Faculty of Engineering
Department of Civil Engineering

Highway and airport engineering

Prepared By: Prof. Dr. Mahmoud Enieb

1

Highway Geometric Design

Prepared By: Prof. Dr. Mahmoud Enieb

2

Instructor:
Prof. Dr. Mahmoud Enieb
Prof. of Highway and Traffic Engineering

Instructor's Office 105 first floor of civil engineering

Email: m.enieb@aun.edu.eg

Prepared By: Prof. Dr. Mahmoud Enieb

3

Office hours

11:00 AM – 12:00 AM
(Sun, Thu)

12:00 AM – 13:00 AM
(Mon, Tue, Wed)

Prepared By: Prof. Dr. Mahmoud Enieb

4

Classroom
No. 2

(Thu 9:30-11:00)

Course Description

- This part mainly covers the aspects of highways geometric design.
- Also, it covers design controls and criteria including; highway functional classification, design standards, design vehicles, sight distance, horizontal and vertical alignments, cross section elements, intersection and interchange.

Textbooks and online

- American Association of State Highway and Transportation Officials,(AASHTO), **A policy on Geometric design of Highways and Streets**, 2004.
- N.J. Garber and L.A. Hoel, **Traffic and Highway Engineering**, Cengage Learning 2009.
- http://techalive.mtu.edu/modules/module0003/Superelevation.htm
- G.J. Taylor, **Roadway Horizontal Alignment Design**, A SunCam online continuing education course, 2013. www.suncam.com

Course objectives

- Be able to understand factors affecting highway design.
- To familiarize students with sight distance concept.
- Learn how to design horizontal and vertical alignment.
- To familiarize students with intersections and interchange design.

Topics Covered

- Factors and criteria influencing in highway design.
- Stopping and Passing sight distance (SSD, PSD).
- Horizontal curves.
- Superelevation.
- Vertical curves.
- Cross section elements
- Intersection and interchange.

Class Schedule

- 2 class sessions each week; 75 minutes each

Grading Plan:

- Mid Exam (30 points) TBA
- Final Exam (100 points) TBA
- Others (20 points) Term project and Qzs & homework.

General notes

- All cellular phone must be turned off before class begins.
- Eating and/or drinking is not allowed in the classroom.
- Talking to a fellow student while the lecture is in progress will not be tolerated.
- You will be asked to leave the class if this behavior is disruptive.
- As required by the university, cases of academic dishonesty will be handled through the proper channels.

Highway Engineering

Highway engineering is an engineering discipline which involves the design, construction and maintenance of Highway Roads & Systems, urban streets as well as parking facilities.

Important aspects of highway engineering include overall planning of routes, financing, environmental impact evaluation, and value engineering to compare alternatives

Geometric Design

The fundamental objective of Geometric Design is to produce:

– a smooth-flowing and

– safe highway facility

by providing a consistent design standard that satisfies the characteristics of the driver and the vehicle use the road

Geometric Design

- Geometric Design deals with the dimensioning of the elements of highways
  - Such as Horizontal curves
  - Vertical curves
  - Type of Rural and Urban roads
  - Cross section elements
  - Intersections

The characteristics of driver, pedestrian, vehicle, and road **serves as** the basis for determining the physical dimensions of these elements.

(lengths of vertical curves or radius of circular curves are determined to assure that the minimum stopping sight distance is provided to highway users for the design speed of the highway)

Factors influencing highway design

1. Functional classification of the highway being designed
2. Expected traffic volume(design hourly volume) and vehicle mix
3. Design speed
4. Design vehicle
5. Cross section of the highway (lanes, shoulders, and medians)
6. Presence of heavy vehicles on steep grades
7. Topography of the area in which the highway will be located
8. Level of service to be provided (A, B, C, D, E, F)
9. Available funds
10. Safety
11. Social and environmental factors

Prepared By: Prof. Dr. Mahmoud

15

Highway Functional Classification

- Highway depending on the **area** which they are located are categorized
  - **Rural roads**
  - **Urban roads**

Within the classification of urban and rural, highway are categorized into the following group:

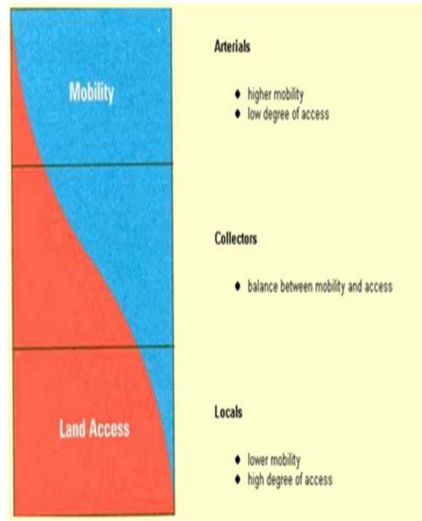
- **Principal arterials (included freeway)**
- **Minor arterials**
- **Major collectors**
- **Minor Collector**
- **local roads and streets**

Prepared By: Prof. Dr. Mahmoud Enieb

16

Highway Functional Classification

- **Arterial**:
  - ✓ highest level of service,
  - ✓ high mobility,
  - ✓ low access,
  - ✓ long trips,
  - ✓ fast speeds
- **Collector**:
  - ✓ less highly developed level of service,
  - ✓ lower speed for shorter trips,
  - ✓ collects traffic from local roads and
  - ✓ connecting them with arterials
- **Local**:
  - ✓ all roads not defined as arterials or collectors,
  - ✓ provides access to land with littler or not through traffic,
  - ✓ low speed



Prepared By: Prof. Dr. Mahmoud Enieb

17

Factors considered in Classification

- Adjacent Land Use:
  - Urban vs. rural classification
- Service Function:
  - Service to traffic (mobility). Example: freeways
  - Access to land. Example: local
  - both
- Traffic Volume:
  - Freeways: high volume
  - Collectors and locals: low volume
- Flow Characteristics:
  - Freeways: uninterrupted facility
  - Locals; interrupted facility

Prepared By: Prof. Dr. Mahmoud

18

Factors considered in Classification (contd.)

- Running Speed:
  - Generally, increase from locals to collectors to arterials to freeways
- Vehicle Type:
  - Proportion of passenger cars, buses, large trucks
- Connections:
  - Normal for roads to connect to the same classification or one higher or one lower

Prepared By: Prof. Dr. Mahmoud Enieb

19

Table 1. Design Classes and Design Types Associated with Each Functional Class

Functional Class	Design Class	Design Type
Arterial	Freeway	8-Lane 6-Lane 4-Lane
	Major Arterial	6-Lane Divided 4-Lane Divided
	Minor Arterial	5-Lane 4-Lane
Collector	Major Collector	5-Lane 4-Lane 3-Lane
	Minor Collector	2-Lane
Local	Local	Loop Cul-de-Sac

Prepared By: Prof. Dr. Mahmoud Enieb

20

Controls and Criteria

- Design Vehicles
  - Passenger cars, buses, trucks, RVs (recreational vehicle)
  - Physical characteristics: weight, dimensions
  - Establish intersection radius, pavement markings
- Vehicle Performance
  - Operating characteristics: accel/decel
  - Impacts air quality, noise, land use

Prepared By: Prof. Dr. Mahmoud Enieb

21

Controls and Criteria

- Driver
  - Information handling
  - Reaction time
    - Time to perceive + react to a hazard in vehicle's path
    - Expected / unexpected
  - Speed
  - Driver errors

Prepared By: Prof. Dr. Mahmoud Enieb

22

Controls and criteria

- Traffic
  - Composition and volume
    - Average daily traffic (ADT) is not adequate
    - Design hourly volume (DHV)
    - 30th-highest hourly volume (30HV) in one year
    - K-factor (% of ADT; 8~12% urban, 12~18% rural)
  - Speed
    - Operating Speed (typically the 85th percentile speed)
    - Free-flow Speed (close to zero density)
    - Running Speed (actual speed)
    - Design Speed (as high as practical)

Prepared By: Prof. Dr. Mahmoud

23

Controls and criteria

- Capacity
  - Maximum hourly flow rate (per lane) under prevailing conditions

1. Determines adequacy of existing roadways
2. Helps select roadway type
3. Helps define needs
4. Design level of service (LOS)

Prepared By: Prof. Dr. Mahmoud Enieb

24

Highway Design Standards

- **Design Hourly Volume (DHV)**
- ✓ The 30th-highest hourly volume for rural highways is usually between 12 and 18 percent of the ADT, with the average being 15 percent, (K-factor).
- ✓ The 30th-highest hourly volume may also be used as the DHV for urban highways. It is usually determined by applying between 8 and 12 percent to the ADT, with the average being 10 percent,(K-factor).

$$\textbf{K-factor} = \frac{DHV}{AADT} \times 100$$

- **D = directional distribution** = one way volume in peak direction (expressed as a percentage of two-way traffic) Rural 55 to 80%
- Can also adjust for how traffic is distributed between lanes (e.g., 3 lanes, highest/outside lane may be 40% of total directional flow).

Prepared By: Prof. Dr. Mahmoud Enieb

25

Highway Design Standards

- **Design Speed**
- ✓ Design speed is defined as a selected speed to determine the various geometric features of the roadway. Design speed depends on the functional classification of the highway, the topography of the area in which the highway is located, and the land use of the adjacent area.
- ✓ Posted speed = speed limit
- ✓ Operating speed = free flow (spot speed)
- ✓ Running speed = length of highway section ÷ running time
- ✓ Design speed = selected speed used to determine geometric design features

Prepared By: Prof. Dr. Mahmoud Enieb

26

Design Speed Considerations

- Functional classification of the highway
- Character of the terrain
- Density and character of adjacent land uses
- Traffic volumes expected to use the highway
- Economic and environmental considerations

Freeways	Design Speeds	
Terrain	**Rural**	**Urban**
Flat	70-80	70
Rolling	60-70	60-70
Mountainous	50-60	50-60
Arterial Highways		
Terrain	**Rural**	**Urban**
Flat	60-70	30-60
Rolling	40-60	30-50
Mountainous	30-50	30-50
Collector and Local Roads		
Terrain	**Rural**	**Urban**
Flat	30-50	30-40
Rolling	20-40	20-40
Mountainous	20-30	20-30

Source: Traffic *Engineering Handbook (Fourth Edition),* Institute of Transportation Engineers, Washington, DC, 1992, p. 156. Note: 1 mile/hr = 1.613 km/hr

Values represent the minimum acceptable design speeds for the various conditions of terrain and traffic volumes associated with new or reconstructed highway facilities

Example1

- Draw the cross section required for a highway showing all visible dimensions needed for construction using the following data:
- Present daily traffic composed of 3000 passenger car, 300 trucks and the same numbers of buses.
- Design speed = 120 km/h
- Directional distribution = 65%
- Expected increase of future traffic = 80%
- Practical lane capacity = 700 pce's/hour
- DHV/AADT = 0.12
- Original ground level at (c.s.) = 10.00m
- Surface road level at (c.s.) = 12.00 m

Solution Example1

- 3000 passenger car, 300 trucks and 300 buses.
- AADT = 3000 x 1 + 300 x 3 + 300 x 2.5
  = 4650 pce's/day
- $AADT_{design}$ = 4650 x [1+ (80/100)]
- $AADT_{design}$ = 4650 x 1.8 = 8370 pce's/day
- DHV = 8370 x 0.12 = 1004 pce's/h
- $DHV_{one\ direction}$ = 1004 x 0.65 = 652 pce's/h
- No. of lane = 652/700 = 0.93 $\cong$ 1 lane per direction

Example2

- Draw the cross section required for the renewed highway showing all visible dimensions according to the following data:
- Max. future AADT on original roads = 3000 Vpd
- The 30th highest hour factor, K =0.12
- % Age of trucks = 15
- % age of buses = 5
- Design speed = 100 km/h
- Directional distribution = 60%
- Induced traffic volume = 1000 pce's/hour
- Development traffic volume = 1250 pce's/hour
- Practical lane capacity = 800 pce's/hour
- Original ground level at (c.s.) = 9.00m
- Surface road level at (c.s.) = 11.20 m

Solution Example2

- $AADT_{future}$ = 3000 x 0.8 x 1 + 3000 x 0.15 x 3 + 3000 x 0.05 x 2.5
 = 4125 pce's/day
- Total $AADT_{future}$ = 4125*0.12+1000+1250
 = 2745 pce's/h
- $DHV_{one\ direction}$ = 2745 x 0.60 = 1647pce's/h
- No. of lane =1647 /800 =2.05 ≅ 2 lane per direction

Example3

- Traffic counts in 2020 at a counting point on a national highway gave ADT as follows:
- 4000 cars, 1750 taxis, 250 trucks, 100 buses.
- National traffic growth in the area is expected to be 5% for private cars and taxi, 3% for trucks and buses.
- Generated traffic for the highway after improvements will be 20% of the 2020 ADT.
- It is required to design the cross section of the highway to satisfy the traffic needs by year 2030 show all visible dimensions on a drawing sketch.
- Practical lane capacity = 1000 pce's/hour

Prepared By: Prof. Dr. Mahmoud Enieb

33

Solution Example3

- $AADT_{2020}$ = (4000 +1750)x 1 + 250 x 3 + 100 x 2.5 = 5750 + 750 + 250 = 6750 pce's/day
- $AADT_{2030}$ = $5750x(1+0.05)^{10}$ + $(750 + 250)x(1+0.03)^{10}$
  = 9366 + 1344 = 10710 pce's/day

Generated traffic = 0.2 x 6750= 1350 pce's/day

- Total $AADT_{future}$ = 10710 + 1350 =
  = 12060 pce's/day
- DHV = 12060 x 0.15 = 1809 pce's/h
- $DHV_{one\ direction}$ = 1809 x 0.67 = 1212 pce's/h
- No. of lane = 1212/1000 = 1.21 ≅ 2 lane per direction

Prepared By: Prof. Dr. Mahmoud Enieb

34

Example4

- A rural highway located in a mountainous terrain is to be designed to carry a DHV 1250 vph, 25 percent of which are trucks.
- Draw cross section of highway with all details for the following data with the anticipated converted traffic 600 pcu/h
- Design speed = 100 kph.
- Directional distribution = 55%
- DHV per lane = 720 pce's/hour

Solution Example4

- DHV_{future} = 1250 x 0.75 x 1 + 1250x 0.25 x 3 = 1875 pce's/h
- Total DHV_{future} = 1875+600 = 2475 pce's/h
- $DHV_{one\ direction}$ = 2475 x 0.55 = 1361 pce's/h
- No. of lane = 1361/720 = 1.89 ≅ 2 lane per direction

Problem 1

- Traffic count in year 2018 at counting point on an urban highway gave ADT as follows: 6000 light vehicles, and 700 heavy vehicles. Normal traffic growth in that area is expected to be 6% for light vehicles, 4% for heavy vehicles. And Generated traffic for highway will be 30% of the ADT(2018). It is required to design the cross section for the roadway to satisfy the traffic needs by year 2038. Also draw a cross section for the roadway showing all necessary dimension. Give that : 1 light vehicle =1.0 PCE, 1 heavy vehicle = 3.0 PCE, Practical lane capacity = 700 PCE/hr/lane. Lane width = 3.75m. Direction distribution factor (D)=65%, K=0.12. Original ground level =10.0m. Road level=12.0m. Use median of 3 m width and take side slopes (2 Hz :1 Vr)

Prepared By: Prof. Dr. Mahmoud Enieb

37

Problem 2

- Traffic count on a section of national rural highway showed that ADT is 5000 vehicles in year 2018. It is proposed to improve highway for traffic needs by 2038. A traffic development due to improvements on land adjacent to the highway is expected to be 600 vehicle/day as by year 2018. Given data:
- Expected increase of future traffic = 120%
- % Truck, T = 20%, D = 65%.
- Original ground level = 8.00 m,
- Surface highway level = 10.00 m,
- Design lane capacity = 750 P.C.E / hour / lane.
- Draw the cross section (C.S.) required for the renewed highway showing all visible dimensions.

Prepared By: Prof. Dr. Mahmoud Enieb

38

Problem 3

- Draw the cross section required for a rural highway showing all visible dimensions according to the following data:
- ADT (2018) = 6000 vehicle /day
- The future increase in traffic in the end of the design period = 50%.
- Design lane capacity = 600 pce's/hour
- Directional factor, D = 66%
- % Trucks, T = 15% Truck = 3.0 pce's
- Original ground level = (8 m)
- Surface roadway level = (11 m)
- Design period = 20 year .

Problem 4

- If the future ADT for Two directions will be 10,000 Vehicle/day and D = 66% and Lane Capacity is 600 pce's / hr / lane. The traffic composition is (65% passenger car, 20% Single Truck, 5% Truck with trailer, 5% Bus, 5% hand drive car). Required:
- Number of lanes per direction, assume:
- Passenger car = 1 pce's.
- Single truck = 3 pce's.
- Truck with trailer =3.5 pce's,
- Bus = 2.5 pce's.
- Hand driver car = 6 pce's
- K = 0.12

Problem 5

- Traffic count in year 2018 at counting point on an urban highway ADT as follows:
- 1000 private cars, 5000 taxis, 250 trucks, and 300 buses.
- Normal traffic growth in the area is expected to be 7% for private cars and taxis, 5% for trucks and buses.
- Generated traffic for the highway after improvements will be 40% of the 2018 ADT.
- Development traffic for highway is expected 600 pce's/day.
- Lane Capacity is 750 pce's/ hr / lane
- It is required to design the cross section of the highway to satisfy the traffic needs by year 2038, if D = 65% K = 0.12.

Problem 6

- a) Discuss the highway classification systems and their purposes.
- b) Draw a neat sketch showing the rural highway network of highway system. State the function of each link type in the network.
- c) With sketch, explain urban highway network components. State the function of each link type in the network.
- d) State vehicle characteristics contribute highway geometric design.

Solution problem 1

- $AADT_{2018}$ = 6000x 1 + 700 x 3
  = 6000 + 2100 = 8100 pce's/day
- $AADT_{2038}$ = $6000x(1+0.06)^{20}$ + $(2100)x(1+0.04)^{20}$
  = 19242 + 4601 = 23843 pce's/day

Generated traffic = 0.3 x 8100= 2430 pce's/day

- Total $AADT_{future}$ = 23843 + 2430 =
  = 26273 pce's/day
- DHV = 26273 x 0.12 = 3152 pce's/h
- $DHV_{one\ direction}$ = 3152 x 0.65 = 2049 pce's/h
- No. of lane = 2049/700 = 2.93 ≅ 3 lane per direction

Solution Problem 2

- ADT_{2018} = 5000 vehicles/day.
- Traffic development = 600 vehicles/day
- ADT_{2018} = 5000 x 0.8 x 1 + 5000 x 0.2 x 3
  = 4000 + 3000 = 7000 pce's/day

Traffic development = 600 x 0.8 x 1 + 600 x 0.2 x 3

Traffic development = 480 + 360 = 840 pce's/day

- ADT_{2038} = 7000 x [1+ (120/100)]
- ADT_{2038} = 7000 x 2.2 = 15400 pce's/day
- ADT_{design} = 15400 +840 = 16240 pce's/day

- DHV = 16240 x 0.15 = 2436 pce's/h
- $DHV_{one\ direction}$ = 2436 x 0.65 = 1583 pce's/h
- No. of lane = 1583/750 = 2.1 ≅ 2 lane per direction

Solution Problem 3

- ADT_{2018} = 6000 vehicles/day.
- ADT_{2018} = 6000 x 0.85 x 1 + 6000 x 0.15 x 3
  = 5100 + 2700 = 7800 pce's/day
- ADT_{2038} = 7800 x [1+ (50/100)]
- ADT_{2038} = 7800 x 1.5 = 11700 pce's/day
- DHV = 11700 x 0.15 = 1755 pce's/h
- $DHV_{one\ direction}$ = 1755 x 0.66 = 1158 pce's/h
- No. of lane = 1158/600 = 1.93 ≅ 2 lane per direction

Prepared By: Prof. Dr. Mahmoud Enieb

45

Solution Problem 4

- ADT_{future} = 10000 vehicles/day.
- ADT_{future} = 10000 x [0.65 x 1
- + 0.2 x 3 + 0.05 x 3.5 + 0.05 x 2.5
- + 0.05 x 6]
  = 6500
  + 6000 + 1750 + 1250
  + 3000 = 18500 pce's/day
- DHV = 18500 x 0.12 = 2220 pce's/h
- $DHV_{one\ direction}$ = 2220 x 0.66 = 1465 pce's/h
- No. of lane = 1465/600 = 2.44 ≅ 3 lane per direction

Prepared By: Prof. Dr. Mahmoud Enieb

46

Solution problem 5

- 6000 passenger car + taxi, 250 trucks and 300 buses.
- ADT_{2018} = 6000 x 1 + 250 x 3 + 300 x 2.5
  = 6000 + 750 + 750 = 7500 pce's/day
- ADT_{2038} = 6000 x $(1+ 0.07)^{20}$
- + 1500 x $(1 + 0.05)^{20}$
- = 23218 + 3980 = 27198 pce's/day
- Generated traffic = 0.40 x 7500 = 3000 pce's/day
- Development traffic = 600 pce's/day
- ADT_{design} =27198+3000+600=30798 pce's/day
- DHV = 30798 x 0.12 = 3695 pce's/h
- $DHV_{one\ direction}$ = 3695 x 0.65 = 2402 pce's/h
- No. of lane = 2402/750 = 3.2 ≅ 4 lanes per direction