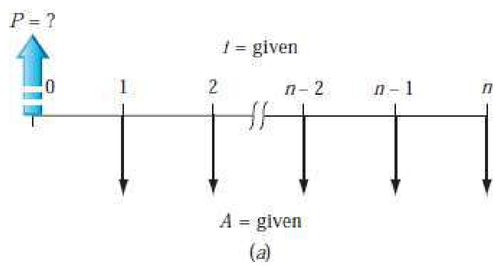
Solution of Example 2.2

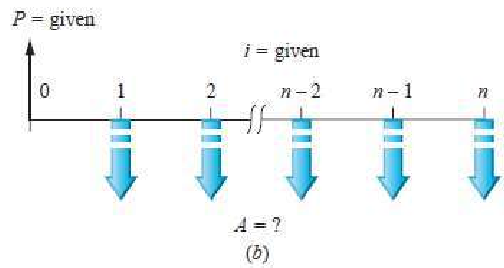
- (a) To find the equivalent investment required in 3 years, apply the F/P factor. Use $1 million units and the tabulated value for 10% interest.
  - *F3 = P(F/P,i,n) = 200(F/P, 10%, 3) = 200(1.3310)*
  - *= = $266.2 ($266,200,000)*
- (b) The year 2008 is 4 years prior to the planned construction date 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.
  - *P-4 = F(P/F,i,n) = 200(P/F,10%,4) = 200(0.6830)*
  - *= = $136.6 ($136,600,000)*

Notation for Calculating a Present Value

Uniform Series Present Worth Factor and Capital Recovery Factor (P / A and A / P)

- The equivalent present worth *P* of a uniform series *A* of end-of-period cash flows (investments)





Cash flow diagrams used to determine (*a*) *P*, given a uniform series *A*,

Cash flow diagrams used to determine A, given a present worth P

An expression for the present worth can be determined by considering each A value as a future worth F , calculating its present worth with the P/F factor,

$$P = A\left[\frac{1}{(1+i)^1}\right] + A\left[\frac{1}{(1+i)^2}\right] + A\left[\frac{1}{(1+i)^3}\right] + \cdots + A\left[\frac{1}{(1+i)^{n-1}}\right] + A\left[\frac{1}{(1+i)^n}\right]$$

$$P = A\left[\frac{1}{(1+i)^1} + \frac{1}{(1+i)^2} + \frac{1}{(1+i)^3} + \cdots + \frac{1}{(1+i)^{n-1}} + \frac{1}{(1+i)^n}\right] \qquad \text{---(1)}$$

* 1/(1+i)

$$\frac{P}{1+i} = A\left[\frac{1}{(1+i)^2} + \frac{1}{(1+i)^3} + \frac{1}{(1+i)^4} + \cdots + \frac{1}{(1+i)^n} + \frac{1}{(1+i)^{n+1}}\right] \qquad \text{---(2)}$$

(2) - (1)

$$\frac{1}{1+i}P = A\left[\frac{1}{(1+i)^2} + \frac{1}{(1+i)^3} + \cdots + \frac{1}{(1+i)^n} + \frac{1}{(1+i)^{n+1}}\right]$$

$$-\quad P = A\left[\frac{1}{(1+i)^1} + \frac{1}{(1+i)^2} + \cdots + \frac{1}{(1+i)^{n-1}} + \frac{1}{(1+i)^n}\right]$$

$$\frac{-i}{1+i}P = A\left[\frac{1}{(1+i)^{n+1}} - \frac{1}{(1+i)^1}\right]$$

$$P = \frac{A}{-i}\left[\frac{1}{(1+i)^n} - 1\right]$$

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad i \neq 0$$

Notation for Calculating a Present Value

Uniform Series Present Worth Factor and Capital Recovery Factor (P / A and A / P)

- Finding the present amount from a series of end-of-period cash flows.

$$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] = A(P/A, i\%, N)$$

- Example: How much would be needed today to provide an annual amount of \$50,000 each year for 20 years, at 9% interest each year?

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Notation for Calculating a Present Value

Uniform Series Present Worth Factor and Capital Recovery Factor (P / A and A / P)

- Finding the present amount from a series of end-of-period cash flows.

$$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] = A(P/A, i\%, N)$$

- Example: How much would be needed today to provide an annual amount of \$50,000 each year for 20 years, at 9% interest each year?

$$P = \$50,000(P/A, 9\%, N) = \$50,000(9.1285) = \$456,427$$

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Interest tables

8%	TABLE 13 Discrete Cash Flow: Compound Interest F					
	Single Payments		Uniform Series Payments			
n	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

Notation for Calculating a Present Value

Uniform Series Present Worth Factor and Capital Recovery Factor (P / A and A / P)

- Finding A when given P.

$$A = P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] = P(A/P, i\%, N)$$

- Example: If you had $500,000 today in an account earning 10% each year, how much could you withdraw each year for 25 years?

Notation for Calculating a Present Value

Uniform Series Present Worth Factor and Capital Recovery Factor (P / A and A / P)

- Finding A when given P.

$$A = P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] = P(A/P, i\%, N)$$

- Example: If you had \$500,000 today in an account earning 10% each year, how much could you withdraw each year for 25 years?

$$A = \$500,000(A/P, 10\%, 25) = \$500,000(0.1102) = \$55,100$$

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Notation for Calculating a Present Value

Example

- How much money should you be willing to pay now for a guaranteed \$600 per year for 9 years starting next year, at a rate of return of 16% per year?

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Notation for Calculating a Present Value

Example

- How much money should you be willing to pay now for a guaranteed \$600 per year for 9 years starting next year, at a rate of return of 16% per year?
- A =\$600, i = 16%, and n = 9.
- The present worth is
  - $P = 600(P/A, 16\%, 9) = 600(4.6065) = \$2763.90$

Notation for Calculating a Present Value

Example

- A Cement factory will require an investment of **\$200 million** to construct (year 2012). The plant 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?

Interest tables

10%	TABLE 15 Discrete Cash Flow: Compound Interest F					
	Single Payments		Uniform Series Payments			
n	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

Notation for Calculating a Present Value

Example – Solution

- 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.*

Notation for Calculating a Present Value

There are interest factors for a series of end-of-period cash flows.

- A = end-of-period cash flows in a uniform series continuing for a certain number of periods, starting at the end of the first period and continuing through the last

$$F = A\left[\frac{(1+i)^N - 1}{i}\right] = A(F/A, i\%, N)$$

- **Example:** How much will you have in 40 years if you save $3,000 each year and your account earns 8% interest each year?

$$F = \$3,000(F/A, 8\%, 40) = \$3,000(259.0565) = \$777,170$$

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Interest tables

8% TABLE 13 Discrete Cash Flow: Compound Interest F

	Single Payments		Uniform Series Payments			
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
14	2.9372	0.3405	0.04130	24.2149	0.12130	8.2442
15	3.1722	0.3152	0.03683	27.1521	0.11683	8.5595
16	3.4259	0.2919	0.03298	30.3243	0.11298	8.8514
17	3.7000	0.2703	0.02963	33.7502	0.10963	9.1216
18	3.9960	0.2502	0.02670	37.4502	0.10670	9.3719
19	4.3157	0.2317	0.02413	41.4463	0.10413	9.6036
20	4.6610	0.2145	0.02185	45.7620	0.10185	9.8181
21	5.0338	0.1987	0.01983	50.4229	0.09983	10.0168
22	5.4365	0.1839	0.01803	55.4568	0.09803	10.2007
23	5.8715	0.1703	0.01642	60.8933	0.09642	10.3711
24	6.3412	0.1577	0.01498	66.7648	0.09498	10.5288
25	6.8485	0.1460	0.01368	73.1059	0.09368	10.6748
26	7.3964	0.1352	0.01251	79.9544	0.09251	10.8100
27	7.9881	0.1252	0.01145	87.3508	0.09145	10.9352
28	8.6271	0.1159	0.01049	95.3388	0.09049	11.0511
29	9.3173	0.1073	0.00962	103.9659	0.08962	11.1584
30	10.0627	0.0994	0.00883	113.2832	0.08883	11.2578
31	10.8677	0.0920	0.00811	123.3459	0.08811	11.3498
32	11.7371	0.0852	0.00745	134.2135	0.08745	11.4350
33	12.6760	0.0789	0.00685	145.9506	0.08685	11.5139
34	13.6901	0.0730	0.00630	158.6267	0.08630	11.5869
35	14.7853	0.0676	0.00580	172.3168	0.08580	11.6546
40	21.7245	0.0460	0.00386	259.0565	0.08386	11.9246

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Notation for Calculating a Present Value

Example

- Finding A when given F.

$$A = F\left[\frac{i}{(1+i)^N - 1}\right] = F(A/F, i\%, N)$$

  - ***A / F or sinking fund factor***
  - *The uniform series A begins at the **end of year (period) 1** and continues **through the year of the given F.** The last A value and F occur at the same time.*

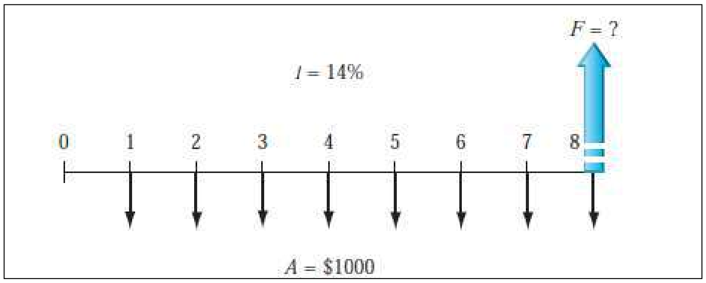
- Example: How much would you need to set aside each year for 25 years, at 10% interest, to have accumulated \$1,000,000 at the end of the 25 years?

$$A = \$1,000,000(A/F, 10\%, 25) = \$1,000,000(0.0102) = \$10,200$$

Notation for Calculating a Present Value

Example

- The president of Ford Motor Company wants to know the equivalent future worth of a \$1 million capital investment each year for 8 years, starting 1 year from now. Ford capital earns at a rate of 14% per year.
  - ***F = 1000(F/A, 14%,8) = 1000(13.2328) = \$13,232.80*1000 = \$13,232,800***



Notation for Calculating a Present Value

Example

- **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.*

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Notation for Calculating a Present Value

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?

$$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] = A(P/A, i\%, N)$$

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Notation for Calculating a Present Value

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?

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

$$\boxed{P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] = A(P/A, i\%, N)}$$

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Notation for Calculating a Present Value

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?

So,

$$\$8,000 = \$1,000(F/A, i\%, 5)$$

$$(F/A, i\%, 5) = \frac{\$8,000}{\$1,000} = 8 = \frac{(1+i)^5 - 1}{i}$$

Again, this can be solved using the interest tables and interpolation, but we generally resort to a computer solution. i= 23.69%

$$\boxed{F = A\left[\frac{(1+i)^N - 1}{i}\right] = A(F/A, i\%, N)}$$

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Minimum Attractive Rate of Return (MARR)

- For any investment to be profitable, the investor (corporate or individual) **expects to receive more money than the amount of capital invested**. I
  - *In other words, a fair* ***rate of return, or return on investment****, must be realizable.*

> The Minimum Attractive Rate of Return (MARR) is a reasonable rate of return established for the evaluation and selection of alternatives. A project is not economically viable unless it is **expected to return at least the MARR**. MARR is also referred to as the *hurdle rate, cutoff rate, benchmark rate,* and *minimum acceptable rate of return.*

- The MARR is not a rate that is calculated as a ROR.
  - ***The MARR is established by (financial) managers*** *and is used as* ***a criterion against which an alternative's ROR is measured****, when making the* ***accept/reject investment decision****.*

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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 5

5.2_ Common Economic Analysis Methods

Dr. Hamza Alkuime

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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

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Basic elements of transportation planning

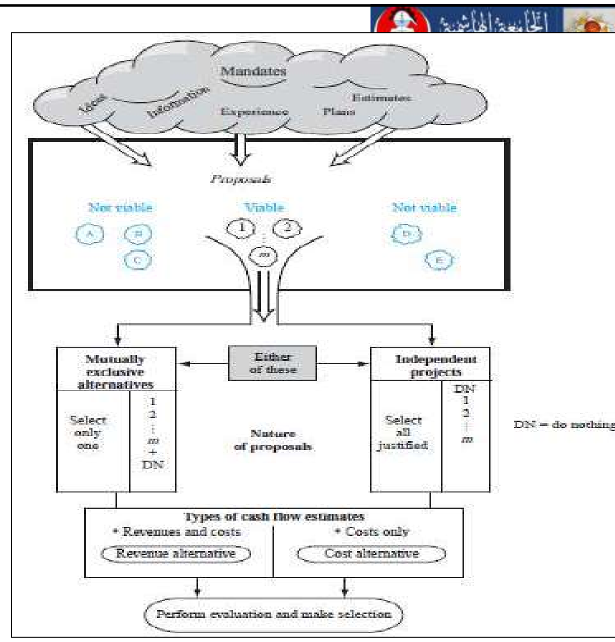
The transportation planning process comprises seven basic elements:

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*

- 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**

Basic Analysis Tools

- The nature of the economic proposals is always one of two types:
  1. ***Mutually exclusive alternatives:***
     - Only one of the proposals can be selected.
     - For terminology purposes, each viable proposal is called an alternative.
  2. ***Independent projects:***
     - More than one proposal can be selected.
     - Each viable proposal is called a project
- The ***do-nothing (DN) proposal*** is usually understood to be an option when the evaluation is performed.
  - *The DN alternative or project* ***means*** *that the* ***current approach is maintained;*** *nothing new is initiated. No new costs, revenues, or savings are generated.*
- Mutually exclusive alternatives **compete with one another (and the with the DN project)** and are compared pairwise.
- Independent projects are evaluated one at a time and **compete only with the DN project.**



Economic Analysis Methods

Commonly used economic analysis methods are:

- Present Worth (PW) Analysis
- Annual Worth Analysis
- Benefit/Cost Analysis
- Rate of Return Analysis

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Common Economic Analysis Methods

Method 1 : Present Worth (PW) Analysis

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Method 1 : Present Worth (PW) Analysis

- The present worth method is quite popular in industry because
  - *All future costs and revenues are **transformed** to **equivalent monetary units NOW;***
    - That is, all future cash flows are converted (discounted) to present amounts (e.g., dollars) at a specific rate of return, which is the **MARR**.
- Approaches

  A. *Present Worth (PW) Analysis of Equal-Life Alternatives*

  B. *Present Worth Analysis of Different-Life Alternatives*

  C. *Capitalized Cost Analysis*

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A. Present Worth (PW) Analysis of Equal-Life Alternatives

Mutually exclusive (ME) alternatives selection

The following guidelines are applied to justify a single project or to select one from several alternatives:

- **One alternative:**
  - *If PW > 0 and the requested MARR is **met** or exceeded*
  - *The alternative is economically justified*
- **Two or more alternatives:**
  - Select the alternative with the PW that is **numerically largest**
    - That is, less negative or more positive.
  - This indicates a lower PW of cost for cost alternatives or a larger PW of net cash flows for revenue alternatives.

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Common Economic Analysis Methods

Method 1 : Present Worth (PW) Analysis

A. Present Worth (PW) Analysis of Equal-Life Alternatives

A. Present Worth (PW) Analysis of Equal-Life Alternatives

Mutually exclusive (ME) alternatives selection

Which alternative would you select ?

PW_A	PW_B
\$−2300	\$−1500
−500	+1000
+2500	+2000
+4800	−400

A. Present Worth (PW) Analysis of Equal-Life Alternatives

Mutually exclusive (ME) alternatives selection

Which alternative would you select ?

PW_A	PW_B	Selected Alternative
$-2300	$-1500	B
−500	+1000	B
+2500	+2000	A
+4800	−400	A

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A. Present Worth (PW) Analysis of Equal-Life Alternatives

Independent projects selection

For independent projects, each PW is considered separately,

- *that is, compared with the DN project, which always has PW = 0.*

The selection guideline is as follows:

- ***One or more independent projects:***
  - Select all projects with PW >= 0 at the MARR
- *The independent projects must have positive and negative cash flows to obtain a PW value that can exceed zero;*
  - that is, they must be revenue projects.

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A. Present Worth (PW) Analysis of Equal-Life Alternatives

Example 5.1

During lab research, three equal-service machines need to be evaluated economically. Perform the present worth analysis with the costs shown below. The MARR is 10% per year.

	Electric-Powered	Gas-Powered	Solar-Powered
First cost, $	−4500	3500	−6000
Annual operating cost (AOC), $/year	−900	−700	−50
Salvage value *S*, $	200	350	100
Life, years	8	8	8

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10% TABLE 15 Discrete Cash Flow: Compound Interest Fa

	Single Payments		Uniform Series Payments			
n	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

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A. Present Worth (PW) Analysis of Equal-Life Alternatives

Independent projects selection - *Example 5.1 –Solution*

Solution

These are cost alternatives. The salvage values are considered a "negative" cost, so a + sign precedes them. (If it costs money to dispose of an asset, the estimated disposal cost has a − sign.) The PW of each machine is calculated at $i = 10\%$ for $n = 8$ years. Use subscripts E, G, and S.

$$PW_E = -4500 - 900(P/A,10\%,8) + 200(P/F,10\%,8) = \$-9208$$
$$PW_G = -3500 - 700(P/A,10\%,8) + 350(P/F,10\%,8) = \$-7071$$
$$PW_S = -6000 - 50(P/A,10\%,8) + 100(P/F,10\%,8) = \$-6220$$

The solar-powered machine is selected since the PW of its costs is the lowest; it has the numerically largest PW value.

Common Economic Analysis Methods

Method 1 : Present Worth (PW) Analysis

B. Present Worth Analysis of Different-Life Alternatives

B. Present Worth Analysis of Different-Life Alternatives

- When the present worth method is used to compare **mutually exclusive alternatives that have different lives**, the **equal-service requirement must** be met.
- The procedure of method A (Present Worth (PW) Analysis of Equal-Life Alternatives) is followed, with **one exception** for that the PW of the alternatives must:
  - ***be compared*** *over the same number of years*
  - *end at the same time to satisfy the equal-service requirement*

B. Present Worth Analysis of Different-Life Alternatives

Approaches

- The equal-service requirement is satisfied by using either of two approaches:

1. **Least Common Multiple (LCM)**
   - Compare the PW of alternatives over a period of time equal to the **least common multiple (LCM)** of their estimated lives.
2. **Study period:**
   - Compare the PW of alternatives using a **specified study period of n years.**
   - This approach does not necessarily consider the useful life of an alternative.
   - The study period is also called the planning horizon

- For **independent projects**
  - *use of the LCM approach is* ***unnecessary*** *since each project is* ***compared to the do-nothing alternative****, not to each other, and satisfying the equal-service requirement is not a problem.*
  - *Simply use the MARR to determine the PW over the respective life of each project and* ***select all projects with a PW ≥ 0****.*

B. Present Worth Analysis of Different-Life Alternatives

Least common multiple (LCM) appraoch

- For either approach, **calculate the PW at the MARR** and use the same selection guideline as that **for equal-life alternatives.**
- The **LCM approach makes the cash flow estimates extend to the same period**, as required.
  - *For example, lives of 3 and 4 years are compared over a 12-year period*
- The assumptions when using the LCM approach are that:
  - ***1.** The service provided will be needed over the entire LCM years or more.*
  - ***2.** The selected alternative can be repeated over each life cycle of the LCM in exactly the same manner.*
  - ***3.** Cash flow estimates are the same for each life cycle*

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B. Present Worth Analysis of Different-Life Alternatives

Study Period Approach

- A time horizon is chosen over which the economic analysis is conducted, and **only those cash flows which occur during that time period are considered** relevant to the analysis.
- All cash flows occurring **beyond the study period are ignored.**
- An estimated market value at the end of the study period must be made.
- The **time horizon chosen might be relatively short**,
  - *especially when short-term business goals are very important.*

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B. Present Worth Analysis of Different-Life Alternatives

Example 5.3

- Two manufacturers offered the estimates below.

	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

a. Determine which vendor should be selected on the basis of a present worth comparison, if the **MARR is 15% per year**.

b. The company has a standard practice of evaluating all options **over a 5-year period**. If a study period of **5 years is used and the salvage values are not expected to change**, which vendor should be selected?

15% **TABLE 19** Discrete Cash Flow: Compound Interest Fa

	Single Payments		Uniform Series Payments			
n	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

B. Present Worth Analysis of Different-Life Alternatives

Example 5.3 – Solution (part a)

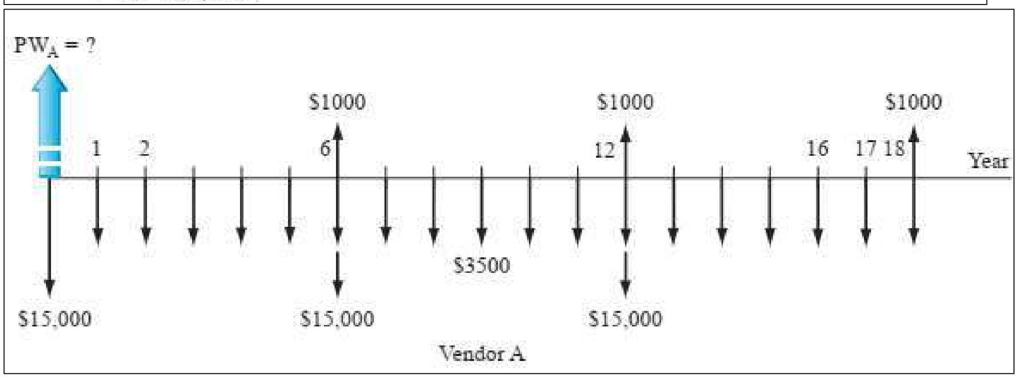
- Since the equipment has different lives,
  - *Compare them over the LCM of 18 years.*
- For life cycles after the first, the first cost is repeated in year 0 of each new cycle, which is the last year of the previous cycle.
  - *These are*
    - Years 6 and 12 for vendor A
    - Year 9 for B.

B. Present Worth Analysis of Different-Life Alternatives

Example 5.3 – Solution (part a)

Vendor A

$$
\begin{aligned}
PW_A = & -15{,}000 - 15{,}000(P/F,15\%,6) + 1000(P/F,15\%,6) \\
& -15{,}000(P/F,15\%,12) + 1000(P/F,15\%,12) + 1000(P/F,15\%,18) \\
& -3{,}500(P/A,15\%,18) \\
= & \$-45{,}036
\end{aligned}
$$

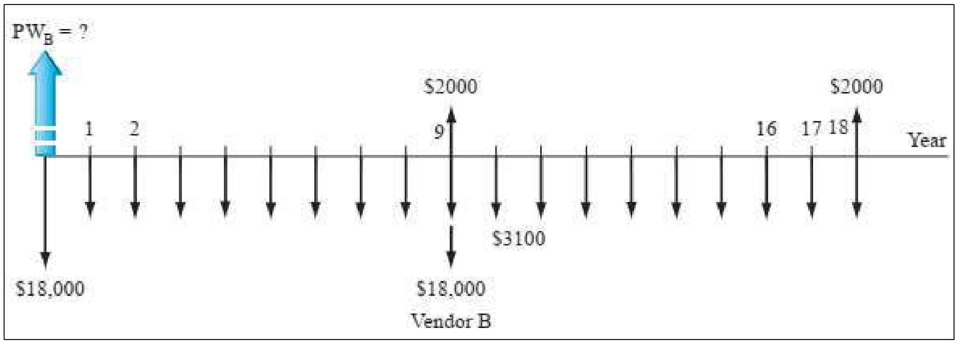


B. Present Worth Analysis of Different-Life Alternatives

Example 5.3 – Solution (part a)

Vendor B

$$PW_B = -18{,}000 - 18{,}000(P/F,15\%,9) + 2000(P/F,15\%,9) + 2000(P/F,15\%,18) - 3100(P/A,15\%,18) = \$-41{,}384$$



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B. Present Worth Analysis of Different-Life Alternatives

Example 5.3 – Solution (part a)

$$PW_A = -15{,}000 - 15{,}000(P/F,15\%,6) + 1000(P/F,15\%,6) - 15{,}000(P/F,15\%,12) + 1000(P/F,15\%,12) + 1000(P/F,15\%,18) - 3{,}500(P/A,15\%,18) = \$-45{,}036$$

$$PW_B = -18{,}000 - 18{,}000(P/F,15\%,9) + 2000(P/F,15\%,9) + 2000(P/F,15\%,18) - 3100(P/A,15\%,18) = \$-41{,}384$$

Vendor B is selected

since it costs less in PW terms; that is, the PW_B value is numerically larger than PW_A

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B. Present Worth Analysis of Different-Life Alternatives

Example 5.3 – Solution (part B)

(*b*) For a 5-year study period, no cycle repeats are necessary. The PW analysis is

$$PW_A = -15{,}000 - 3500(P/A,15\%,5) + 1000(P/F,15\%,5) = \$-26{,}236$$

$$PW_B = -18{,}000 - 3100(P/A,15\%,5) + 2000(P/F,15\%,5) = \$-27{,}397$$

- 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,
  - *That is, LCM or fixed study period, is used to satisfy the equal-service requirement.*

Common Economic Analysis Methods

Method 1 : Present Worth (PW) Analysis

C. Capitalized Cost Analysis

C. Capitalized Cost Analysis

- Many public sector projects have very long expected useful lives.
  - *For example bridges, dams, highways and toll roads, railroads, and hydroelectric and other power generation facilities*
  - *A **perpetual or infinite life** is the effective planning horizon.*
  - *The **economic worth** of these types of **projects or endowments** is evaluated using the **present worth of the cash flows**.*
- **Capitalized Cost (CC)**
  - *is the present worth of a project that has a very long life (more than, say, 35 or 40 years) or when the planning horizon is considered very long or infinite.*

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C. Capitalized Cost Analysis

- Replace the symbols *P* and PW with CC (capitalized cost) equivalence.
  - *Since the A value can also be termed AW for annual worth, the capitalized cost formula is simply*

$$P = A\left[\frac{1 - \frac{1}{(1+i)^n}}{i}\right]$$

$$CC = \frac{A}{i} \quad \text{or} \quad CC = \frac{AW}{i} \qquad [5.1]$$

Since n = ∞

P/A = A* (P/A, i, n) = A / i = CC =PW

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C. Capitalized Cost Analysis

- The cash flows (costs, revenues, and savings) in a capitalized cost calculation are usually of three types:
  - *Recurring (or periodic)*
    - For example: An annual operating cost of $50,000
    - A rework cost estimated at $40,000 every 12 years
  - *Nonrecurring*
    - For example:
      - the initial investment amount in year 0 and one-time cash flow estimates at future times
      - $500,000 in fees 2 years.
  - *Annual*
    - 10,000 /year

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C. Capitalized Cost Analysis

Procedures

The procedure to determine the CC for an infinite sequence of cash flows is as follows:

1. Draw a cash flow diagram showing all nonrecurring (one-time) cash flows and **at least two cycles** of all recurring (periodic) cash flows.
2. Find the present worth of all nonrecurring amounts. This is their CC value.
3. Find the *A* value through *one life cycle* of all recurring amounts.
   - *This is the same value in ball succeeding life cycles.*
   - *Add this to all other uniform amounts (A) occurring in years 1 through infinity. The result is the total equivalent uniform annual worth (AW).*
4. Divide the AW obtained in step 3 by the interest rate *i* to obtain a CC value.
   - *This is an application of Equation [5.1].*
5. Add the CC values obtained in steps 2 and 4

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C. Capitalized Cost Analysis

Example 5.6

- 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:

  a. 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.

C. Capitalized Cost Analysis

Procedures

The procedure to determine the CC for an infinite sequence of cash flows is as follows:

1. Draw a cash flow diagram showing all nonrecurring (one-time) cash flows and at least two cycles of all recurring (periodic) cash flows.
2. Find the present worth of all nonrecurring amounts. This is their CC value.
3. Find the *A* value through *one life cycle* of all recurring amounts.
   - *This is the same value in ball succeeding life cycles.*
   - *Add this to all other uniform amounts (A) occurring in years 1 through infinity. The result is the total equivalent uniform annual worth (AW).*
4. Divide the AW obtained in step 3 by the interest rate *i* to obtain a CC value.
   - *This is an application of Equation [5.1].*
5. Add the CC values obtained in steps 2 and 4

5% TABLE 10 Discrete Cash Flow: Compound Interest Fa

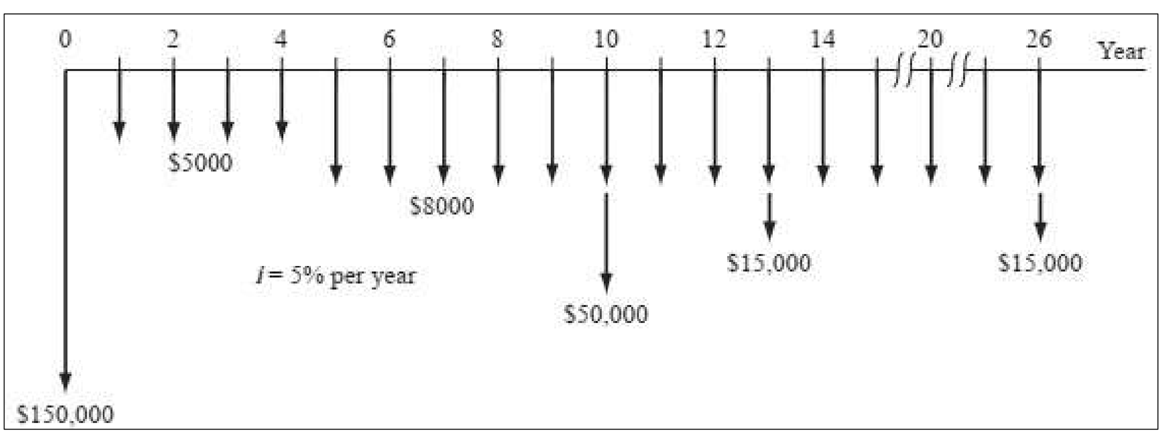
	Single Payments		Uniform Series Payments			
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A
1	1.0500	0.9524	1.00000	1.0000	1.05000	0.9524
2	1.1025	0.9070	0.48780	2.0500	0.53780	1.8594
3	1.1576	0.8638	0.31721	3.1525	0.36721	2.7232
4	1.2155	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

C. Capitalized Cost Analysis

Example 5.6 –Solution (Part a)

The five-step procedure to find CC now is applied.

1. Draw a cash flow diagram for two cycles



C. Capitalized Cost Analysis

Example –Solution (Part a)

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 .

$$CC_1 = -150{,}000 - 50{,}000(P/F{,}5\%{,}10) = \$-180{,}695$$

C. Capitalized Cost Analysis

Example –Solution (Part a)

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.)

$$CC_4 = \frac{-3{,}000}{0.05}(P/F{,}5\%{,}4) = \$-49{,}362$$

C. Capitalized Cost Analysis

Example –Solution (Part a)

5. The total capitalized cost CC_T for Haverty County Transportation Authority is the sum of the four component CC values.

$$CC_T = -180{,}695 - 16{,}940 - 100{,}000 - 49{,}362$$
$$= \$-346{,}997$$

C. Capitalized Cost Analysis

Example –Solution (Part b)

(*b*) Equation [5.2] determines the *AW* value forever.

$$AW = Pi = CC_T(i) = \$346{,}997(0.05) = \$17{,}350$$

Correctly interpreted, this means Haverty County officials have committed the equivalent of \$17,350 forever to operate and maintain the toll management software.

C. Capitalized Cost Analysis

Two alternatives

- For the comparison of **two alternatives** **on the basis of capitalized cost**
  - *use the same procedure to find the A value and CC_T for each alternative.*
- Since the capitalized cost represents the total present worth of financing and maintaining a given alternative forever, the alternatives will automatically be compared for the same number of years (i.e., infinity).
- The alternative with the smaller capitalized cost will represent the more economical one.

C. Capitalized Cost Analysis

Example 5.6 – Another procedures

Example 5.6 $i = 0.05$

① Determine the type of each cost

① Recurring Cost

$R_1 = -15000 / 13$ year

② Non recurring Costs

$P_1 = -15000$

$F_1 = -5000$

③ Annual Cost

$A_1 = -5000$

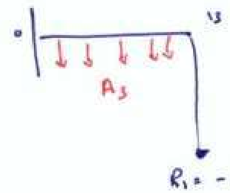
$A_2 = -8000$

C. Capitalized Cost Analysis

Example 5.6 – Another procedures

(2) Convert the recurring cost to an equivalent annual value (A).

$\Rightarrow$ Convert R_1 to A_3



$\rightarrow$ In this diagram R_1 is consider as an future value R_1 (F)

$A_3 / R_1 = A_3 / F = \cancel{F}\ R_1$

$\Rightarrow A_3 = \cancel{F}(A/F, i, N) = R_1 (A/F, i, N) = -15000\,(A/F, 5\%, 13) = -846.9$

$\Rightarrow \boxed{A_3 = -846.9}$

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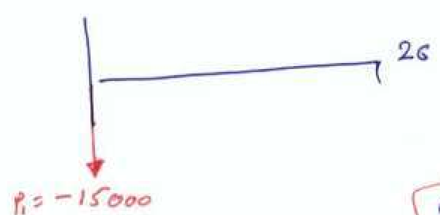
C. Capitalized Cost Analysis

Example 5.6 – Another procedures

(3) Find CC for P_1



$\boxed{CC_1 = P_1 = -15000}$

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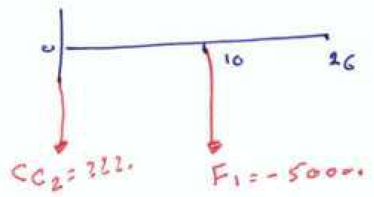
C. Capitalized Cost Analysis

Example 5.6 – Another procedures

(4) Find CC for F_1



$CC_2 = P/F_1 = F_1(P/F_1, i, N) = -50000\,(P/F_1, 5\%, 10)$

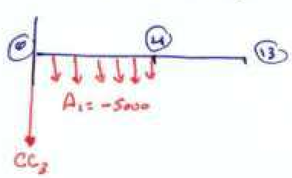
$= -50000 \times 0.6139$

$\boxed{CC_2 = -30695}$

C. Capitalized Cost Analysis

Example 5.6 – Another procedures

(5) Find CC for A_1



$i = 5\%$

$N = 4$

$CC_3 = P/A = P/A_3$

$= A_3\,(P/A, i, N)$

$= -5000\,(P/A, 5\%, 4)$

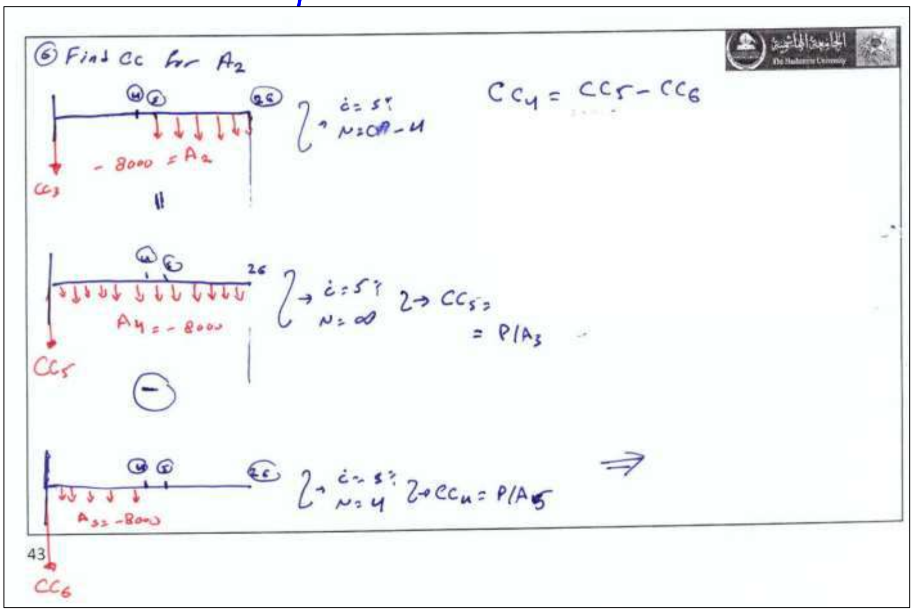
$= -5000 \times 3.5460$

$CC_3 = -17730$

$\boxed{\Rightarrow CC_3 = -17730}$

C. Capitalized Cost Analysis

Example 5.6 – Another procedures



C. Capitalized Cost Analysis

Example 5.6 – Another procedures

→ step 6

$CC_4 = CC_5 - CC_6$

$= P/A_4 - P/A_5$

$= A_4 (P/A_4, i, n) - A_5 (P/A, i, n).$

$= (-8000)(P/A, 5\%, \infty) - (-8000)(P/A, 5\%, 4)$

$= (-8000)[(P/A, 5\%, \infty) - (P/A, 5\%, 4)]$

$= -8000 \left[\frac{1}{i} - 3.460 \right]$

$= -8000 \left[\frac{1}{0.05} - 3.460 \right] = -8000 [20 - 3.460]$

$\boxed{CC_4 = -131634}$

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C. Capitalized Cost Analysis

Example 5.6 – Another procedures

(7) Find Cc for A_s

$$CC_7 = \frac{A_s}{i} = \frac{-846.4}{0.05} = -16940$$

$$\boxed{\Rightarrow CC_7 = -16940}$$

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Common Economic Analysis Methods

Method 2 :Annual Worth Analysis (AW)

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Method 2 :Annual Worth Analysis (AW)

- For many engineering economic studies, the **AW method is the best to use**.
  - *AW is easy to understand by any individual acquainted with annual amounts, for example, dollars per year.*
- The AW value is the equivalent uniform annual worth of all estimated receipts and disbursements during the life cycle of the project or alternative,

$$\text{AW} = \text{PW}(A/P,i,n) = \text{FW}(A/F,i,n) \qquad [6.1]$$

- The annual worth method offers a prime computational and interpretation advantage because
  - *The AW value needs to be calculated for **only one life cycle.***
- The AW value determined over one life cycle is the AW for all future life cycles.
  - *Therefore, it is **not necessary to use the LCM** of lives to satisfy the equal-service requirement.*

Method 2 :Annual Worth Analysis

- When alternatives being compared have different lives, the **AW** method makes the assumptions that:
  - *The services provided are <u>needed</u> for at least the LCM of the lives of the alternatives.*
  - *The selected alternative will be repeated for succeeding life cycles in exactly the same manner as for the first life cycle.*
  - *All cash flows will have the same estimated values in every life cycle.*

Evaluating Alternatives by Annual Worth Analysis

Mutually exclusive (ME) alternatives selection

- For **MUTUALLY EXCLUSIVE** alternatives,
  - *The **AW is calculated over the respective life of each alternative***
  - *the selection guidelines are the same as those used for the PW method.*
- Whether cost- or revenue-based, the guidelines are as follows:
  - ***One alternative:***
    - If AW > 0, the requested MARR is **met** or exceeded
    - The alternative is economically justified
  - ***Two or more alternatives:***
  - Select the alternative with the AW that is **numerically largest,**
    - That is, less negative or more positive.
  - This indicates a lower AW of cost for cost alternatives or a larger AW of net cash flows for revenue alternatives.

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Method 2 :Annual Worth Analysis

Example 6.1

- Two manufacturers offered the estimates below.

a. Determine which vendor should be selected on the basis of an Annual worth comparison, if the **MARR 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

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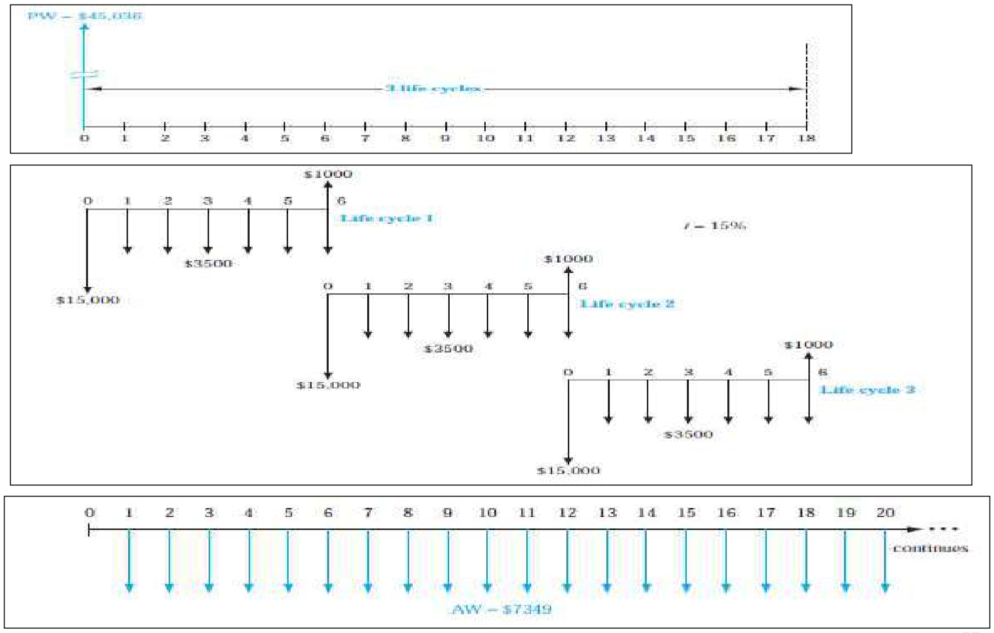
Method 2 :Annual Worth Analysis

Solution



Method 2 :Annual Worth Analysis

Solution

Solution

Calculate the equivalent uniform annual worth value for all cash flows in the first life cycle.

$$AW = -15{,}000(A/P,15\%,6) + 1000(A/F,15\%,6) - 3500 = \$-7349$$

When the same computation is performed on each succeeding life cycle, the AW value is $-7349. Now Equation [6.1] is applied to the PW value for 18 years.

$$AW = -45{,}036(A/P,15\%,18) = \$-7349$$

The one-life-cycle AW value and the AW value based on 18 years are equal.

Mutually exclusive (ME) alternatives selection

Example 6.4

- Michele is the general manager of a business unit, and she wishes to choose between two manufacturers of temperature retention units that are mobile and easy to sterilize after each use.
- Use the cost estimates below to select the more economic unit at a MARR of **8%** per year.

	Hamilton (H)	Infinity Care (IC)
Initial cost P, \$	−15,000	−20,000
Annual M&O, \$/year	−6,000	−9,000
Refurbishment cost, \$	0	−2,000 every 4 years
Trade-in value S, % of P	20	40
Life, years	4	12

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Mutually exclusive (ME) alternatives selection

Example 6.4 – Solution

Solution

The best evaluation technique for these different-life alternatives is the annual worth method, where AW is taken at 8% per year over the respective lives of 4 and 12 years.

$$\begin{aligned} AW_H &= \text{annual equivalent of } P - \text{annual M\&O} + \text{annual equivalent of } S \\ &= -15{,}000(A/P,8\%,4) - 6000 + 0.2(15{,}000)(A/F,8\%,4) \\ &= -15{,}000(0.30192) - 6000 + 3000(0.22192) \\ &= \$-9{,}863 \end{aligned}$$

$$\begin{aligned} AW_{IC} &= \text{annual equivalent of } P - \text{annual M\&O} - \text{annual equivalent of refurbishment} \\ &\quad + \text{annual equivalent of } S \\ &= -20{,}000(A/P,8\%,12) - 9000 - 2000[(P/F,8\%,4) + (P/F,8\%,8)](A/P,8\%,12) \\ &\quad + 0.4(20{,}000)(A/F,8\%,12) \\ &= -20{,}000(0.13270) - 9000 - 2000[0.7350 + 0.5403](0.13270) + 8000(0.05270) \\ &= \$-11{,}571 \end{aligned}$$

The Hamilton unit is considerably less costly on an annual equivalent basis.

If the projects are independent, the AW at the MARR is calculated.

All projects with AW ≥ 0 are acceptable.

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Common Economic Analysis Methods

Method 3 :Benefit/Cost analysis

Method 3 :Benefit/cost analysis

- The evaluation methods of previous are usually applied to alternatives in the private sector
  - *that is, for-profit and not-for-profit corporations and businesses*
- A public sector project is a product, service, or system used, financed, and owned by the citizens of any government level.
- The primary purpose of public projects is to
  - *provide service to the citizenry for the public good at no profit.*
  - *Areas such as public health, criminal justice, safety, transportation, welfare, and utilities are publicly owned and require economic evaluation*
- The benefit/cost (B/C) ratio introduces objectivity into the economic analysis of public sector evaluation, thus reducing the effects of politics and special interests.
- To perform a benefit/cost economic analysis of public alternatives,
  - *the costs (initial and annual), the benefits, and the disbenefits, if considered, must be estimated as accurately as possible in monetary units.*

Method 3 :Benefit/cost analysis

- **Costs**
  - *Estimated expenditures to the government entity for construction, operation, and maintenance of the project, less any expected salvage value*
  - *Cost (C) = Expenditures - salvage value (S)*
- **Benefits**
  - Advantages to be experienced *by the owners, the public*
- **Disbenefits**
  - *Expected undesirable or negative consequences to the owners if the alternative is implemented.*
  - *Disbenefits may be indirect economic disadvantages of the alternative*

Method 3 :Benefit/cost analysis

- It is difficult to estimate and agree upon the economic impact of benefits and disbenefits for a public sector alternative.
- For example, assume a short bypass around a congested area in town is recommended.
  - *How much will it benefit a driver in dollars per driving minute to be able to bypass five traffic lights while averaging 35 miles per hour, as compared to currently driving through the lights averaging 20 miles per hour and stopping at an average of two lights for an average of 45 seconds each?*
- The bases and standards for benefits estimation are always difficult to establish and verify.
- The disbenefits that accrue from an alternative are even ***harder*** to estimate.
  - *In fact, the disbenefit itself may not be known at the time the evaluation is performed.*

Method 3 :Benefit/cost analysis

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:

$$B/C = \frac{\text{benefits} - \text{disbenefits}}{\text{costs}} = \frac{B-D}{C} \quad [9.2]$$

The decision guideline is simple:

If B/C $\geq$ 1.0, accept the project as economically justified for the estimates and discount rate applied.
If B/C $<$ 1.0, the project is not economically acceptable.

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Method 3 :Benefit/cost analysis

Example

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

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Method 3 :Benefit/cost analysis

Example

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

B = 90,000
D = 10,000

C = 750,000(A/P,8%,20) + 50,000
= 750,000(0.10185) + 50,000
= $126,388

S = 30,000

B/C = (B-D)/(C-S)
= (90,000 – 10,000)/(126,388 – 30,000)
= 0.83

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Method 3 :Benefit/cost analysis

Example

- 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.
- Even though the new road is not very smooth, it allows access to an area that previously could only be reached with off-road vehicles.
- 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**

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Method 3 :Benefit/cost analysis

Example 10_ Solution

$$B = 900{,}000(1.5) - 900{,}000 = \$450{,}000$$

$$C = 300{,}000 + 25{,}000(P/A,6\%,20)$$
$$= 300{,}000 + 25{,}000(11.4699)$$
$$= \$586{,}748$$

$$B/C = 450{,}000/586{,}748 = 0.77$$

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Method 3 :Benefit/cost analysis

Example

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

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Method 3 :Benefit/cost analysis

Example

First convert all cash flows to AW values

$$B = 30{,}800{,}000(A/F,7\%,20) \\ = 30{,}800{,}000(0.02439) \\ = \$751{,}212$$

$$D = \$105{,}000$$

$$C = 1{,}200{,}000(A/P,7\%,20) + 400{,}000 \\ = 1{,}200{,}000(0.09439) + 400{,}000 \\ = \$513{,}268$$

$$B/C = (751{,}212 - 105{,}000)/513{,}268 \\ = 1.26$$

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Method 3 :Benefit/cost analysis

Benefit/Cost (B/C) Analysis of two alternative selection

1. Determine the equivalent total costs (PW or AW) for both alternatives.
   - *Order the alternatives by equivalent total cost: first smaller, then larger.*
   - *Calculate the incremental cost (ΔC) for the larger-cost alternative. This is the denominator in B/C.*
- Calculate the equivalent total benefits and any disbenefits estimated for both alternatives.
   - *Calculate the incremental benefits (ΔB) for the larger-cost alternative.*
- Calculate the ΔB/ΔC ratio using Equation [9.2],
- Use the selection guideline to select the higher-cost alternative if ΔB/ΔC > 1.0
   - *If ΔB/ΔC > 1.0, choose the higher-cost alternative, because its extra cost is economically justified*
   - *If ΔB/ΔC < 1.0, choose the lower-cost alternative*

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Method 3 :Benefit/cost analysis

Example 9.4

- The estimates below should be considered to determine which design to recommend at the city council meeting.
- The patient usage copay is an estimate of the amount paid by patients over the insurance coverage generally allowed for a hospital room.
- The discount rate is 5%, and the life of the building is estimated at 30 years. (a) Use incremental B/C analysis to select design A or B

	Design A	Design B
Construction cost, $	10,000,000	15,000,000
Building maintenance cost, $/year	35,000	55,000
Patient usage copay, $/year	450,000	200,000

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Method 3 :Benefit/cost analysis

Example 9.4 – Solution

- Step 1 :

1. The AW of costs is the sum of construction and maintenance costs.

$$AW_A = 10{,}000{,}000(A/P,5\%,30) + 35{,}000 = \$685{,}500$$
$$AW_B = 15{,}000{,}000(A/P,5\%,30) + 55{,}000 = \$1{,}030{,}750$$

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Method 3 :Benefit/cost analysis

Example 9.4 – Solution

- Step 2 : Δ

2. Design B has the larger AW of costs, so it is the alternative to be incrementally justified. The incremental cost is

$$\Delta C = AW_B - AW_A = \$345{,}250 \text{ per year}$$

Method 3 :Benefit/cost analysis

Example 9.4 – Solution

- Step 3 :

3. The AW of benefits is derived from the patient usage copays, since these are consequences to the public. The benefits for the ΔB/C analysis are not the estimates themselves, but the *difference* if design B is selected. The lower usage copay is a positive benefit for design B.

$$\Delta B = \text{usage}_A - \text{usage}_B = \$450{,}000 - \$200{,}000 = \$250{,}000 \text{ per year}$$

Method 3 :Benefit/cost analysis

Example 9.4 – Solution

- Step 4 :

4. The incremental B/C ratio is calculated by Equation [9.2].

$$\Delta B/C = \frac{\$250{,}000}{\$345{,}250} = 0.72$$

Method 3 :Benefit/cost analysis

Example 9.4 – Solution

- Step 5 :

5. The B/C ratio is less than 1.0, indicating that the extra costs associated with design B are not justified. Therefore, design A is selected for the construction bid.

Method 3 :Benefit/cost analysis

Benefit/Cost (B/C) Analysis of Multiple, Mutually Exclusive Alternatives

- Choose the largest-cost alternative that is justified with an incremental B/C >=1.0
  - *when this selected alternative has been compared with another justified alternative*

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Method 3 :Benefit/cost analysis

Example 9.6

- 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

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80

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
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

Method 3 :Benefit/cost analysis

Example 9.6 solution

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
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 ΔC, $/year	6.948		1.164	2.236
Incremental benefits ΔB, $/year	7.377		3.077	0.50
ΔB/C	1.06		2.64	0.22
Increment justified?	Yes	Eliminated	Yes	No
City selected	1		3	3

Method 3 :Benefit/cost analysis

Example

- The city of St. Louis, Missouri, is considering various proposals regarding the disposal of used tires.
- All of the proposals involve shredding, but the charges for the service and the handling of the tire shreds differ in each plan.
- An incremental B/C analysis was initiated but never completed.
  - *(a) Fill in all the missing blanks in the table.*
  - *(b) Determine which alternative should be selected.*

Alternative	PW of Costs,$	PW of Benefits, $	PW of Disbenefits, $	B/C Ratio	Incremental B/C When Compared with Alternative J	K	L	M
J	20	?	1	1.05	—	?	?	?
K	23	28	?	1.13		—	?	?
L	28	35	3	?			—	?
M	?	51	4	1.34				—

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Method 3 :Benefit/cost analysis

Example

(a) PW of B_J: $1.05 = (B - 1)/20$
$B = 22$

PW of D_K: $1.13 = (28 - D)/23$
$D = 2$

PW of B/C_L: $(B - D)/C = (35 - 3)/28 = 1.14$

PW of C_M: $1.34 = (51 - 4)/C$
$C = 35$

Incremental B/C calculations

K vs. J: $\Delta B/C = [(28 - 2) - (22 - 1)]/(23 - 20)$
$= 1.67$

L vs. J: $\Delta B/C = [(35 - 3) - (22 - 1)]/(28 - 20)$
$= 1.38$

M vs. J: $\Delta B/C = [(51 - 4) - (22 - 1)]/(35 - 20)$
$= 1.73$

L vs. K: $\Delta B/C = [(35 - 3) - (28 - 2)]/(28 - 23)$
$= 1.20$

M vs. K: $\Delta B/C = [(51 - 4) - (28 - 2)]/(35 - 23)$
$= 1.75$

M vs. L: $\Delta B/C = [(51 - 4) - (35 - 3)]/(35 - 28)$
$= 2.14$

(b) Revenue alternatives. Perform the incremental comparisons

J vs. DN: $B/C = 1.05$	Eliminate DN
K vs. J: $\Delta B/C = 1.67$	Eliminate J
L vs. K: $\Delta B/C = 1.20$	Eliminate K
M vs. L: $\Delta B/C = 2.14$	Eliminate L

Select M

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Method 3 :Benefit/cost analysis

Benefit/Cost (B/C) Analysis of *independent projects*

- When two or more ***independent projects*** are evaluated using B/C analysis and there is no budget limitation, no incremental comparison is necessary.
- The only comparison is between each project separately with the do-nothing alternative.
- The project B/C values are calculated, and those with B/C > =1.0 are accepted.

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Transportation Engineering and Planning (110 401367)

Spring 2021-2022

Module No. 6

Evaluation of Transportation Alternatives

Dr. Hamza 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

Basic Issues in Evaluation

- The basic concept of an evaluation is simple and straightforward
  - *, but the actual process itself can be complex and involved.*
- A transportation project is usually proposed because of a perceived problem or need
- In most instances, there are many ways to solve the problem, and each solution or alternative will result in a unique outcome in terms of project cost and results.
- The question is will the benefits of the project be worth the cost ?

3

3

Basic Issues in Evaluation

Objectives of Evaluation

- The objective of an evaluation is
  - *to furnish the appropriate information about the outcome of each alternative so that a selection can be made.*

4

4

Basic Elements of Transportation Planning

The transportation planning process comprises seven basic elements,

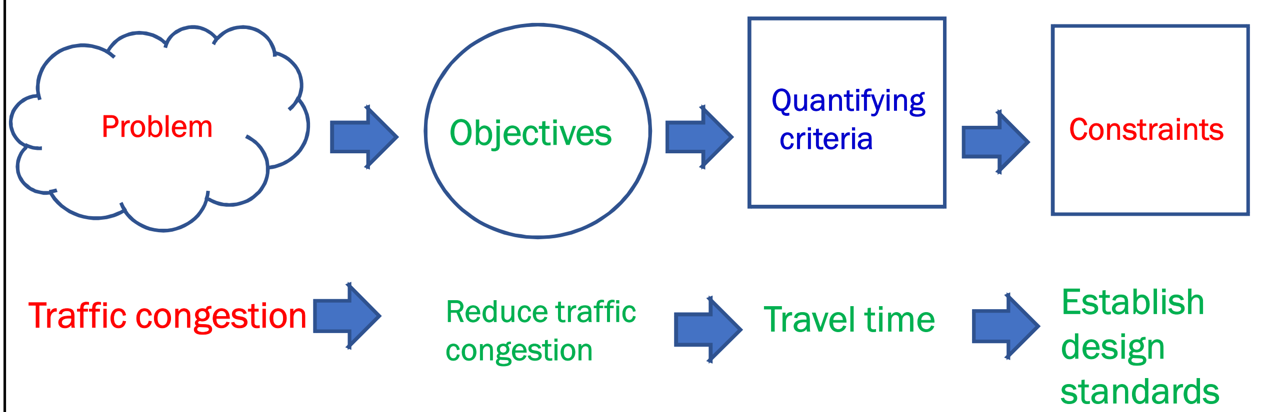
1. Situation definition
2. Problem definition
3. Search for solutions
4. Analysis of performance
5. Evaluation of alternatives
6. Choice of project
7. Specification and construction

5

5

Basic Elements of Transportation Planning

2. Problem Definition:



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6

Basic Issues in Evaluation

Selecting Evaluation Criteria

- A transportation project is intended to accomplish one or more goals and objectives, which are made operational as criteria.
- Selected criteria
  1. *shall be related as closely as possible to the stated objective*
  2. *shall be Easy to measure*
  3. *shall be sensitive to changes made in each alternative*
- It is advisable to limit the number of criteria to those that will be most helpful in reaching a decision
  - in order to keep the analysis manageable for both the engineer who is doing the work and the person(s) who will act on the result

Basic Issues in Evaluation

Criteria's for Evaluating Transportation Alternatives

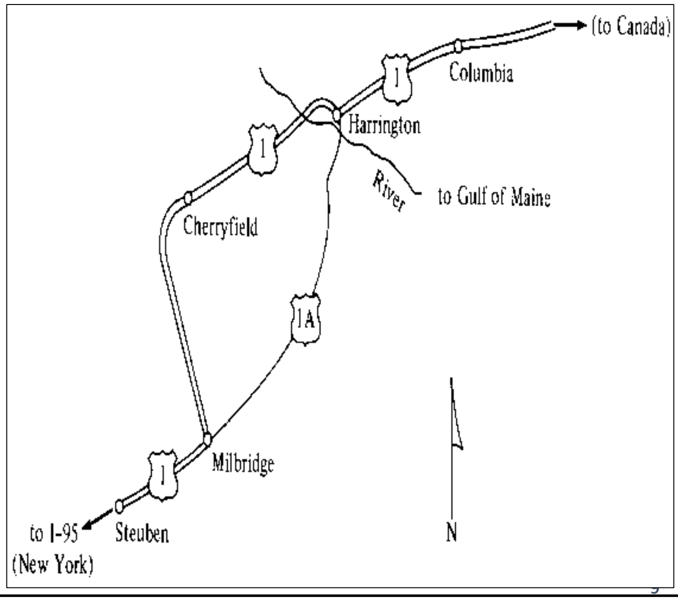
- Capital costs
  - *Construction*
  - *Right of way*
  - *Vehicles*
- Facility operating costs
- Vehicle operating costs
- Maintenance costs
- Safety
- Travel time
  - Total hours and cost of system travel
  - Average door-to-door speed
  - Distribution of door-to-door speeds
- Social and environmental costs
  - Noise
  - Visual quality
  - Community cohesion
  - Air and water quality

Basic Elements of Transportation Planning

Case study : Planning the relocation of a rural road

Step 2- Problem definition

- Problems
  - *High accident rate on 1A rout*
  - *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.*



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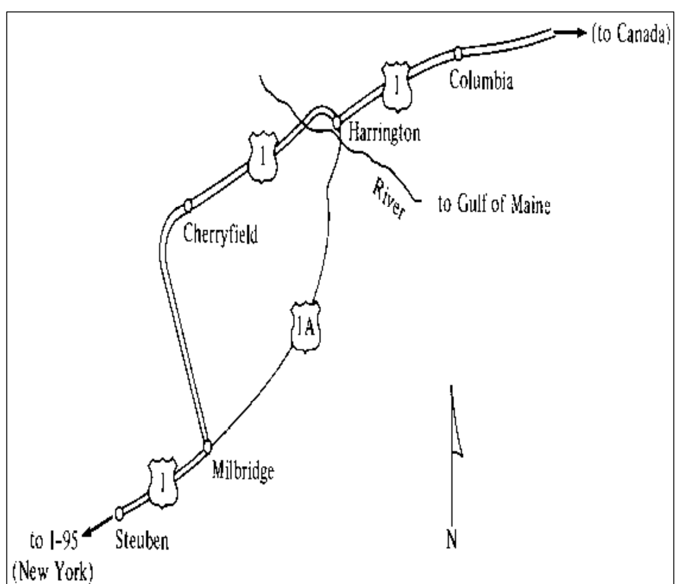
Case study : Planning the relocation of a rural road

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



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Basic Issues in Evaluation

Measures of Effectiveness

- ***Measures of effectiveness***
  - *The numerical or relative results for each criteria*
- The measures of effectiveness are used in the evaluation process within two different approaches
  - *Approach one : Common unit approach*
  - *Approach Two : Numerical score approach*

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 ($\mu g/m^3$ 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

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Basic Issues in Evaluation

Approach one : Common Unit approach

- Procedures
  - *Convert each measure of effectiveness to a common unit **then**, for each alternative, compute the summation for all measures*
- A common unit is money
  - It may be possible to make a transformation of the relevant criteria to equivalent dollars and then compare each alternative from an economic point of view

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Case study : Planning the relocation of a rural road

Equivalent cost

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 ($\mu g/m^3$ 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

Basic Issues in Evaluation

Approach Two : Numerical score approach

Procedures:

- Convert each measure of effectiveness to a numerical score
  - *If a project alternative does well in one criterion*
    - it is given a high score
  - *if it does poorly in another criterion,*
    - it is given a low score
- A single number can be calculated that represents the weighted average score of all the measures of effectiveness that were considered.

Case study : Planning the relocation of a rural road

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 ($\mu g/m^3$ 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

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

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Basic Issues in Evaluation

Evaluation types

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Basic Issues in Evaluation

Evaluation types

A. Evaluation Based on Economic Criteria

B. Evaluation Based on Multiple Criteria

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A. Evaluation Based on Economic Criteria

Costs components

- The cost of a transportation facility improvement includes two components:
  - ***First costs***
    - *Include: engineering design, right of way, and construction costs*
  - ***Continuing costs***
    - *Include:* maintenance, operation, and administration costs

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A. Evaluation Based on Economic Criteria

Salvage value

- *Salvage value*
  - *Is the worth of an asset at the end of its service life.*
- For example
  - *A transit bus costing $150,000 may be considered to have a service life of 12 years and a salvage value of $20,000,*
  - *A concrete pavement may have a service life of 15 years and no salvage value*

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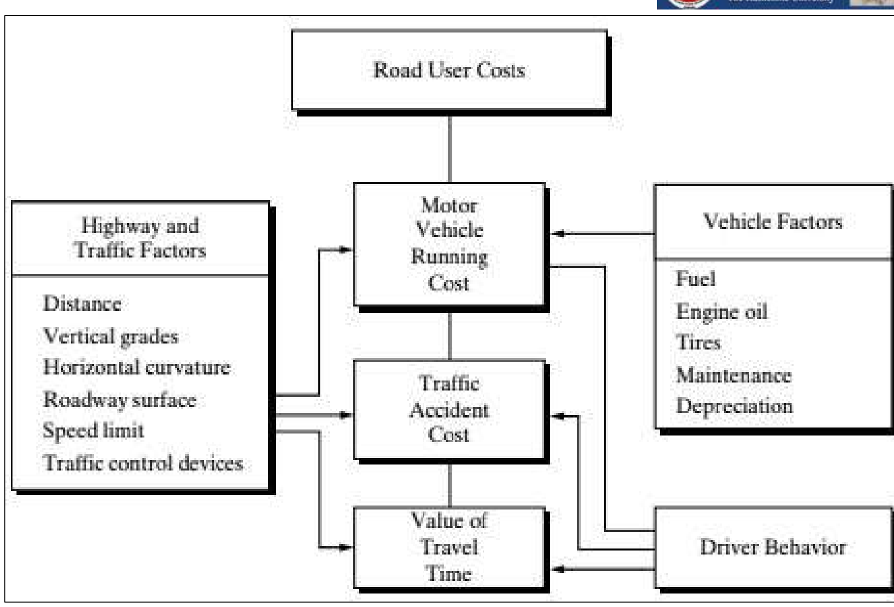
A. Evaluation Based on Economic Criteria

User costs

A. Costs for vehicle operation
B. Travel time costs
C. Costs of accidents



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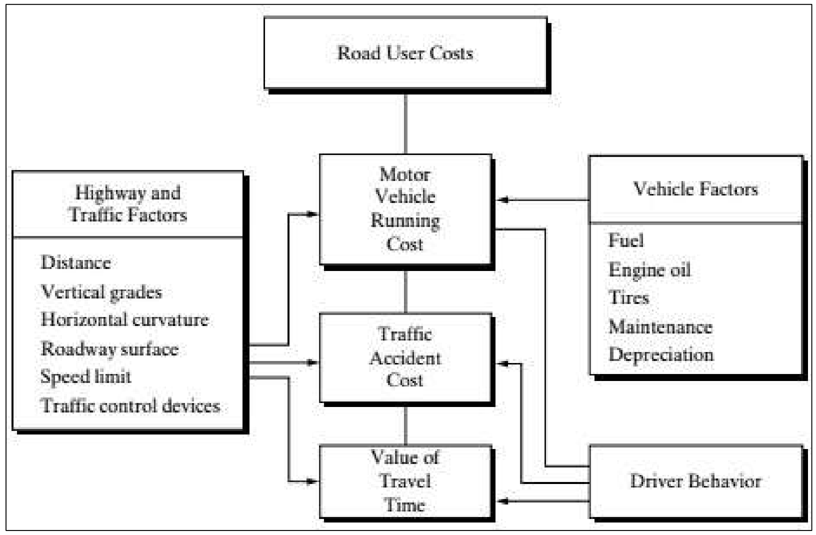
A. Evaluation Based on Economic Criteria

Vehicle Operating Costs

- User costs for motor-vehicle operation are significant items in a highway project evaluation.
  - For example, a road improvement that eliminates grades, curves, and traffic signals (as well as shortening the route) can result in major cost reductions to the motorist



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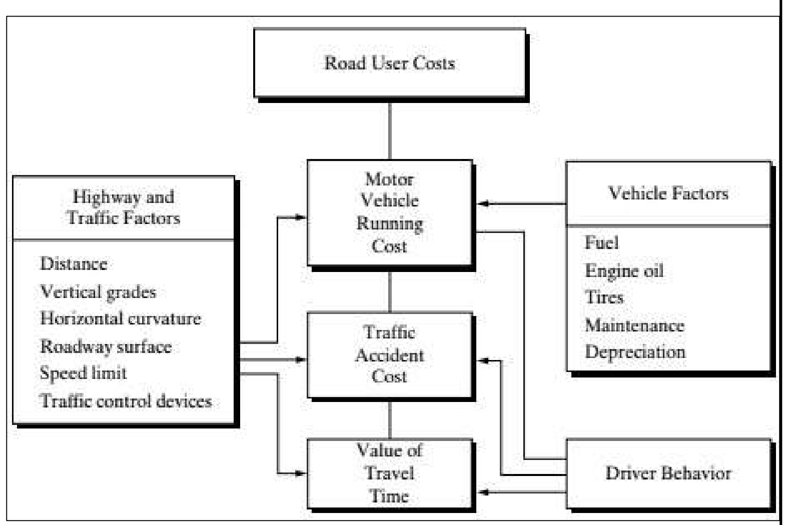
A. Evaluation Based on Economic Criteria

Travel Time Costs

- One of the most important reasons for making transportation improvements is to increase speed or to reduce travel delay.
  - *In the world of trade and commerce,*
    - Time is equivalent to money.
- The value of time saved depends
  1. Mode of travel
  2. Length of trip
  3. Family income



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A. Evaluation Based on Economic Criteria

Travel Time Costs

- $TTCST_{vt} = \frac{1000}{AES_{vt}} \times TTVAL_{vt}$
- Where
  - $TTCST_{vt}$ = Average travel time cost for vehicles of type *vt*
  - AES_{vt} = Average effective speed of vehicle type *vt* (mi/h)
  - $TTVAL_{vt}$ = Average value of one hour of travel time for occupants and cargo in vehicle type *vt* ($/h) in the year (2000)
    - (Table 13.2)

Table 13.2 Value of One Hour of Travel Time for Various Vehicle Types (Year 2000 $)

Small Auto	*Medium Auto*	*4-Tire Truck*	*6-Tire Truck*	*3-or 4-Axle Truck*	*4-Axle Combo*	*5-Axle Combo*
$15.44	$15.47	$16.28	$26.94	$29.17	$33.48	$34.09

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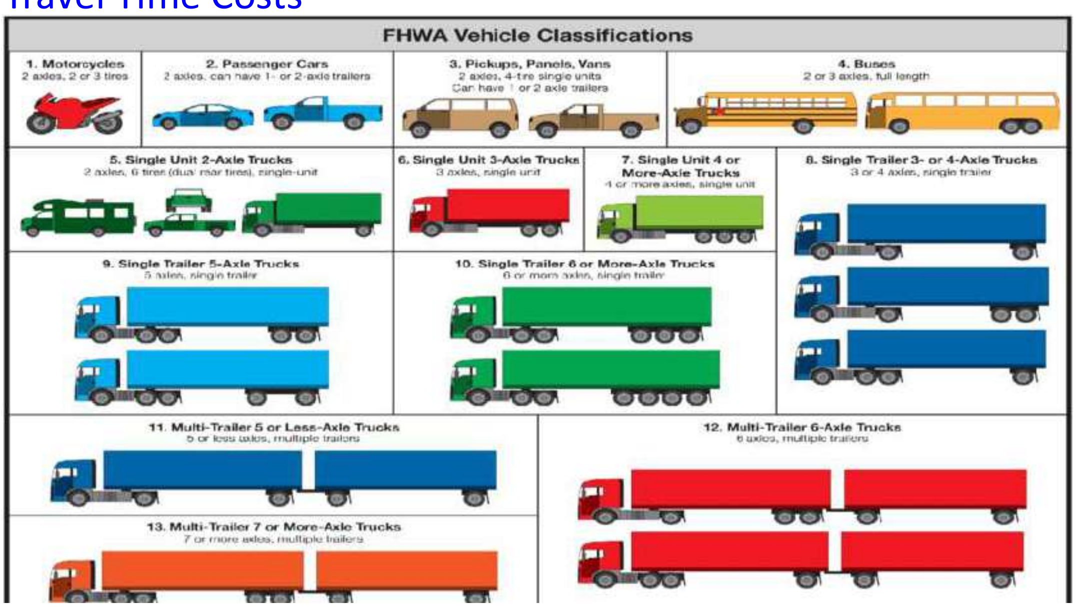
A. Evaluation Based on Economic Criteria

Travel Time Costs



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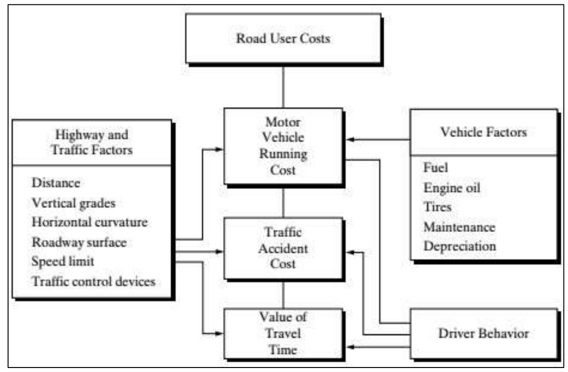
A. Evaluation Based on Economic Criteria

Crash or Accident Costs

- Property damage and injury-related crashes can be valued using insurance data.
- The value of a human life is "**priceless**," but in economic terms, measures such as future earnings have been used.
  - *There is no simple numerical answer to the question "What is the value of a human life lost in a highway crash?*
  - *There is general agreement that economic value does exist and published data vary widely.*
  - *The most prudent approach,*
    - if an economic value is desired, is to select a value that appears most appropriate for the given situation.



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Economic costs of traffic accidents in Jordan

Table 9
The average cost of each injury casualty class

Item	Injury casualty class			Total cost (JD)
	Serious (391)[a]	Medium (3709)[a]	Slight (11 275)[a]	
Loss due to disability	9648	2021	0	11 268 257
Temporary losses	71	71	71	1 091 625
Community and family losses	3314	714	24	4 214 600
Pain and suffering	117	82	0	349 885
Hospitalization and medical treatment	426	426	426	6 549 750
Average cost	13 576	3314	521	
Total cost	5 308 216	12 291 626	5 874 275	23 474 117

[a] Values in brackets indicate the number of casualties.

Al-Masaeid HR, Al-Mashakbeh AA, Qudah AM (1999). Economic costs of traffic accidents in Jordan. *Accid Anal Prev*, 31(4):347-57

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Economic costs of traffic accidents in Jordan

Table 10
Total and average cost of property damage for each type of vehicles

Accident severity level	Type of vehicle	Number of involved vehicles	Average cost per involved vehicle (JD)			Average cost per involved vehicle (JD)	Average cost per involved vehicle (JD)
			Vehicle damage	Detention period	Public and private damages		
Fatal	Car	518	1297	166	17	1480	1591
	Bus	58	910	435	17	1362	
	Truck	151	1450	545	66	2061	
Injury	Car	11 367	653	95	17	765	974
	Bus	1299	1025	252	17	1294	
	Truck	4048	1103	275	66	1444	
PDO	Car	27 200	480	46	17	543	714
	Bus	3028	722	282	17	1020	
	Truck	7358	967	190	66	1223	
All		55 077				805	805

Al-Masaeid HR, Al-Mashakbeh AA, Qudah AM (1999). Economic costs of traffic accidents in Jordan. *Accid Anal Prev*, 31(4):347-57

Economic costs of traffic accidents in Jordan

Table 8
The average cost of a traffic accident fatality

Cost element	Average cost per fatality (JD)	Total cost (JD)
Loss of production	27 547	15 205 944
Community and family losses	9394	5 185 488
Pain and suffering	7500	4 140 000
Hospitalization and medical treatment	2079	1 147 608
All	46 520	25 679 040

Al-Masaeid HR, Al-Mashakbeh AA, Qudah AM (1999). Economic costs of traffic accidents in Jordan. *Accid Anal Prev*, 31(4):347-57

Economic costs of traffic accidents in Jordan

Table 11
The unit cost of each type of casualties, property damage, police activities, and insurance administration for each accident severity level

Accident severity level	Average unit cost						
	Death	Serious injury	Medium injury	Slight injury	Property damage	Police activities	Insurance administration
Fatal	46 520	13 576	3314	521	1591	74	153
Injury	–	13 576	3314	521	985	34	153
PDO	–	–	–	–	714	4	153

Al-Masaeid HR, Al-Mashakbeh AA, Qudah AM (1999). Economic costs of traffic accidents in Jordan. *Accid Anal Prev*, 31(4):347-57

السـنة					البيان
2020	2019	2018	2017	2016	
10806	10554	10309	10053	9798	عدد السـكان بالألف
1729343	1677061	1637981	1583458	1502420	عدد المركبات المسجلة
8451	10857	10431	10446	10835	عدد حوادث الإصابات البشرية
461	643	571	685	750	عدد الوفيات
12690	17013	16203	16246	17435	عدد الجرحى
23.2	29.7	28.6	28.6	29.7	عدد الحوادث لكل يوم
1.3	1.8	1.6	1.9	2.1	عدد الوفيات لكل يوم
34.8	46.6	44.4	44.5	47.8	عدد الجرحى لكل يوم
48.9	64.7	63.7	66.0	72.1	عدد حوادث الإصابات لكل 10 آلاف مركبة
2.7	3.83	3.49	4.33	4.99	عدد الوفيات لكل 10 آلاف مركبة
73.4	101.4	98.9	102.6	116.0	عدد الجرحى لكل 10 آلاف مركبة
4.27	6.09	5.54	6.81	7.65	عدد الوفيات لكل 100 ألف نسمة
117.43	161.2	157.2	161.6	177.9	عدد الجرحى لكل 100 ألف نسمة
0.107	0.109	0.112	0.113	0.126	معدل الخطورة
296	324	313	308	323	التكلفة المالية (مليون دينار)

التقرير السنوي للحوادث المرورية في الأردن لعام 2020

https://www.psd.gov.jo/media/zhhjcyro/-التقرير-السنوي-للحوادث-المرورية-في-الأردن-لعام-2020.pdf

A. Evaluation Based on Economic Criteria

Example 13.1

A. Evaluation Based on Economic Criteria

Example 13.1

- Three improvement plans for a heavily traveled intersection within the city .
  - *Alternative I*
  - *Alternative II*
  - *Alternative III*
- The intersection improvement is expected to achieve three goals:
  - *Improve travel speeds*
  - *Increase safety*
  - *Reduce operating expenses for motorists*

A. Evaluation Based on Economic Criteria

Example 13.1

- The **annual** dollar value of savings compared with existing conditions for each criterion as well as additional construction and maintenance costs is shown in Table 13.4.

Table 13.4 Cost and Benefits for Improvement Plans with Respect to Existing Conditions

Alternative	*Construction Cost*	*Annual Savings in Accidents*	*Annual Travel Time Benefits*	*Annual Operating Savings*	*Annual Additional Maintenance Cost*
I	\$185,000	\$5000	\$3000	\$ 500	\$1500
II	220,000	5000	6500	500	2500
III	310,000	7000	6000	2800	3000

- If the economic life of the road is considered to be 50 years and the discount rate is 3%, which alternative should be selected?
  - *Solve the problem using Present Worth analysis for economic analysis.*

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A. Evaluation Based on Economic Criteria

Example 13.1 – Solution

Solution:

- Compute the NPW of each project.

$$(P/A - 3 - 50) = \frac{(1+i)^N - 1}{i(1+i)^N} = \frac{(1+0.03)^{50} - 1}{0.03(1+0.03)^{50}} = 25.729$$

$$\begin{aligned}
\text{NPW}_{\text{I}} &= -185{,}000 + (-1500 + 5000 + 3000 + 500)(P/A - 3 - 50) \\
&= -185{,}000 + (7000)(25.729) = -185{,}000 + 180{,}103 \\
&= -4897 \\
\text{NPW}_{\text{II}} &= -220{,}000 + (-2500 + 5000 + 6500 + 500)(P/A - 3 - 50) \\
&= -220{,}000 + (9500)(25.729) = -220{,}000 + 244{,}425 \\
&= +24{,}465 \\
\text{NPW}_{\text{III}} &= -310{,}000 + (-3000 + 7000 + 6000 + 2800)(P/A - 3 - 50) \\
&= -310{,}000 + (12{,}800)(25.729) = -310{,}000 + 329{,}331 \\
&= +19{,}331
\end{aligned}$$

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A. Evaluation Based on Economic Criteria

Example 13.1 – Solution

The project with the highest NPW is alternative II.

- Solve by the EUAW method. Note $(A/P - 3 - 50) = 1/25.729 = 0.03887$.

$$
\begin{aligned}
\text{EUAW}_{\text{I}} &= -185{,}000(A/P - 3 - 50) - 1500 + 5000 + 3000 + 500 \\
&= -185{,}000(0.03887) + 7000 = -7190 + 7000 \\
&= -190 \\
\text{EUAW}_{\text{II}} &= -220{,}000(A/P - 3 - 50) - 2500 + 5000 + 6500 + 500 \\
&= -220{,}000(0.03887) + 9500 = 8551 + 9500 \\
&= +949 \\
\text{EUAW}_{\text{III}} &= -310{,}000(0.03887) - 3000 + 7000 + 6000 + 2800 \\
&= -12{,}050 + 12{,}800 \\
&= +750
\end{aligned}
$$

The project with the highest EUAW is Alternative II, which is as expected since EUAW = NPW(0.03887).

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Basic Issues in Evaluation

Evaluation types

B. Evaluation Based on Multiple Criteria

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B. Evaluation Based on Multiple Criteria

- Many problems associated with economic methods limit their usefulness such as
  - *Converting criteria values directly into dollar amounts.*
  - *Choosing the appropriate value of interest rate and service life.*
  - *Distinguishing between the user groups that benefit from a project and those that pay.*
  - *Considering all costs, including external costs.*

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B. Evaluation Based on Multiple Criteria

Types

- 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*

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B. Evaluation Based on Multiple Criteria

Rating and Ranking method

- Rating and Ranking:
  - *Numerical scores are helpful in comparing the relative worth of alternatives in cases where criteria values cannot be transformed into monetary amounts.*
- **Steps**
  - ***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*

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Rating and Ranking method

Example 13.2

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Rating and Ranking method

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*

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Example 13.2 – Solution

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

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Example 13.2 – Solution

Step 2. Determine the relative weight for each objective

- This step requires a subjective judgment on the part of the group making the evaluation and will vary among individuals and vested interests
- Approaches
  - *Allocate the weights on a 100-point scale*
  - *Rank each objective in order of importance then use a formula of proportionality to obtain relative weights*

Example 13.2 – Solution

Step 2. Determine the relative weight for each objective

- The weighting factor is determined by assigning the value n to the highest ranked alternative, n - 1 to the next highest (and so forth), and computing a relative weight as
- $K_j = \frac{W_j}{\sum_{k=1}^{N} W_j}$
  - *Where*
  - K_j *= weighting factor of objective j*
  - W_j *= Relative weight for objective j*

B. Evaluation Based on Multiple Criteria

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
Total			17	100

Example 13.2 – Solution

Step 3. Define an appropriate measure of effectiveness for each objective

No.	Objective	Measure of Effectiveness
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
2	Ridership on the transit line should be maximized.	Total daily ridership
3	Service on the system should be comfortable and convenient	Percent of riders seated during the peak hour
4	The transit line should extend as far as possible to promote development and accessibility	Percent of riders seated during the peak hour
5	The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion	Percent of riders seated during the peak hour

Example 13.2 – Solution

Step 4 . Develop the alternatives that will be tested.

- 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.*

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B. Evaluation Based on Multiple Criteria

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	13	14	11	13.5	15
2	Ridership on the transit line should be maximized.	Total daily ridership	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	Percent of riders seated during the peak hour	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	Percent of riders seated during the peak hour	3.5	3	2	1.5	1.5

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B. Evaluation Based on Multiple Criteria

Step 5. Determine the value of each measure of effectiveness for the selected alternatives

In case of direct relation between the criteria and the objectives (such as Total daily ridership)

$$\left(\frac{Value\ of\ alternative\ i}{Maximum\ value\ for\ all\ altertaives}\right) * Specifed\ percentage\ for\ this\ objective$$

In case of indirect relation between the criteria and the objectives (such as the pollution example)

$$\left(\frac{Minimum\ value\ for\ all\ altertaives}{Value\ of\ alternative\ i}\right) * Specifed\ percentage\ for\ this\ objective$$

B. Evaluation Based on Multiple Criteria

Step 6. Compute a score and ranking for each alternative

- 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.

B. Evaluation Based on Multiple Criteria

Step 6. Compute a score and ranking for each alternative

Table 13.7 Point Score for Candidate Transit Lines

Measure of Effectiveness	*Alternatives*				
	I	*II*	*III*	*IV*	*V*
1	26.0	28.0	22.0	27.0	30.0
2	24.0	22.1	19.2	17.3	16.3
3	8.5	11.9	13.6	17.0	17.0
4	17.0	14.9	12.8	10.6	10.6
5	12.0	10.3	6.9	5.1	5.1
Total	87.5	87.2	74.5	77.0	79.0

- The total point score indicates that the ranking of the alternatives in order of preference is I, II, V, IV, and III.
- Alternatives I and II are clearly superior to the others and are very similar in ranking. These two will bear further investigation prior to making a decision

Basic Issues in Evaluation

Evaluation types

B. Evaluation Based on Multiple Criteria

Cost Effectiveness method

B. Evaluation Based on Multiple Criteria

Cost Effectiveness:

- Cost-effectiveness analysis:
  - *is a form of economic analysis that compares the relative costs and outcomes (effects) of different courses of action*
  - *Is a way to examine both costs and the outcomes of alternatives*
- The cost-effectiveness approach does not yield a recommended result, as do economic methods or ranking schemes.
- However, it is a valuable tool because
  - *it defines more fully the impacts of each course of action and helps to clarify the issues.*
- With more complete information, a better decision should result.
  - *Rather than closing out the analysis, the cost effectiveness approach opens it up and permits a wide variety of factors to be considered.*

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Cost Effectiveness method

Example 13.3

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B. Evaluation Based on Multiple Criteria

Example 13.3

- 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

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B. Evaluation Based on Multiple Criteria

Example 13.3

- Objective (Plans are intended to provide)
  - *Added capacity*
  - *Improved levels of service*
  - *Reductions in travel time during peak hours.*
- Measure of effectiveness
  - *Persons and Businesses displaced*
  - *Annual total fatal accidents and personal injuries*
  - *Annual transit passengers*
  - *Average door-to-door auto trip speed (mi/h)*
  - *Daily emissions of carbon monoxide (tons)*

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B. Evaluation B

Example 13.3 - Solution

Table 13.9 Measure of Effectiveness Data for Alternative Highway-Transit Plans

Measure of Effectiveness	*Plan A* Null	*Plan B* All Rail	*Plan C* All Highway	*Plan D* Rail and Highway	*Plan E* 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

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B. Evaluation Based on Multiple Criteria

Example 13.3 - Solution

- B/C analysis

Table 13.8 Benefit–Cost Comparisons for Highway and Transit Alternatives

Plan Comparisons	*Annual Cost Difference ($ million)*	*Annual Savings ($ million)*	*BCR*
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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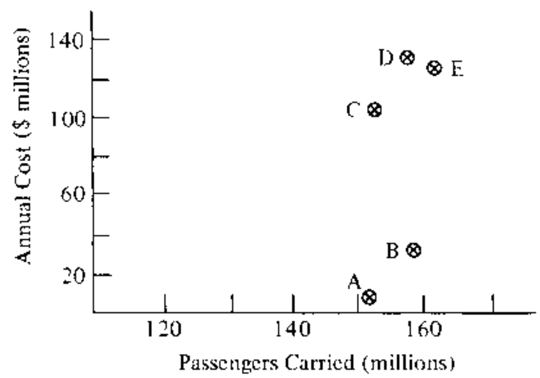
B. Evaluation Based on Multiple Criteria

Example 13.3 - Solution

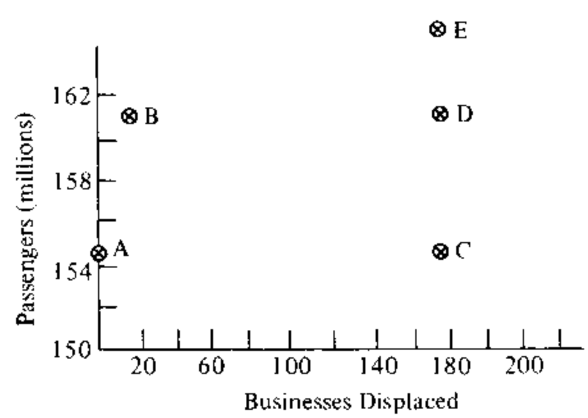
- This cost-effectiveness analysis indicates that Plan B produces a significant increase in transit passengers over Plan A.
- Although Plans C, D, and E are much more costly, they do not produce many more transit riders for the added investment



B. Evaluation Based on Multiple Criteria

Example 13.3 - Solution

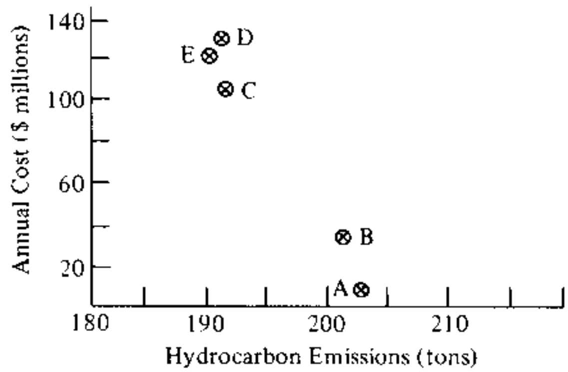
- In terms of businesses displaced versus transit passengers carried
  - *Plans C and D require considerable disruption with very little increase in transit patronage over*
  - *Plan B, which is clearly preferred if the impact on the community is to be minimized.*



B. Evaluation Based on Multiple Criteria

Example 13.3 - Solution

- Plan C, which is considerably more costly than Plan B, results in a significant reduction in pollution levels, whereas the other two plans, D and E, although more expensive than C, have little further impact on pollution levels.



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Basic Issues in Evaluation

Evaluation types

B. Evaluation Based on Multiple Criteria

Evaluation of Completed Projects

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B. Evaluation Based on Multiple Criteria

Evaluation of Completed Projects

- How effective it has been in accomplishing its objectives
- What can be learned that is useful for other project decisions
- What changes should be made to improve the current situation, or if the project should be continued or abandoned.

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Evaluation of Completed Projects

Example 13.4

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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

	Before	*After*	*Change (%)*
Line A: new shelters	1500	1700	13.3
Line B: no shelters	1950	2000	2.5

Evaluation of Completed Projects

Example 13.5

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

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 and discussed its advantages and disadvantages.

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

Measure of Effectiveness	*Lindenwold (Rail)*	*Shirley (Bus)*	*Higher Rated System*
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

Basic Issues in Evaluation

Evaluation types

B. Evaluation Based on Multiple Criteria

Evaluating Effects of Transportation on Social and Natural Systems

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B. Evaluation Based on Multiple Criteria

4. Evaluating Effects of Transportation on Social and Natural Systems

- 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?
    - Should the project be included as a budget item for implementation or deferred to a later date?

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B. Evaluation Based on Multiple Criteria

4. Evaluating Effects of Transportation on Social and Natural Systems

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

- *The users of the transportation improvement*
- *The community*
- *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*

B. Evaluation Based on Multiple Criteria

4. Evaluating Effects of Transportation on Social and Natural Systems

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

B. Evaluation Based on Multiple Criteria

4. Evaluating Effects of Transportation on Social and Natural Systems

- 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

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B. Evaluation Based on Multiple Criteria

4. Evaluating Effects of Transportation on Social and Natural Systems

- 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*

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Is the Evaluation of Transportation Projects Important ?

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Is Transportation Evalaution Is 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 32 كم يتخلله 21 موقفا يعني أن الباص لم يعد سريعا وأن الوقت الزمني للرحلة طويل
“”موقع عمان نت 2011,

https://en.wikipedia.org/wiki/Amman_Bus_Rapid_Transit
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Case studies

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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.

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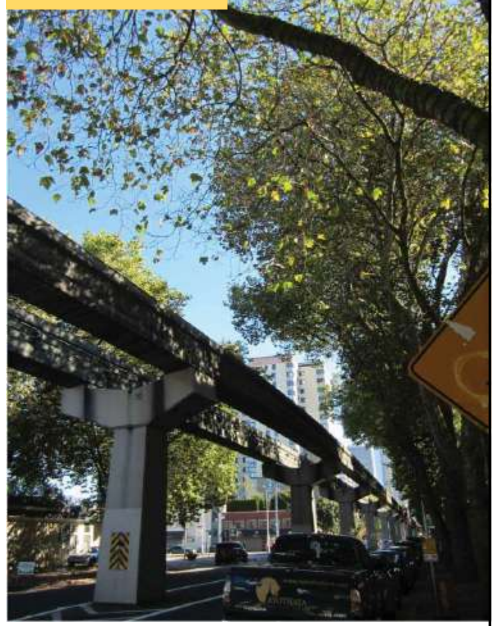
Monorail

Monorail in Seattle



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Comparison Between Monorail System and BRT System in Amman City

cientific Paper of Fourth Jordan International Conference and Exhibition for Roads and Traffic

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