CE 269
Traffic Engineering

Lecture 3

Level of Service and Designing Highways

Previously on Traffic Engineering

Exact relationships

- $q = kv_s$
- $v_t = \frac{1}{\Delta N} \sum_i v_i$
- $v_s = \frac{1}{L} \sum_i v_i$
- $v_t = v_s + \frac{\sigma_s^2}{v_s}$, and $v_t \geq v_s$

Approximate relationships

- $s_i \approx v_{i-1} h_i$
- $k \approx \frac{q}{v_t} \left(1 + \frac{q}{v_t} \widehat{Cov}(\mathbf{v}, \mathbf{h})\right)^{-1} \approx \frac{q}{v_t}$
- $v_s \approx \frac{1}{\frac{1}{\Delta N} \sum_i \frac{1}{v_i}}$

Previously on Traffic Engineering

Speed and Density:

$$v = v_f \left(1 - \frac{k}{k_j}\right)$$

where v_f is the free flow speed and k_j is the jam density.

Flow and Density:

$$q = v_f \left(k - \frac{k^2}{k_j}\right)$$

What is the maximum flow (capacity) according to the above equation?
$k_m = \frac{k_j}{2}$ and $q_m = \frac{v_f k_j}{4}$.

Speed and Flow:

$$q = k_j \left(v - \frac{v^2}{v_f}\right)$$

What is the speed at the maximum flow? $v_m = \frac{v_m}{2}$.

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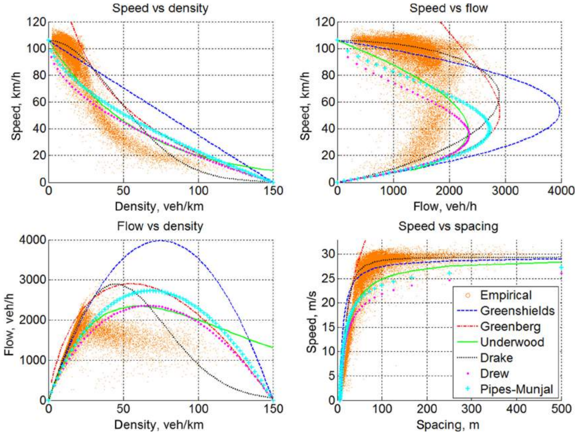
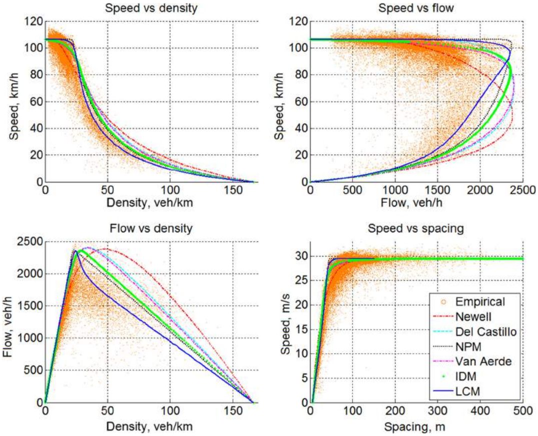


Previously on Traffic Engineering



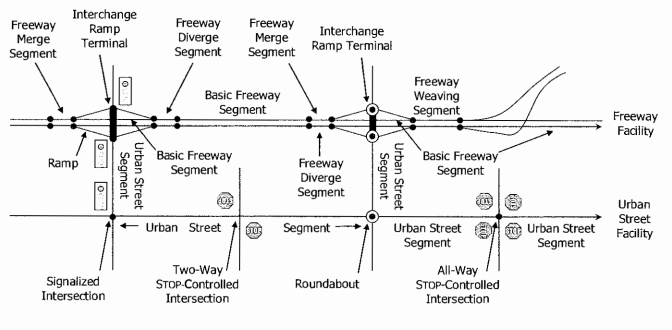
Lecture Outline

1. Design Variables
2. Performance Evaluation
3. Planning New Facilities

Design Variables

Traffic Facilities

A transportation network comprises of several facilities, each with a specific purpose.



There are guidelines for when to build a certain facility and how to evaluate their performance.

Design Variables

Introduction

According to Indo-HCM, uninterrupted facilities can refer to the following type of roads:

- Single-lane highways
- Two-lane two-way highways
- Multi-lane interurban highways
- Multi-lane expressways

Urban roads are usually interrupted since they have junctions or signals. We will revisit design elements of such systems later.

Expressways (or freeways) are fully access controlled and do not have auto-rickshaw and two-wheeler traffic.

Design Variables

Introduction

In today's lecture we will first look at how to categorize the performance of a Four-lane interurban highways under *average* conditions.

The procedure for performance evaluation and design of new facilities for the above types of facilities are more or less similar.

Most of this is based on empirical studies and is built on data from the field. To aid transferability, several corrections are typically proposed.

Next, this knowledge is used for planning purposes in determining how to design a new highway. Specifically, we will decide on how many lanes to build in the carriageway to handle a known amount of traffic.

Design Variables

Base Variables

Base Capacity: The maximum number of vehicles that can pass a given point on a lane or roadway during one hour under the base conditions of traffic flow.

Design Speed: Design speed depends on the function of the road and terrain conditions. Design speeds for various classes of interurban highways given in IRC: SP-84 (2014) and IRC: SP-87 (2013) is to be followed.

Design Variables

Adjusted Variables

Adjusted Capacity: The maximum number of vehicles that can pass a given point on a lane or roadway during one hour under the prevailing roadway and traffic conditions. It is obtained by adjusting the base capacity for the roadway and traffic conditions present at site.

Operating Speed: Theoretically, it is the average speed (in km/h) of the traffic stream, comprising only passenger cars, when the traffic density is approaching zero i.e. there are negligible number of vehicles present on the carriageway. Therefore, it is the speed of a vehicle when the presence of other vehicles does not restrain its movement.

From operational point of view, it is the 85th percentile speed of standard passenger cars measured under low volume conditions. Such low volume conditions are said to occur if the time headway between two successive vehicles is 8 seconds or more.

Design Variables

Highway Geometry Related

Gradient: The rate of rise or fall of the road surface along its length with respect to the horizontal is called gradient. It refers to the steepness of the road section and is expressed in percentage (%).

Horizontal Curvature: Weighted average of the curvatures of the curved sections for one km of the roadway, the weights being the proportion of the length of curved sections. Its units are degrees/km.

Roughness: Aggregated deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage. Roughness measured in terms of the International Roughness Index (IRI) in m/km.

Shoulder Type: A shoulder is a portion of the road contiguous with the carriageway intended for stopped vehicles, emergency use and providing lateral structural support to the road. It can either be paved and unpaved.

Design Variables

Derived Quantities

A major challenge to model Indian highways is to account for heterogeneity of vehicles. To this end, the concept of *Passenger Car Units* and *Stream Equivalence Factors* are used.

Passenger Car Unit (PCU): It measures the relative interaction between a vehicle and a traffic stream with respect to a standard passenger car under a specified set of roadway and traffic conditions.

Stream Equivalence Factors: Instead of working with PCUs, one could alternately use a linear combination of the proportions of different types of vehicles.

Performance Evaluation

Performance Evaluation

Level of Service

The performance of an existing facility is typically carried out by classifying it into 6 categories.

These categories, called the level of service, range from A to F and are based on the density and volume-to-capacity (v/c) ratios. A is ideal and F denotes jammed conditions.

Where is LoS calculated? Pick segments that are homogeneous. When road characteristics change, they serve as boundaries for other segments for which LoS is calculated separately.

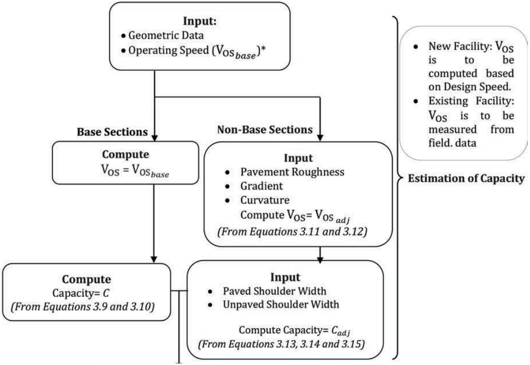
How to collect data for LoS? Indo-HCM recommends collecting classified vehicle counts for a week aggregated in 5-min intervals.

LOS	Description	Illustration
A	It represents a condition of free flow. Individual drivers are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to manoeuvre within the traffic stream is high. The general level of comfort and convenience provided to the road users is excellent.	
B	It represents a zone of stable flow, with the drivers still having reasonable freedom to select their desired speed and manoeuvre within the traffic stream. Level of comfort and convenience provided is somewhat less than level of service A, because the presence of other vehicles in the traffic stream begins to affect individual behaviour.	
C	This also is a zone of stable flow, but marks the beginning of the range of flow in which the operation of individual drivers starts getting affected by interactions with others in the traffic stream. The selection of speed is now affected by the presence of others, and manoeuvring within the traffic stream requires vigilance on the part of the user. The general level of comfort and convenience starts declining at this level.	
D	It represents the limit of stable flow, with conditions approaching close to unstable flow. Due to high density, the drivers are restricted in their freedom to select desired speed and manoeuvre within the traffic stream. The general level of comfort and convenience is poor. Small increases in traffic flow will usually cause operational problems at this level.	
E	It represents operating conditions when traffic volumes are at or close to the capacity level. The speeds are reduced to a low, but relatively uniform value. Freedom to manoeuvre within the traffic stream is severely restricted, and is generally accomplished by forcing a vehicle to give way to accommodate such manoeuvres. Comfort and convenience are very poor, and driver frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor disturbances within the traffic stream will cause breakdowns.	
F	It represents the zone of forced/ breakdown flow. This condition occurs when the amount of traffic approaching a point exceeds the amount that can pass it. Queue formation occurs at such bottlenecks with traffic operating in stop-and-go waves, which are extremely unstable. It can also result in substantial traffic delays, and ultimately a total jam condition.	

Performance Evaluation

Capacity Estimation

Before calculating the LoS, it is essential to adjust the capacity of facilities based on roadway and traffic conditions.



Most of these adjustments are simple regression-style corrections that have been estimated from datasets from multiple states.

Performance Evaluation

Capacity Estimation

Before calculating the LoS, it is essential to adjust the capacity of facilities based on roadway and traffic conditions.

Operating Speed Adjusted: Next, the operating speed is adjusted based on geometric conditions.

$$V_{OS_{adj}} = V_{OS_{base}} - 4.7IRI - 0.6GR - 0.3CU$$

where $V_{OS_{adj}}$ is adjusted operating speed in kmph, IRI is international roughness index in m/km (no adjustment is needed if ≤ 2.7, gradient is in %, and curvature is in deg/km. Do the signs make sense?

Base Capacity: The base capacity is first calculated based on the adjusted operating speed. Speeds are measured in kmph and C is measured in PCU/h/direction.

$$C = 30V_{OS_{adj}} + 1540$$

Adjusted Capacity: The base capacity is then adjusted based on roadway geometry.
For sections with median width $\geq 2.5m$,

$$C_{adj} = C + 188PSW + 170UPSW + 74$$

For sections with median width $< 2.5m$,

$$C_{adj} = C + 188PSW + 170UPSW$$

where C_{adj} is the adjusted capacity in PCU/h/direction, C is the base capacity, PSW is the difference between actual width and base width of the paved shoulder (actual width - 1.5 m), and UPSW is the width of unpaved shoulder. Do the signs make sense?

Performance Evaluation

Example

For the following road and traffic conditions, estimate the capacity of the facility.

- Operating speed: 100 km/h
- Lane width: 3.5 m
- Gradient: 1.4%
- Pavement roughness (IRI): 3.6 m/km
- Curvature: 172.5 deg/km
- Paved shoulder width: 0.5 m
- Median width: 1.5 m
- Terrain: Plain

Performance Evaluation

Passenger Car Units

Passenger car units convert other vehicles into 'cars' using factors that are based on their sizes.

A size-based factor does not account for the speeds with which passenger cars in the stream travel. To adjust for this, dynamic PCUs have been proposed in the literature

$$PCU_i = \frac{V_c/V_i}{A_c/A_i}$$

where V_c and A_c are the speed and area of standard car ($\leq 1400cc$ engine) and V_i and A_i are the speed and area of vehicle type i.

Performance Evaluation

Passenger Car Units

S. No.	Vehicle Type	Four Lane Divided Highway Segments	
		Range	Median
1.	Standard Car *(SC)*	-	1.00
2.	Big Car *(BC)*	1.4 - 1.5	1.45
3.	Motorized Two-Wheeler *(TW)*	0.3 - 0.5	0.40
4.	Auto-rickshaw *(AUTO)*	1.1 - 1.3	1.20
5.	Light Commercial Vehicles *(LCV)*	2.7 - 3.3	3.10
6.	Two / Three Axle Trucks *(TAT)*	3.5 - 4.6	4.40
7.	Multi-Axle Trucks *(MAT)*	6.3 - 7.0	6.60
8.	Bus *(B)*	4.4 - 5.3	5.00
9.	Tractors including Trailers *(TT)*	3.9 -7.0	6.20

Vehicle Type	Four Lane Divided Highway Segments	
	Traffic Proportion: Lower Limit (a)	Traffic Proportion Upper Limit (b)
Standard Car *(SC)*	8	40
Big Car *(BC)*	6	37
Motorized Two-Wheeler *(TW)*	4	38
Auto-rickshaw *(AUTO)*	2	15
Light Commercial Vehicles *(LCV)*	4	33
Two / Three Axle Trucks *(TAT)*	2	27
Multi-Axle Trucks *(MAT)*	1	10
Bus *(B)*	1	15
Tractors including Trailers *(TT)*	1	3

PCUs are sensitive to traffic and the tables shown earlier suggest average values but do not show this dependence.

Instead of PCUs, one could use a stream equivalence factor, which is a metric that would be larger for a traffic stream with a greater proportion of vehicles larger than standard cars.

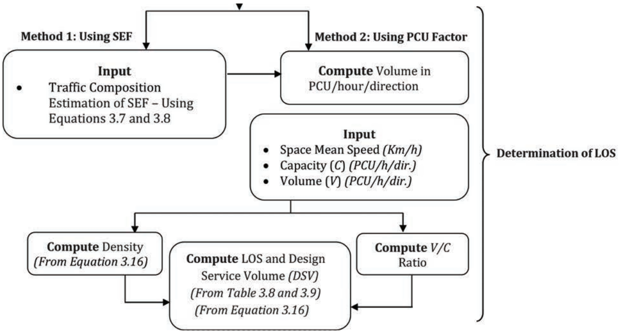
$$S_e = 1 + 0.6p_{BC} - 1.5p_{TW} + 2.6p_{LCV} + 3.6p_{TAT} + 6.4p_{MAT} + 1.2p_{Auto} + 4.8p_{BUS} + 59.8\frac{1}{N}$$

where p values indicate the proportion of vehicles and the subscripts refer to the vehicle type. The total traffic volume (veh/h) is indicated by N.

Performance Evaluation

Level of Service Estimation Steps

The LoS can be either calculated using PCUs or SE factors. The adjusted capacity is used as input to this process.



Either the density or V/C ratios can be used to estimate the final classification.

Performance Evaluation

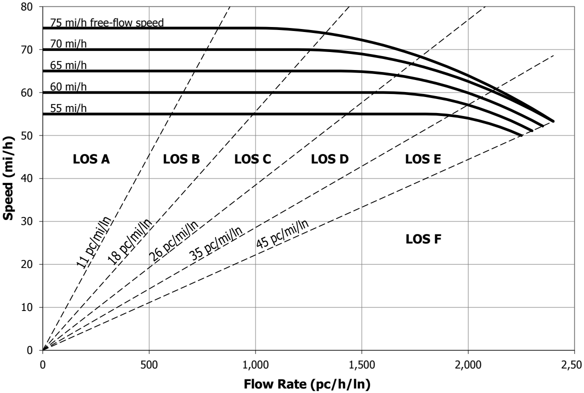
Level of Service Estimation Steps

LOS	Density (PCU/km/ direction)	Volume-to-Capacity ratio (v/c)	Service Volumes (PCU/day)	Recommended DSV Value for Upgradation (PCU/day)
A	≤ 18	0.00 - 0.20	≤18000	22500**@ LOS-B:** Suggested threshold flow for conversion from **four lane to six lane divided road** to ensure **enhanced safety** in traffic operations.
B	19 - 27	0.21 - 0.30	18001 - 27000	
C	28 - 45	0.31 - 0.50	27001 - 45000	
D	46 - 64	0.51 - 0.70	45001 - 63000	
E	65 - 90	0.71 - 1.00	63001 - 90000	
F	> 90	> 1.00	> 90000	

Calculate the LoS using SE factors and PCUs for the previous example if the space mean speed is 40 km/h and the observed proportion of vehicles is as follows:

Vehicle Category	Volume *(veh/h)*	Composition *(in %)*
Standard Car *(SC)*	431	34
Big Car *(BC)*	256	20
Two-Wheeler *(TW)*	282	23
Light Commercial Vehicle *(LCV)*	49	4
Two / Three Axle Trucks *(TAT)*	24	2
Multi Axle Trucks *(MAT)*	61	5
Auto-Rickshaw *(AUTO)*	86	7
Bus *(B)*	61	5
Total	1250	100

If you are working on data from a different country or reading the reference texts, note that the design guidelines may be different.



Planning New Facilities

Planning New Facilities

Reverse Engineering

The set of rules to find the LoS can be used to also plan new facilities.

Note that the lane widths and the number of lanes did not feature in the previous calculations because the volume and capacity were combined for all lanes.

Suppose we want to determine the number of lanes to achieve a certain LoS, we need to have a rough estimate of the demand. This requires a few additional design variables.

Planning New Facilities

Design Variables

Annual Average Daily Traffic (AADT): It is the annual average daily traffic when traffic measurements are taken for entire 365 days of the year.

Average Daily Traffic (ADT): It is the volume of daily traffic when traffic measurements are taken for a few days (less than one year) averaged by the number of days for which the measurements have been taken.

Design Hourly Volume (DVH): It is the 30th highest hourly volume which means that this hourly volume is exceeded only during 29 hours in a year.

Design Service Volume: It is defined as maximum service volume at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during one hour under prevailing roadway, traffic and control conditions while maintaining a designated level of service.

Peak Hour Ratio (PHR): It is the percentage of ADT or AADT that passes through a given section in the peak hour can be readily ascertained through field observations. In the absence of field observations, however, default value of PHR may be adopted as 10%.

Planning New Facilities

Example

Determine the number of lanes for a LoS B facility with the following input data.

- AADT: 20,000 veh/day
- Design speed: 100 km/h
- Traffic composition: SC – 28%, BC – 20%, TW – 10%, LCV – 12%, TAT – 10%, MAT – 7%, Auto – 3%, BUS – 10%
- Terrain: Plain
- Proportion of AADT during peak hour: 0.08
- Proportion of peak hour volume travelling in the peak direction: 0.6

Your Moment of Zen