

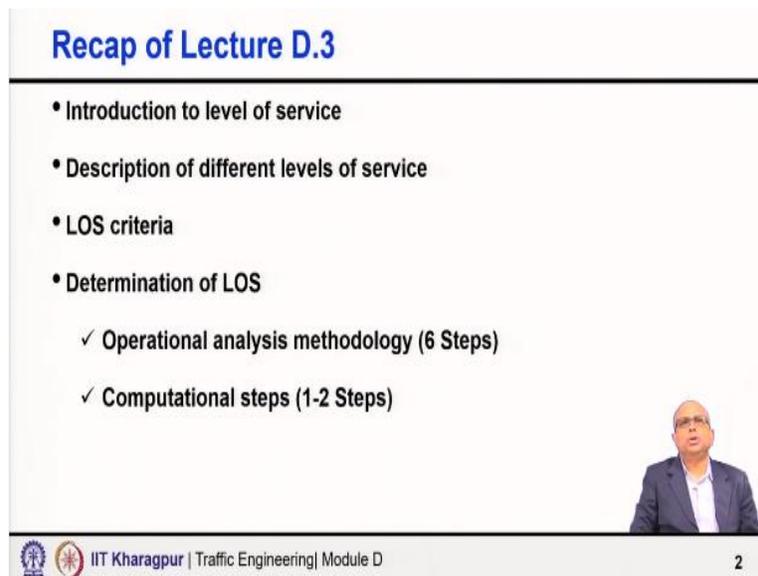
Traffic Engineering
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Lecture 19

Analysis of Basic Freeway and Multi-lane Highway Segments (as per HCM, 2016) - III

Welcome to module D lecture 4, in this lecture also we shall continue our discussion about analysis of basic freeway and multilane segments as per highway capacity manual 2016.

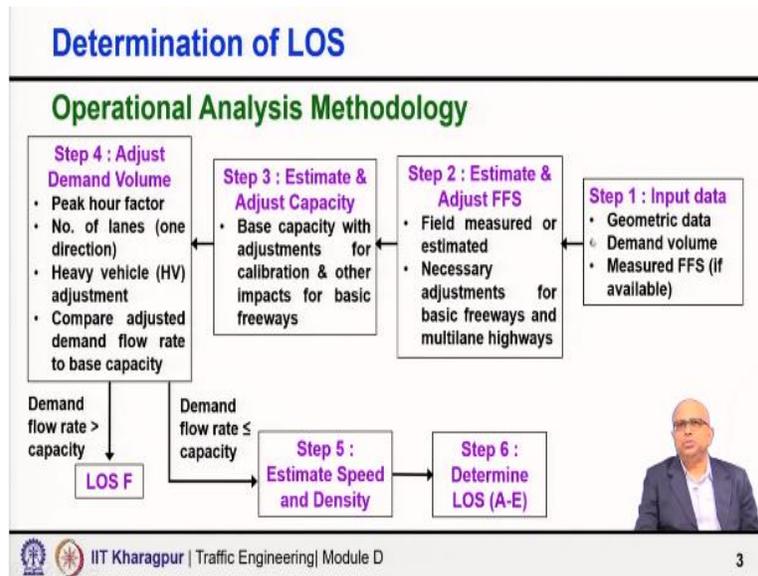
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The slide is titled "Recap of Lecture D.3" in blue text. It contains a bulleted list of topics: "Introduction to level of service", "Description of different levels of service", "LOS criteria", and "Determination of LOS". Under "Determination of LOS", there are two sub-points: "Operational analysis methodology (6 Steps)" and "Computational steps (1-2 Steps)", both preceded by checkmarks. A small video inset of the professor is visible in the bottom right corner of the slide. At the bottom of the slide, there is a footer with the IIT Kharagpur logo, the text "IIT Kharagpur | Traffic Engineering | Module D", and the number "2".

And to have a quick recap what we discussed in lecture 3 is how the level of service can be defined for multilane highway segments and also for freeways, description of different levels of service starting from A to F, then the LOS criteria, what are the density thresholds that are used to define the LOS and what are the steps broadly six steps for the operational analysis of freeways and multilane highways segments, then step one and step two, the computational steps we discussed.

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To continue with that lets once again look at this six steps, we start with the input data where we have geometric data, demand volume and measured free flow service, if we can do field measurement and that of course, that is desirable, if we cannot do that then we have to estimate and adjust the free flow speed, so how we can do several adjustments may be necessary separately for freeway segments and multilane highway segments. So, these two steps, first the step 2A estimation of FFS and step 2B adjustment of further adjustment of FFS based on local conditions, that much we discussed.

So, we now continue the same discussion, now we take step three, step three again estimate and adjust capacity. So, there are two components, estimation of capacity and adjustment of capacity.

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Determination of LOS

Step 3A: Estimate Capacity

- Base capacity values for different FFS values can be obtained for basic freeway segments & multilane highway segments using Table 4.1 (from Exhibit 12-4 of HCM, 2016)
- Because of the ability to interpolate between different FFS values, the resulting segment capacities should also be interpolated
- Alternatively, base capacity 'c' (in pc/h/l) for basic freeway & for multilane highway can be estimated directly with Eqs. 4.6 and 4.7 respectively:



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Determination of LOS

$$c \text{ (basic freeway)} = 2200 + 10 \times (FFS_{adj} - 50) \dots\dots (4.6)$$
$$c \text{ (multilane highway)} = 1900 + 20 \times (FFS_{adj} - 45) \dots\dots (4.7)$$

- When, c (basic freeway) \geq 2400 pc/h/l
- c (multilane highway) \geq 2300 pc/h/l
- FFS (basic freeway) \geq 75 mi/h
- FFS (multilane highway) \geq 70 mi/h



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First 3A estimation of capacity, base capacity value for different free flow speed values can be obtained for basic freeway segments and multilane highway segments using table 1 what I have already shown earlier, you can see that what are the free flow speed values and then corresponding two columns, one for freeway segments, another for multilane highway segments which I produced it here in this module as table 4.1, basically that is exhibit 12-4 of highway capacity manual 2016.

So, once the FFS values are known or FFS value is known for a given segment and we know whether it is multilane highway segment or it is a freeway segment accordingly from table 4.1 or exhibit 12-4 of highway capacity manual we can select the values. Now, because of the ability to

interpolate between different free flow segment values you know that the values were given at 5 mile per hour interval, so we can do interpolation so we can take what is the value for x and then next level may be x plus 1 what is the that level and then two free flow speed values what are the corresponding capacities and we can interpolate it if required, so that is one way we can do it.

Alternatively we can use equation 4.6 and 4.7 which was again mentioned, these were mentioned earlier but again I have mentioned it here that we can directly use these equations, this is for basic freeway segments and this is for multilane highway segments. So, once we know the adjusted free flow speeds then we can use either equation the first one or the second one as appropriate depending on whether the segment is basic freeway segment or multilane highway segment we can also calculate the capacity value. So, we can one way either take it from a table or exhibit and then interpolate it or we can directly calculate it.

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Determination of LOS

Step 3B: Adjust Capacity

- Capacity of a **basic freeway** may be adjusted further to account for impacts of adverse weather, driver population, poor sight distance, Poor pavement conditions, or a combination of such influences

$$C_{adj} = C \times CAF \quad \dots\dots(4.8)$$

Where, C_{adj} = adjusted capacity of segment (pc/h)
 C = base capacity of segment (pc/h)
 CAF = capacity adjustment factor (unitless)

- **No adjustment is possible for multilane highways since no empirical research exists for its application**

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Then next step 3B we have to do further adjustment of capacity and these adjustments are to suit to the local condition or prevailing condition, because capacity of a basic freeway need to be adjusted further to account for impact of several factors I have mentioned only a few here for example, adverse weather, driver population, somewhere there could be site distance, poor side distance and which may impact the overall flow and the capacity, sometimes it may be poor pavement condition and sometimes even other factors so or say combination of various influences.

So, therefore, whatever capacity we have got we multiply it by an appropriate factor what is called as capacity adjustment factor, sometime this may be a single value, sometimes there may be

multiple values, there are so many things but we get that factor or those factors combination of factors and then accordingly get the C adjusted or the adjusted capacity of segment as per prevailing condition, of course, similar kind of adjustment may not be, we may not be able to do for multilane highway since no empirical research exists for its application.

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Determination of LOS

Step 4: Adjust Demand Volume

- Since speed-flow curves and parameters of **Table 4.2** (from **Exhibit 12-6 of HCM, 2016**) are based on flow rates in equivalent passenger cars per hour, demand volumes expressed as vehicles per hour under prevailing conditions must be converted to this basis by using **Equation 4.9**:

$$v_p = \frac{V}{PHF \times N \times f_{HV}} \dots\dots(4.9)$$

Where, v_p = demand flow rate under equivalent base conditions (pc/h/ln)
 V = demand volume under prevailing conditions (veh/h)
 PHF = peak hour factor (decimal)




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Then this step four, so we have gone to up to step four, step one, step two, step three, step four there in adjust demand volumes. Now, why we are doing these steps? Because speed flow curves and parameters of table 2 which again I have shown in earlier lecture shown as table 4.2, wherever 4.1 and 4.2 are shown together how the basic capacity values we are getting and then what are the further adjustment factors which are actually the adjustments are exhibit 12-6 of highway capacity manual 2016, these are based on flow rates in equivalent passenger car per hour, so the unit what was used passenger car hour per hour per lane.

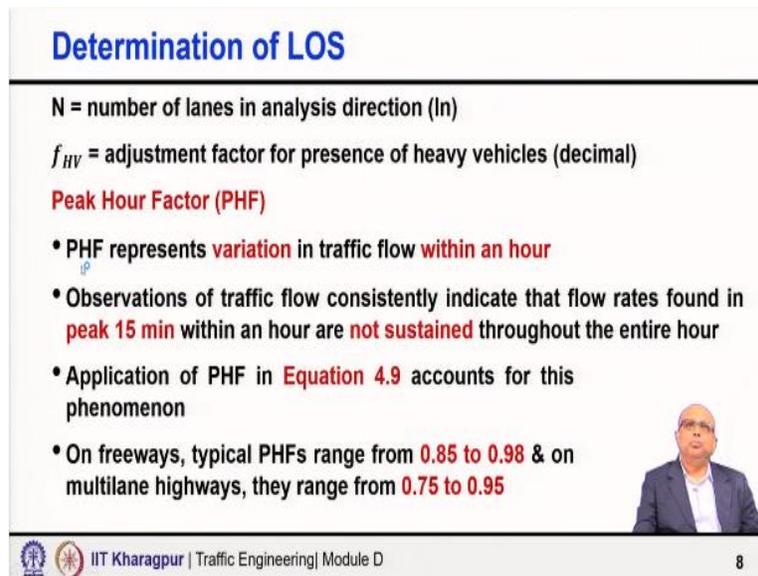
So, now we then need to therefore adjust this volume whatever we have got so far to convert them to equivalent passenger car per hour per lane and also you know the capacity is expressed considering the 15 minute flow rate, so we need to take care of that, so the peak hour factor also will come.

So, how we are converting the demand volume under prevailing condition to equivalent demand flow rate under base conditions v_p with the help of recover factor also the number of lanes, because we need to express it on passenger car per hour per lane, so that N is number of lane and f_{HV} this is

the correction factor to account for heavy vehicle population that are there in the traffic stream, because the base condition assumes all are passenger car, homogeneous.

So, we need not the vehicle but equivalency, some kind of equivalence we have to use for heavy vehicles and the appropriate adjustment factor for that f_{HV} to account for that heavy vehicle proportion in the traffic stream.

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Determination of LOS

N = number of lanes in analysis direction (ln)

f_{HV} = adjustment factor for presence of heavy vehicles (decimal)

Peak Hour Factor (PHF)

- PHF represents **variation** in traffic flow **within an hour**
- Observations of traffic flow consistently indicate that flow rates found in **peak 15 min** within an hour are **not sustained** throughout the entire hour
- Application of PHF in **Equation 4.9** accounts for this phenomenon
- On freeways, typical PHFs range from **0.85 to 0.98** & on multilane highways, they range from **0.75 to 0.95**

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So, the peak hour factor as I said earlier, peak hour factor represents variation in traffic flow within an hour and observations of traffic flow consistently indicate the flow rates found in peak 15 minute within an hour are generally not sustained throughout the entire hour, and as I said earlier that the capacity is expressed and the flow rates are expressed as 15 minute volume expressed into equivalent hourly flow rate.

So, the peak hour factor once we are applying then this accounts for this phenomena which is set here and on freeways typical PHF ranges from 0.85 to 0.98 and on multilane highway the range is 0.75 to 0.95 as given in highway capacity manual. So, based on this fact we can apply a particular PHF value to take care of the 15 minute hourly flow rate.

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Determination of LOS

Adjustment for Heavy Vehicles

- All heavy vehicles are classified as single unit trucks (SUTs) or truck trailers (TTs)
- Recreational vehicles and buses are treated as SUTs
- Heavy vehicle adjustment factor (f_{HV}) is computed by combining two heavy vehicle classes, that are added to get an overall truck percentage P_T

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \dots\dots(4.10)$$

P_T = proportion of SUTs & TTs in traffic stream (decimal)

E_T = passenger car equivalent of one HV in traffic stream (PCE) [For general terrains, PCE (level) = 2.0, PCE (Rolling) = 3.0 from Exhibit 12-25]



Determination of LOS

N = number of lanes in analysis direction (ln)

f_{HV} = adjustment factor for presence of heavy vehicles (decimal)

Peak Hour Factor (PHF)

- PHF represents variation in traffic flow within an hour
- Observations of traffic flow consistently indicate that flow rates found in peak 15 min within an hour are not sustained throughout the entire hour
- Application of PHF in Equation 4.9 accounts for this phenomenon
- On freeways, typical PHFs range from 0.85 to 0.98 & on multilane highways, they range from 0.75 to 0.95

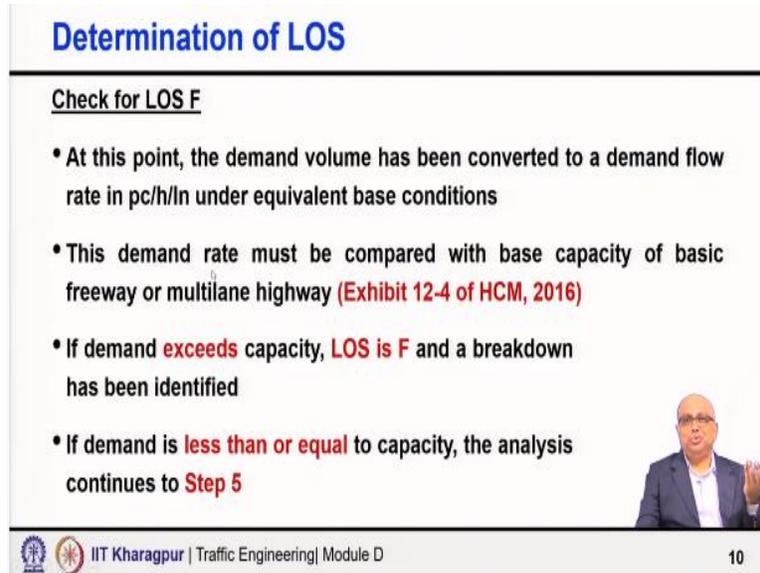


Then the adjustment for heavy vehicle that is the next one f_{HV} , that f_{HV} as I said all heavy vehicles are classified as single unit truck or truck trailers TTs, so SUTs or TT, recreational vehicle and buses are taken as considered as SUT therefore, the heavy vehicle adjustment factor is computed by combining two heavy vehicle classes that are added to get an overall truck percentage P_T .

So, take that P_T is the proportion of SUTs and TTs in the traffic stream, total share in decimal and then it is the passenger car equivalent of one heavy vehicle what we are considering together and that is obviously the effect of heavy vehicle will depend on the terrain condition also, so for level terrain that PCE is taken as 2 and for rolling terrain the value is taken as 3. So, that is what is the value of E_T appropriately we can take P_T we know so we can calculate f_{HV} and then the number of

lanes already we know, so we can now get the value of v_p which is the demand flow rate under equivalent base condition.

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Determination of LOS

Check for LOS F

- At this point, the demand volume has been converted to a demand flow rate in pc/h/ln under equivalent base conditions
- This demand rate must be compared with base capacity of basic freeway or multilane highway (Exhibit 12-4 of HCM, 2016)
- If demand **exceeds** capacity, **LOS is F** and a breakdown has been identified
- If demand is **less than or equal** to capacity, the analysis continues to **Step 5**

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Now, once we have done that we know the capacity, we know the volume. So, the first thing is to check whether our volume to capacity ratio is greater than 1, why we need to do that because you know that if it is greater than 1 then straight way we can say that the level of service is F, that is the purpose.

So, at this point the demand volume has been converted to a demand flow rate in passenger car per hour per lane under equivalent base condition and the demand rate therefore, must be compared with the base capacity of basic freeway or multilane segment as I said earlier and if the demand exceeds capacity that means volume to capacity ratio is greater than 1, then straight away we can say the LOS is F. If it is not so, if the demand is less than the capacity then we have to go to the next step which is step five.

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Determination of LOS

Step 5: Estimate Speed and Density

- Using Equation 4.1 and Table 4.2 (Exhibit 12-6 consisting of speed-flow parameters), expected mean speed of traffic stream (mi/h) is computed

$$S = FFS_{adj} \text{ for } v_p \leq BP \quad \dots\dots\dots 4.1 (a)$$

$$S = \frac{FFS_{adj} - (FFS_{adj} - \frac{c_{adj}}{D_c})(v_p - BP)^a}{(c_{adj} - BP)^a} \text{ for } BP < v_p < c \quad \dots\dots 4.1 (b)$$

v_p = adjusted demand flow rate (pc/hr/ln)

Other variables are described in Exhibit 12-6 (HCM, 2016)



Here with known speed and the flow we have to calculate the density, so to calculate the speed we know the flow we know the speed flow equation, these equations also I have mentioned earlier but I have reproduced it here you know there is a up to break point the speed is free flow speed, obviously free flow speed adjusted for the prevailing condition.

So, directly we can use this value and between break point and the capacity if it is in that range which is curve follows parabola and there all this value equation can be used and what could be the value of A for multi lane highways and what could be the value of A for freeways all these are given in table 4.2 so you can go back or you can go to the appropriate exhibit in highway capacity manual and here knowing the v_p , knowing the v_p and free flow speed adjusted, knowing the capacity everything is known.

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Determination of LOS

- After that, Equation 4.11 is used to estimate density of traffic stream:

$$D = \frac{v_p}{S} \dots\dots(4.11)$$

Where, D = density of traffic stream (pc/mi/ln)

v_p = demand flow rate (pc/h/ln)

S = mean speed of traffic stream for base conditions (mi/h)

- Eq. 4.11 is used only for $v/c \leq 1.00$; for $v/c > 1.00$, LOS is F



Determination of LOS

Step 5: Estimate Speed and Density

- Using Equation 4.1 and Table 4.2 (Exhibit 12-6 consisting of speed-flow parameters), expected mean speed of traffic stream (mi/h) is computed

$$S = FFS_{adj} \text{ for } v_p \leq BP \dots\dots\dots 4.1 (a)$$

$$S = \frac{FFS_{adj} - (FFS_{adj} - \frac{c_{adj}}{D_c})(v_p - BP)^a}{(c_{adj} - BP)^a} \text{ for } BP < v_p < c \dots\dots 4.1 (b)$$

v_p = adjusted demand flow rate (pc/hr/ln)

Other variables are described in Exhibit 12-6 (HCM, 2016)



So, we can actually calculate the density, once the speed is known and the v_p is known. So, this equation will give you the speed so the speed is known and vehicle volume is known equivalent hourly flow rate in pcu or passenger car per hour per lane is known, so we can simply flow by speed we can get the density.

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Determination of LOS

Step 6: Determine LOS

- Using the **density** obtained from **Equation 4.11, Table 4.3 (from Exhibit 12-15 of HCM, 2016)** is used to determine the expected prevailing LOS

LOS	Density (pc/mi/ln)
A	≤ 11
B	$> 11 - 18$
C	$> 18 - 26$
D	$> 26 - 35$
E	$> 35 - 45$
F	Demand exceeds capacity or Density > 45

(Source: Exhibit 12-15 of HCM, 2016)



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Now, the density is known, now step six so we can easily now determine the capacity, because this table also you are familiar with this table, so you know that there are different ranges say for example, density less than 11 means A, greater than 11 up to 18 it is B, greater than 18 up to 26 it is C and so on. So, now the calculated density whatever we have got we will see here it corresponds to what level of service, so accordingly we will say what is the LOS.

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Determination of LOS

Example 1: Find the expected LOS for a four-lane freeway (two lanes in each direction) during the worst 15 min of peak hour with following characteristics:

- Lane width = 11 ft
- Right-side lateral clearance = 2 ft
- Commuter traffic (regular users)
- Peak hour factor (PHF) = 0.92
- Peak hour, peak direction demand volume = 2,000 veh/h
- Facility operates under ideal conditions
- Total ramp density: 4 ramps/mi (with one cloverleaf interchange per mile)
- Traffic composition: 5% trucks
- Level terrain
- One cloverleaf interchange per mile



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Now, let us look at the applications to understand it even better, so will pick up two examples quickly, one is the freeway segment, another example with multilane highway segment.

First the freeway segment, find the expected LOS for a four lane freeway, two lane in each direction, every information is important, during the worst 15 minute of peak hour with following characteristics, lane width is 11 feet, right side shoulder clearance 2 feet, commuter traffic is regular class, peak hour factor is 0.92, peak hour, peak direction, traffic volume, this is going to be critical, that is the demand volume 2000 vehicle per hour, notice that it is vehicle per hour, not in passenger car per hour per lane.

Facility operates under ideal condition, that means no other adjustment will happen for the capacity once we calculate the capacity, total ramp density is 4 ramps per mile and traffic composition includes 5 percent of the truck, so that will matter when we convert this vehicle into passenger car per hour per lane, it is level terrain and one clover leaf interchange per mile.

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Determination of LOS

Computational Steps

Step 1: Input Data

- All input data are specified

Step 2: Estimate and Adjust FFS

- FFS of the freeway is estimated from **Equation 4.2** as follows:

$$FFS = BFSS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84} \dots\dots\dots (4.2)$$

BFSS = base FFS for basic freeway segment (mi/h)

f_{LW} = adjustment for lane width (mi/h) (**Exhibit 12-20 of HCM, 2016**)



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Determination of LOS

f_{RLC} = adjustment for right-side lateral clearance(mi/h) (from Exhibit 12-20 of HCM, 2016)

Exhibit 12-20 (HCM, 2016)

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥ 12	0.0
$\geq 11-12$	1.9
$\geq 10-11$	6.6

TRD = total ramp density (ramps/mi)

Right-Side Lateral Clearance (ft)	Lanes in One Direction			
	2	3	4	≥ 5
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Exhibit 12-21 (HCM, 2016)

Note: Interpolate for non-integer values of right-side lateral clearance



So, that is what is the thing, so input data, all input data are specified, all inputs we require are there, now we apply this equation 4.2 because it is the freeway segment, so correction with respect to LW lane width but lane width here what will be the value lane width it is 11 to 12, it is 1.9, what was the lane width 11 feet, so that is why we take this correction factor as 1.9 mile per hour, reduction will happen. Then total ramp density, this also we can right side lateral clearance we can take based on the number of lanes the table is produced here.

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Determination of LOS

$$FFS = BFFS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84}$$

- Adjustment for lane width for 11-ft lanes (Exhibit 12-20): 1.9 mi/h
- Adjustment for right-side lateral clearance for 2-ft clearance on freeway with two lanes in one direction (Exhibit 12-21): 2.4 mi/h
- Total ramp density (TRD): 4 ramps/mi
- $FFS = 75.4 - 1.9 - 2.4 - 3.22 \times 3.2 = 60.8$ mi/h
- Facility is operating under ideal conditions, speed adjustment factor (SAF) is 1, and $FFS_{adj} = FFS = 60.8$ mi/h



Determination of LOS

f_{RLC} = adjustment for right-side lateral clearance(mi/h) (from Exhibit 12-20 of HCM, 2016)

Exhibit 12-20 (HCM, 2016)

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥ 12	0.0
$\geq 11-12$	1.9
$\geq 10-11$	6.6

TRD = total ramp density (ramps/mi)

Right-Side Lateral Clearance (ft)	Lanes in One Direction			
	2	3	4	≥ 5
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Exhibit 12-21 (HCM, 2016)

Note: Interpolate for non-integer values of right-side lateral clearance



So, you can come to this and adjustment following 11 feet lane is 1.9 meter, adjustment for right side lateral clearance for 2 feet clearance on freeway two lane in each direction that is 2.4 mile per hour, so that much adjustment we have to do, total ramp density is 4 ramps per mile, that is what we have get and so that correction is also applied. So, we can actually calculate the FFS.

So, 75.4, why 75.4? Because that is what is the default values that is what we have taken, please connect it to my earlier lecture, I says above 75 mile per hour, that is where the equation starts or the model or the prediction model is developed beyond that and the default value precisely 75.4, so use this 75.4 minus 1.9 minus 2.4 and minus 3.22 into TRD to the power 0.84 is 3.2, so 60.8 mile per hour, so this is my FFS, taking BFSS as 75.4 default values for freeways.

Now, the facility is operating under ideal condition that is what has been told earlier also, so facility operates under ideal condition, so no further local adjustment is necessary, so the adjusted FFS is also same as FFS that is 60.8 mile per hour.

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Determination of LOS

Step 3: Estimate and Adjust Capacity

Exhibit 12-4 (HCM, 2016): Base Capacity Values for Basic Freeway & Multilane Highways

FFS (mi/h)	Capacity of Basic Freeway Segments (pc/h/ln)	Capacity of Multilane Highway Segments (pc/h/ln)
75	2400	NA
70	2400	2300*
65	2350	2300*
60	2300	2200
55	2250	2100
50	NA	2000
45	NA	1900

• For FFS = 60.8 mi/h, by interpolation, c = 2308 pc/h/ln

Notes: 1. NA = Not available
2. *Capacities for multilane highways with 65 & 70 mi/h FFS are extrapolated and not based on base data



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Determination of LOS

$$FFS = BFFS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84}$$

- Adjustment for lane width for 11-ft lanes (Exhibit 12-20): 1.9 mi/h
- Adjustment for right-side lateral clearance for 2-ft clearance on freeway with two lanes in one direction (Exhibit 12-21): 2.4 mi/h
- Total ramp density (TRD): 4 ramps/mi
- $FFS = 75.4 - 1.9 - 2.4 - 3.22 \times 3.2 = 60.8$ mi/h
- Facility is operating under ideal conditions, speed adjustment factor (SAF) is 1, and $FFS_{adj} = FFS = 60.8$ mi/h



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Then once we know that it is 60.8 mile per hour, we can go to this table, we know the value of capacity for basic freeway segment for 60 is 2300 and for 65 it is 2350, so we can interpolate it for the value 60.8 that interpolation has been done and then you get a value of 2308.

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Determination of LOS

- Alternatively, base capacity 'c' (in pc/h/l) for basic freeway can be estimated directly with Eq. 4.6 :

$$c \text{ (basic freeway)} = 2200 + 10 \times (FFS_{adj} - 50) \dots\dots\dots (4.6)$$

- When, c (basic freeway) \geq 2400 pc/h/ln and FFS (basic freeway) \geq 75 mi/h
- Therefore, $c = 2,200 + 10 \times (60.8 - 50) = 2,308 \text{ pc/h/ln}$
- For ideal conditions, CAF is 1, and $C_{adj} = c = 2,308 \text{ pc/h/ln}$



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Determination of LOS

Step 3: Estimate and Adjust Capacity

Exhibit 12-4 (HCM, 2016): Base Capacity Values for Basic Freeway & Multilane Highways

FFS (mi/h)	Capacity of Basic Freeway Segments (pc/h/ln)	Capacity of Multilane Highway Segments (pc/h/ln)
75	2400	NA
70	2400	2300*
65	2350	2300*
60	2300	2200
55	2250	2100
50	NA	2000
45	NA	1900

* For FFS = 60.8 mi/h, by interpolation, c = 2308 pc/h/ln

Notes: 1. NA = Not available
2. *Capacities for multilane highways with 65 & 70 mi/h FFS are extrapolated and not based on base data



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Alternatively, I told that you can use the capacity equation, so we have also done that here both we have shown here, so you can do that take the FFS adjusted value 60.8 and you exactly get here also again 2308, you just see both cases you get the same value. And for ideal condition again there is no further adjustment to capacity, so the capacity adjustment factor is 1, CAF is 1, so adjusted capacity is also same as the calculated capacity under ideal condition to 2308.

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Determination of LOS

Step 4: Adjust Demand Volume

- Demand flow rate (pc/h/ln) under equivalent base conditions is given by:

$$v_p = \frac{V}{PHF \times N \times f_{HV}} \dots\dots(4.9)$$

V = demand volume under prevailing conditions = 2000 veh/h
PHF = peak hour factor = 0.92
N = number of lanes in analysis direction = 2
 f_{HV} = adjustment factor for presence of heavy vehicles



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Now, the demand volume need to be adjusted, so we have the value of V that we know 2000 vehicle per hour but peak hour factor is given as 0.92 we know there are two lanes on each side and f_{HV} that we have to get.

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Determination of LOS

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \dots\dots(4.10)$$

P_T = proportion of SUTs & TTs in traffic stream = 5%
 E_T = passenger car equivalent of one HV in traffic stream = 2.0 for level terrain (Exhibit 12-25)

- $f_{HV} = \frac{1}{1 + 0.05(2.0 - 1)} = 0.952$
- $v_p = \frac{V}{PHF \times N \times f_{HV}} = \frac{2000}{0.92 \times 2 \times 0.952} = 1,142 \text{ pc/h/ln}$



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To calculate f_{HV} we use this formula I have mentioned this earlier, E_T value is given as 2 and P_T is 5 percent 0.05, so if you calculate the value of f_{HV} and now with the known calculated value of f_{HV} , N as 2 and peak hour factor as 0.92 we convert V to equivalent v_p . Flow rate under ideal

condition, equivalent flow rate under ideal condition in passenger car per hour per lane, so the v_p value is known.

(Refer Slide Time: 22:21)

Determination of LOS

Check for LOS F

- The demand rate (v_p) must be compared with base capacity of basic freeway or multilane highway (Exhibit 12-4)
- If demand **exceeds** capacity, **LOS is F** and a breakdown has been identified
- If demand is **less than or equal** to capacity, the analysis continues to **Step 5**
- $v_p = 1142 \text{ pc/h/ln} < 2,308 \text{ pc/h/ln}$ (base capacity of freeway with FFS = 60.8 mi/h), hence **LOS F** does not exist



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Once the v_p is known we can check whether this value is more than the capacity or not, if it is more than the capacity then straight away we will say the level of service F, capacity is 2308 and v_p is 1142, so v_p is less than the capacity therefore, it is not LOS F directly based on volume to capacity ratio or demand to capacity ratio greater than 1, so therefore, what we have to do, we have to calculate the density.

(Refer Slide Time: 22:47)

Determination of LOS

Step 5: Estimate Speed and Density

- Using Equation 4.1 and Table 4.2 (Exhibit 12-6 of HCM, 2016), expected mean speed of traffic stream is computed
- After that, Equation 4.11 is used to estimate density of traffic stream:

$$D = \frac{v_p}{S} \dots\dots(4.11)$$

Where, D = density of traffic stream (pc/mi/ln)

v_p = demand flow rate (pc/h/ln)

S = mean speed of traffic stream for base conditions (mi/h)

- Eq. 4.11 is used only for $v/c \leq 1.00$; for $v/c > 1.00$, LOS is F



To calculate the density we will again use this equation 4.1, so those equations are there we know that up to break point it is something and then beyond break point it is something else so that equation we have brought it here.

(Refer Slide Time: 23:08)

Determination of LOS

- From Exhibit 12-6, breakpoint for a 60.8 mi/h FFS speed-flow curve is

$$BP_{adj} = [1000 + 40 \times (75 - FFS_{adj})] \times CAF^2 = 1,568 \text{ pc/h/ln}$$

- As $v_p(1,142 \text{ pc/h/ln}) < BP(1,568 \text{ pc/h/ln})$, freeway operates within constant-speed portion of speed-flow curve, so S = 60.8 mi/h (Equation 4.1)

- Hence, Density, $D = \frac{v_p}{S} = \frac{1142}{60.8}$
 $= 18.8 \text{ pc/mi/ln}$



Determination of LOS

Check for LOS F

- The demand rate (v_p) must be compared with base capacity of basic freeway or multilane highway (Exhibit 12-4)
- If demand **exceeds** capacity, **LOS is F** and a breakdown has been identified
- If demand is **less than or equal** to capacity, the analysis continues to **Step 5**
- $v_p = 1142$ pc/h/ln $<$ 2,308 pc/h/ln (base capacity of freeway with FFS = 60.8 mi/h), hence **LOS F** does not exist



So, what is first is the break point that equation is used to calculate the break point value, because up to break point the speed is free flow speed, so break point flow level is 1568 and what was our flow rate 1142. So, it is volume is within the break point, so therefore, the free flow speed itself will be there 60.8 mile what we calculated earlier, you can see here 60.8 is the FFS adjusted that is what, so same value will be there because it is within the break point flow.

So, once it is done then we know we can calculate the D, so the v_p is 1142, S is because it is within the v_p value, v_p is 1142 which is less than this v_p flow, break point flow of 1568 and we know up to break point the speed is same as the FFS or FFS adjusted so you can calculate the density and you calculate the density as 18.8 passenger car per mile per lane.

(Refer Slide Time: 24:36)

Determination of LOS

Step 6: Determine LOS

- Using the **density** obtained from Equation 4.11, Table 4.3 (Exhibit 12-15) is used to determine the expected prevailing LOS

LOS	Density (pc/mi/ln)
A	≤ 11
B	$> 11 - 18$
C	$> 18 - 26$
D	$> 26 - 35$
E	$> 35 - 45$
F	Demand exceeds capacity or Density > 45

- D = 18.8 pc/mi/ln**
- LOS C**



So, once you know that then 18.8 comes under where, greater than 8 and up to 26 in that range, so that is level of service C, so we say density is 18.8 passenger car per mile per lane and level of service is C. So, that is one application how we can apply for basic freeway segments.

(Refer Slide Time: 25:05)

Determination of LOS

Example 2: What is the expected LOS of a five-lane highway (two travel lanes in each direction plus a two-way left-turn lane) in each direction with the following characteristics?

- Lane width: 12 ft
- Traffic composition: 6% trucks
- Posted speed limit = 45 mi/h
- Access points per mile: eastbound = 10; westbound = 0
- Lateral clearance, both sides of roadway: 12 ft
- Commuter traffic (regular users)
- Median type: two-way left-turn lane
- Peak hour demand: 1,500 veh/h
- Rolling terrain
- PHF = 0.90



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Example two is on multilane highway segments, let us take this example, what is the expected LOS on a five lane highway, two travel lanes in each direction plus a two way left turn lane, in Indian condition it is almost like equivalent to a right turn lane, in each direction with the following characteristics.

Lane width 12 feet, traffic composition 6 percent, posted speed limit, yes, this has got some relation to get that BFFS basic free flow speed values we can calculate once the posted speed limit is known 50 and above one formula, less than 50 another formula, so it less than 50 case so we can apply this, this is important, access point per mile, yes, not the ramp density in this case but it is access point per mile but then it is separate for east bound and west bound, so we have to do the calculation separately for the east bound and west bound, because the access point per miles are different.

Lateral clearance both sides of the roadway 12 feet, quite adequate, commuter traffic is regular users, median type two way left turn lane as it is told here, peak hour demand 1500, rolling terrain and rolling terrain and it is peak hour factor 0.9, so mostly all the inputs are given.

(Refer Slide Time: 26:49)

Determination of LOS

Computational Steps

Step 1: Input Data

- All input data are specified

Step 2: Estimate and Adjust FFS

- FFS is estimated from Equation 4.3 as follows:

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A \dots\dots\dots (4.3)$$

$BFFS$ = base FFS for multilane highway segment (mi/h)
 f_{LW} = adjustment for lane width (mi/h) (Exhibit 12-20)
 f_{TLC} = adjustment for total lateral clearance (mi/h) (Exhibit 12-22)

- Because no base FFS is given, it will be estimated as the speed limit plus 7 mi/h, or $45 + 7 = 52$ mi/h



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Determination of LOS

Example 2: What is the expected LOS of a five-lane highway (two travel lanes in each direction plus a two-way left-turn lane) in each direction with the following characteristics?

- Lane width: 12 ft
- Traffic composition: 6% trucks
- Posted speed limit = 45 mi/h
- Access points per mile: eastbound = 10; westbound = 0
- Lateral clearance, both sides of roadway: 12 ft
- Commuter traffic (regular users)
- Median type: two-way left-turn lane
- Peak hour demand: 1,500 veh/h
- Rolling terrain
- PHF = 0.90



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And here since the low base FFS is given, so from the posted speed limit we will calculate and in this case it will be posted speed limit plus 7 mile per hour, if it is 50 and above then it is posted speed limit plus 5 mile per hour, but in this case 7 mile per hour. So, we get BFFS as 52 miles per hour and then we have to check if all these corrections are applicable.

(Refer Slide Time: 27:25)

Determination of LOS

f_M = adjustment for median type (mi/h) (Exhibit 12-23)
 f_A = adjustment for access point density (mi/h) (Exhibit 12-24)

$TLC = LC_R + LC_L$ (4.4)

TLC = total lateral clearance (ft) (max. value 12 ft)
 LC_R = right-side lateral clearance (ft) (max. value 6 ft)
 LC_L = left-side lateral clearance (ft)(max. value 6 ft)

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥ 12	0.0
$\geq 11-12$	1.9
$\geq 10-11$	6.6

- Lane width is 12 ft, which is base condition; therefore, $f_{LW} = 0.0$ mi/h (Exhibit 12-20)



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Lane width first check it lane width it is already 12 feet, yes, so this correction is 0 as per the table because adequate lane width as per the base condition is available, so no further correction.

(Refer Slide Time: 27:42)

Determination of LOS

Computational Steps

Step 1: Input Data

- All input data are specified

Step 2: Estimate and Adjust FFS

- FFS is estimated from Equation 4.3 as follows:

$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A$ (4.3)

$BFFS$ = base FFS for multilane highway segment (mi/h)
 f_{LW} = adjustment for lane width (mi/h) (Exhibit 12-20)
 f_{TLC} = adjustment for total lateral clearance (mi/h) (Exhibit 12-22)

- Because no base FFS is given, it will be estimated as the speed limit plus 7 mi/h, or $45 + 7 = 52$ mi/h



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Determination of LOS

f_M = adjustment for median type (mi/h) (Exhibit 12-23)

f_A = adjustment for access point density (mi/h) (Exhibit 12-24)

$$TLC = LC_R + LC_L \dots\dots\dots (4.4)$$

TLC = total lateral clearance (ft) (max. value 12 ft)

LC_R = right-side lateral clearance (ft) (max. value 6 ft)

LC_L = left-side lateral clearance (ft)(max. value 6 ft)

Exhibit 12-20 (HCM, 2016)

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥ 12	0.0
$\geq 11-12$	1.9
$\geq 10-11$	6.6

- Lane width is 12 ft, which is base condition; therefore, $f_{LW} = 0.0$ mi/h (Exhibit 12-20)



The next if f_{TLC} that we have to say total lateral clearance, now total lateral clearance is lateral clearance left side plus lateral clearance right side, but in each case you have lateral clearance 12 feet and we know that the maximum value is 6 feet, even if 6 feet and above no correction is required that is adequate, so 6 plus 6 12 and so here also that correction is 0, so lane width and correction is 0 and also the TLC the total lateral clearance correction is 0 then f_M , f_M is what? f_M is the median type.

(Refer Slide Time: 28:34)

Determination of LOS

Exhibit 12-22 (HCM, 2016)

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)	TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

- Lateral clearance is 12 ft at each roadside, but a maximum value of 6 ft may be used
- A two-way left-turn lane is considered to have a median lateral clearance of 6 ft
- Thus, TLC is $6 + 6 = 12$ ft, is also a base condition $\Rightarrow f_{TLC} = 0.0$ (Exhibit 12-22)

Note: Interpolation to the nearest 0.1 is recommended



Determination of LOS

Computational Steps

Step 1: Input Data

- All input data are specified

Step 2: Estimate and Adjust FFS

- FFS is estimated from Equation 4.3 as follows:

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A \dots\dots\dots (4.3)$$

$BFFS$ = base FFS for multilane highway segment (mi/h)

f_{LW} = adjustment for lane width (mi/h) (Exhibit 12-20)

f_{TLC} = adjustment for total lateral clearance (mi/h) (Exhibit 12-22)

• Because no base FFS is given, it will be estimated as the speed limit plus 7 mi/h, or $45 + 7 = 52$ mi/h



Now, let us look at this median type table, it is TWLTL, so it is again 0, so median type adjustment is also 0 and what is remaining now is the f_A that is adjustment for access point density. Now, let us go to an appropriate table for calculating the access point density. So, in one side we have like east bound it is 10, so east bound there will be reduction of 2.5 mile per hour free flow speed, but westbound it is 0, so separate value, earlier all the same but now here it would be different for east bound and west bound.

So, one case we have to based on the access point density, one case we have to reduce the free flow speed by 2.5 mile per hour and another case it is 0. So therefore, the FFS free flow speed east bound would be 52, these three components are 0 and here it is 2.5 for the east bound, this is the only correction that will be applicable in the present example. And for west bound no correction because here also waste bound is 0, so the access point density is 0. So, here it will whatever will be the basic free flow speed, so free flow speed will be same for the west bound, east bound it will be reduced by 2.5 mile per hour.

(Refer Slide Time: 30:21)

Determination of LOS

Step 3: Estimate and Adjust Capacity

$$c \text{ (multilane highway)} = 1900 + 20 \times (FFS_{adj} - 45) \dots(4.7)$$

- When, $c \geq 2300$ pc/h/ln; $FFS \geq 70$ mi/h
- $c_{EB} = 1,900 + 20 \times (49.5 - 45) = 1,990$ pc/h/ln
- $c_{WB} = 1,900 + 20 \times (52.0 - 45) = 2,040$ pc/h/ln



Determination of LOS

- Alternatively, base capacity 'c' (in pc/h/l) for basic freeway can be estimated directly with Eq. 4.6 :

$$c \text{ (basic freeway)} = 2200 + 10 \times (FFS_{adj} - 50) \dots\dots\dots (4.6)$$

- When, c (basic freeway) ≥ 2400 pc/h/ln and FFS (basic freeway) ≥ 75 mi/h
- Therefore, $c = 2,200 + 10 \times (60.8 - 50) = 2,308$ pc/h/ln
- For ideal conditions, CAF is 1, and $C_{adj} = c = 2,308$ pc/h/ln



Now, estimate and adjust capacity so we know we can take it from the table also or exhibit given in highway capacity manual but in this case we are calculating it from the equation. As we have we calculated it in earlier case example one, you remember the example one we calculated it using this equation but that equation was for basic freeway segment, for multilane facility the equation is different, so we took this equation and here again because the FFS free flow speed adjusted 1 is different in eastbound and westbound, so the capacity also we have to calculate separately for east bound and west bound.

So, east bound it will be 1900 plus 20 into 49.5 minus 45 and west bound case the all this will be 1920 but this will be 49.5 instead of that it will be 52 for west bound. So, you calculate it, calculated capacity what we got is 1990 for the east bound passenger car per hour per lane and for west bound it is 2040 passenger car per hour per lane, so the capacities are calculated.

(Refer Slide Time: 31:48)

Determination of LOS

Step 4: Adjust Demand Volume

$$v_p = \frac{V}{PHF \times N \times f_{HV}} \dots\dots(4.9)$$

Where, v_p = demand flow rate under equivalent base conditions (pc/h/ln)
V = demand volume under prevailing conditions = **1,500 veh/h**
PHF = peak hour factor = **0.90**
N = number of lanes in analysis direction = **2**
 f_{HV} = adjustment factor for presence of heavy vehicles

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \dots\dots(4.10)$$




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Now, the adjusted volume as you know the v_p equal to V divided by peak hour factor into N into f_{HV} . So, the v is here 1500 vehicle per hour, it is vehicle per hour, peak hour factor is given as 0.9, number of lanes in analysis direction is 2 and f_{HV} heavy vehicle adjustment factor that we have to calculate using this we need PT value and ET value.

(Refer Slide Time: 32:20)

Determination of LOS

P_T = proportion of SUTs & TTs in traffic stream = **6%**

E_T = passenger car equivalent of one HV in traffic stream = **3.0** for rolling terrain (**Exhibit 12-25**)

- $f_{HV,EB} = f_{HV,WB} = \frac{1}{1+0.06(3.0-1)} = 0.893$
- $v_{p,EB} = v_{p,WB} = \frac{V}{PHF \times N \times f_{HV}} = \frac{1500}{0.90 \times 2 \times 0.893} = 933$ pc/h/ln



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Determination of LOS

Adjustment for Heavy Vehicles

- All heavy vehicles are classified as single unit trucks (SUTs) or truck trailers (TTs)
- Recreational vehicles and buses are treated as SUTs
- **Heavy vehicle adjustment factor (f_{HV})** is computed by combining two heavy vehicle classes, that are added to get an overall truck percentage P_T

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \dots\dots(4.10)$$

P_T = proportion of SUTs & TTs in traffic stream (decimal)

E_T = passenger car equivalent of one HV in traffic stream (PCE) [For general terrains, PCE (level) = 2.0, PCE (Rolling) = 3.0 from **Exhibit 12-25**]



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So, the P_T value is known that proportion of heavy vehicle is 6 percent and E_T for rolling terrain I mentioned it, it will be 3, let me go back here we said that this E_T will be 2 for level terrain and 3 for rolling terrain. So, since it is rolling terrain, so we take this E_T value as, so that is what we take the E_T value here as 3. So, applying this again we calculate the f_{HV} east bound and here in this case since the free flow speed is not coming into picture, so the f_{HV} EB east bound EB and for this correction for heavy vehicle for the west bound would be same and that f value is 0.893.

So, now we can calculate what is the v_p equivalent hourly flow rate in passenger car per hour per lane eastbound and west bound will be same so 1500 divided by PHF 0.9 number of lane 2 and this f_{HV} 0.893 so you get 933 passenger car per hour per lane.

(Refer Slide Time: 33:45)

Determination of LOS

Step 5: Estimate Speed and Density

- Using **Equation 4.1** and **Table 4.2 (Exhibit 12-6 of HCM, 2016)**, expected mean speed of traffic stream is computed
- As $v_p(933 \text{ pc/h/ln}) < BP(1400 \text{ pc/h/ln})$, highway operates within constant-speed portion of speed-flow curve, so $S = FFS$ (**Equation 4.1**)
- $S_{EB} = FFS_{EB} = 49.5 \text{ mi/h}$
- $S_{WB} = FFS_{WB} = 52.0 \text{ mi/h}$

$$D = \frac{v_p}{S} \dots\dots(4.11)$$




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Once we know that then we come to this equation what would be the speed because we know that it is we have to check first whether it is less than BP or so, so the BP here is calculated as 1400, highway operates with constant speed portion, so therefore speed will be actually same as free flow speed because this is the flow rate which is less than the or the demand, equivalent demand under ideal condition is less than the BP value, BP for multilane highway it is fixed 1400.

So, earlier case for freeway we had to calculate this but here it is 1400 fixed, so it is less than BP flow rate, so we know that speed will be equal to FFS, so then for east bound it is 49.5 and for west bound final speed is also 52. So, then we can calculate the value of D the density, we know the v_p , we know the S for east bound and for west bound.

(Refer Slide Time: 35:00)

Determination of LOS

- $D_{EB} = \frac{v_{p,EB}}{S_{EB}} = \frac{933}{49.5} = 18.85 \text{ pc/mi/ln}$
- $D_{WB} = \frac{v_{p,EB}}{S_{EB}} = \frac{933}{52} = 17.94 \text{ pc/mi/ln}$

Step 6: Determine LOS

LOS	Density (pc/mi/ln)
A	≤ 11
B	$> 11 - 18$
C	$> 18 - 26$
D	$> 26 - 35$
E	$> 35 - 45$
F	Demand exceeds capacity or Density > 45

- For east bound, LOS C
- For west bound, LOS B

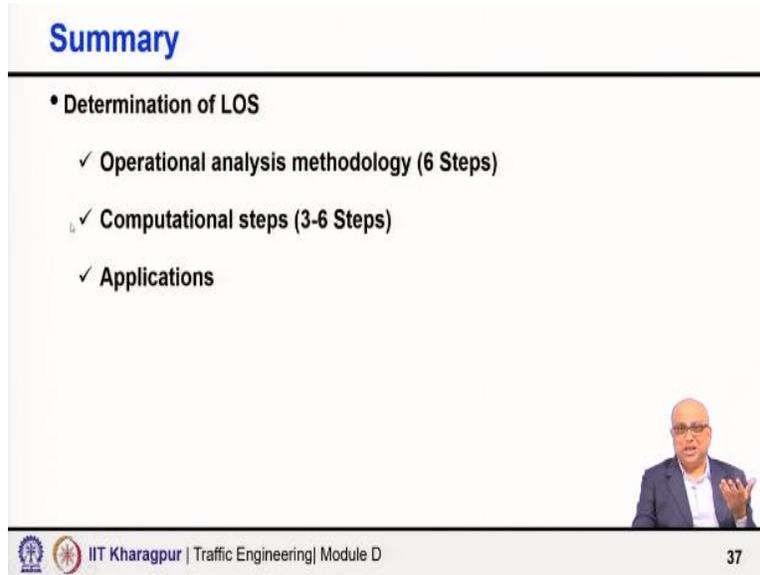


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So, two cases the density we have to calculate separately, so east bound density will be 933 divided by 49.5, so 18.85 passenger car per mile per lane and for west bound the density will be 17.94 passenger cars because it is 933 divided by 52 instead of 49.5 as it was for the east bound direction, west bound direction it is 52 so the value is 17.94.

So, now we can see first go to the east bound 18.85, so 18.85 comes in this range which is correspondence to C, so we can say for east bound the LOS is C. For west bound it is 17.94, so 17.94 is actually greater than 11 and up to 18 in that range because it is 17.94 actually less than 18, so for west bound the LOS is B, so that way we can calculate.

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Summary

- **Determination of LOS**
 - ✓ **Operational analysis methodology (6 Steps)**
 - ✓ **Computational steps (3-6 Steps)**
 - ✓ **Applications**

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So, what we discussed in this lecture, this is the last lecture, we had three lectures to do the capacity and analysis of LOS for freeway and multilane highway segments. So, in this lecture we discussed, we started in the last lecture also with this operational analysis methodology the six steps, we again started with that overall six steps, a brief outline and then step one and step two we discussed in details in our previous lecture, so in this lecture we discussed the other steps, step three to step six what exactly and how we do the computation.

And then we took two example problems, one with freeways segment, another example on multilane highway segment to show you how we can actually do the operational analysis, do all the computations, every step and eventually calculate the level of service, so one example we took with the free flow with the freeways and segment and another example with multilane highway segment, so with this I close this lecture and thank you so much.