Traffic Engineering

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Lecture 18

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

Welcome to module D lecture 3, in this lecture also we shall continue our discussion about analysis of basic freeway and multilane highway segments, following the procedure as per highway capacity manual 2016.

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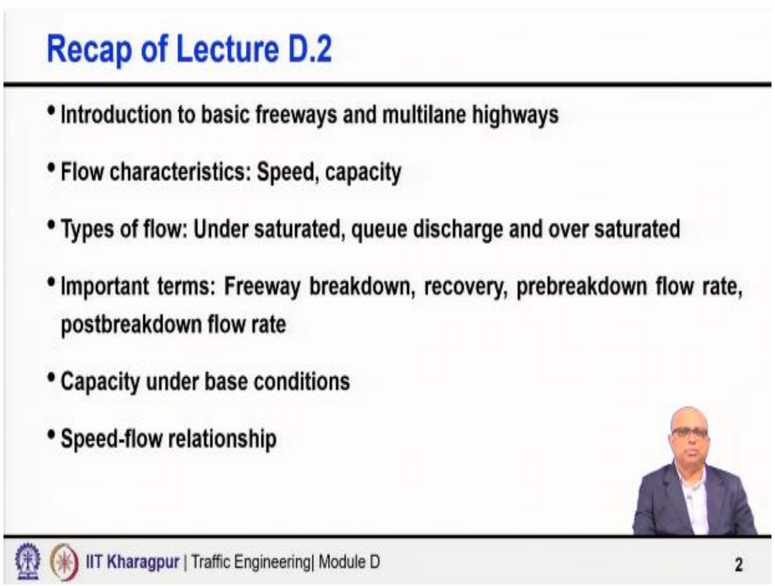

In lecture 2, I said to you about basic freeway and multilane highways, the capacity context, the flow characteristics, also different types of flow, under saturated when the queue is formed, then the queue discharge and over saturated flow state, then also mentioned some of the important terms related to capacity namely freeway breakdown, when breakdown occurs, then the recovery, then pre breakdown flow rate and post breakdown flow rate.

Then how the base conditions is defined and what should be the capacity, what is expected to be the capacity under different base conditions. Also introduced to you about the speed flow relationships, how there are three segments and how the speed flow relationship is likely to be for freeways and multilane highways segments.

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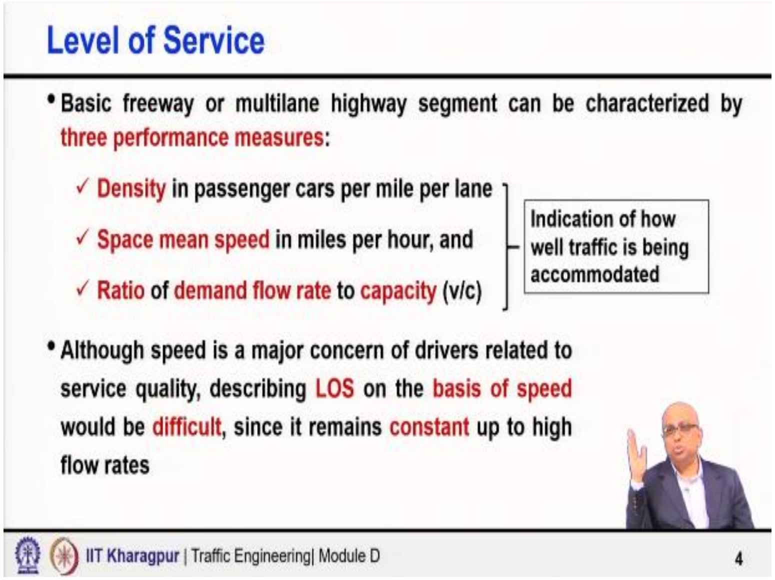

With this background so mainly the discussion was around the capacity and the speed flow relationship and different types of flow. Today in this lecture we shall focus on level of service LOS criteria. For basic freeway and multilane highway segments several performance measures may be considered for example, we can consider density in terms of passenger car per mile per length or space mean speed in miles per hour and even ratio of demand flow rate to capacity or generally the demand to capacity ratio. All these are possibilities, while we are thinking about selecting suitable performance measure.

Although speed is a major concern to drivers related to service quality but for basic freeway and multilane highway segments use of speed as a performance measure is little bit of challenge. Why? The reason is that speed remain constant up to quite high flow rate, as you have seen three segments of the speed flow curves as expected for freeways and multilane segments, up to quite a high volume or flow level the speed is nearly constant. So, if we use speed how we will consider variation with the flow, especially up to that break point, the entire range may operate with the same speed.

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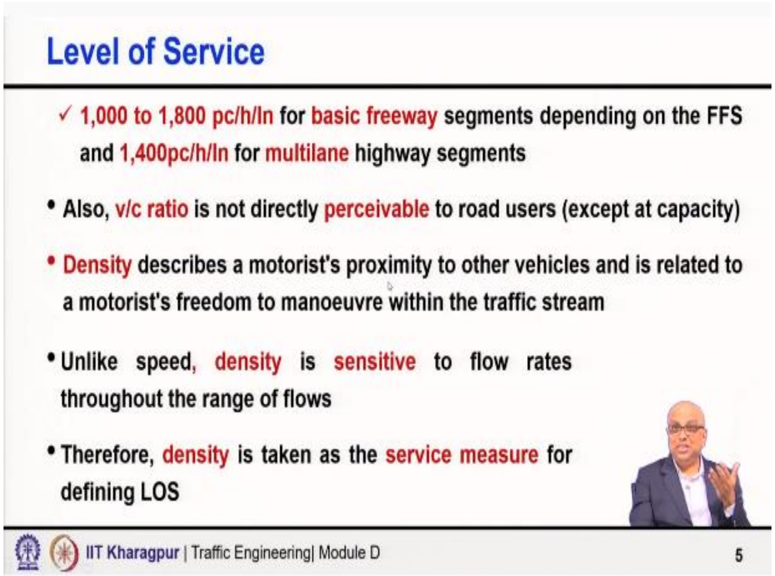

As I said for basic freeway almost up to 1000 to 1800 passenger car per hour per lane, the free speed is actually equal to the free flow speed. Similarly, for multilane highway segments a flow up to 1400 passenger car per hour per lane the speed is like free flow speed, so that is why use of speed is not very appropriate because a quite a big range of flow conditions cannot be captured or cannot be reflected, the change cannot be reflected if we consider the speed, speed does not reflect that.

Volume to capacity ratio is also not directly perceivable to road user except when the flow state is around capacity, then significant congestions and with slight change in the flow the this change of the flow state from the steady state to forced flow condition that kind of, that area in that zone one can perceive easily but otherwise v by c ratio is not directly perceivable to road users.

Specially, when the speed is nearly same up to a very high flow level, on the other hand density describes a motorist proximity to other vehicles, I can see when I am driving how many vehicles are around and my freedom of movement really gets impacted by the presence of other vehicles in the traffic stream while I am driving, so density describes motorist proximity to other vehicles and is related to motorist freedom to maneuver within the traffic stream, also unlike speed the density is sensitive to flow rates throughout the range of flows, even though speed is not changing.

As I said it remains constant and equal to free flow speed up to this break point, up to that quite a high flow level as I said, maybe up to 800 pcu per hour per lane for the basic freeway and 1400 pcu per hour per lane for multilane highway segments but density will change the moment the flow is changing even if the speed is same density is going to increase.

So, density is sensitive to entire flow range, the density is going to change therefore, for freeway, basic freeway and multilane highway segments density is taken as the service measures for defining the LOS boundaries.

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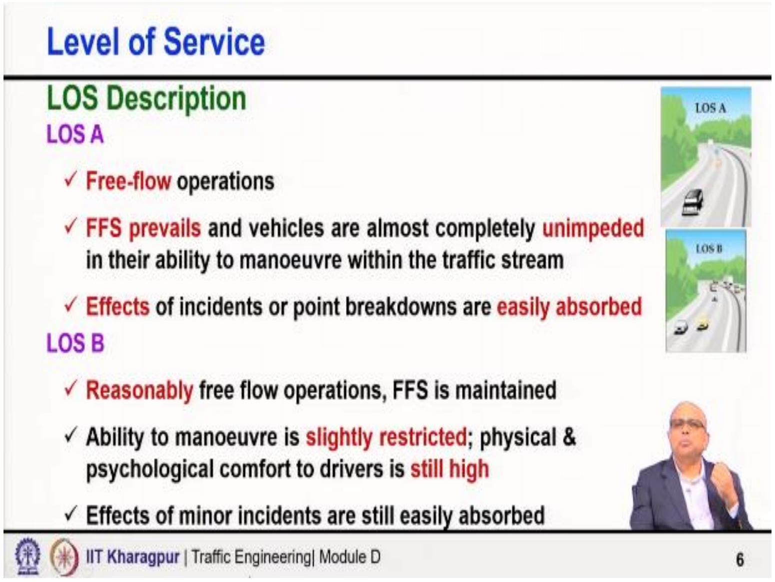

So, there are six LOS, let us quickly try to understand. LOS A nearly represents free flow operations, speed is very high so the free flow speed prevails and vehicles are almost completely unimpeded in their ability to maneuver within traffic stream, nothing no change in the speed, everybody travels and enjoy high freedom of movement and because of that effects of incidence or point breakdowns can easily be absorbed by the traffic stream.

LOS B reasonably free flow operation still the free flow speed is maintained, ability to maneuver is slightly restricted, physical and psychological comfort to drivers is still high and effects of minor incidence are easily absorbed. Not going to change the traffic state significantly.

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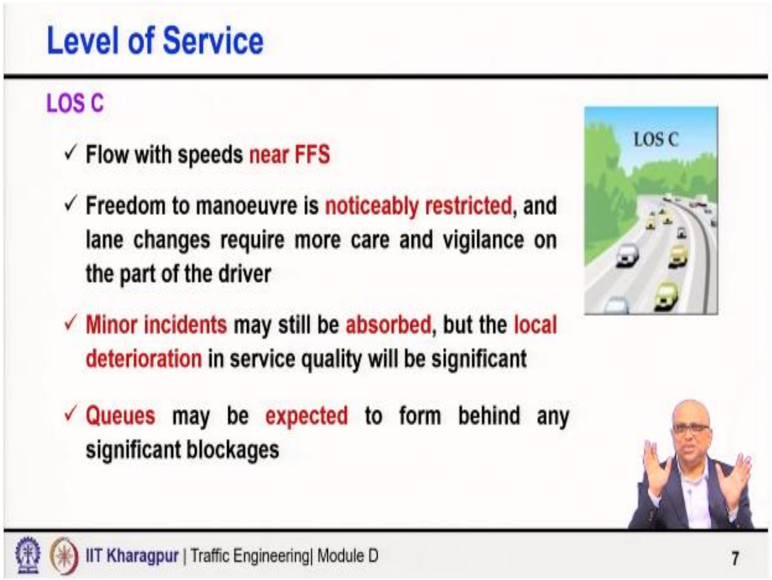

Level of Service C, flow with speeds near free flow speed again, freedom to maneuver is noticeably restricted and lane changes require more care and vigilance, it is possible but more care and vigilance on the part of the driver that is necessary. Minor incident may still be observed but local deterioration in service quality will be significant, queues may be expected to form behind any significant blockage because the flow level also will be high and the operating state is with level of service C.

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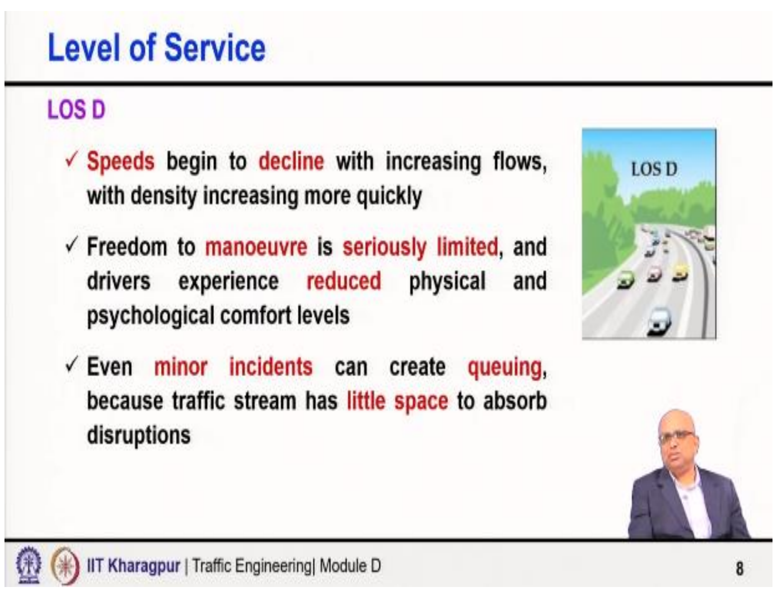

LOS D, speed begins to decline now with increasing flows, so we have gone to the other side where the speed drop starts happening very fast, with density increasing more quickly because there is a speed drop, so earlier the increase in the flow rate whatever the density was increasing but now the density will increase at a faster rate, freedom to maneuver is seriously limited and drivers experience reduced physical and psychological comfort levels. Finally, even minor incidence can create queuing because traffic stream has little space to absorb disruption, so that is what it is.

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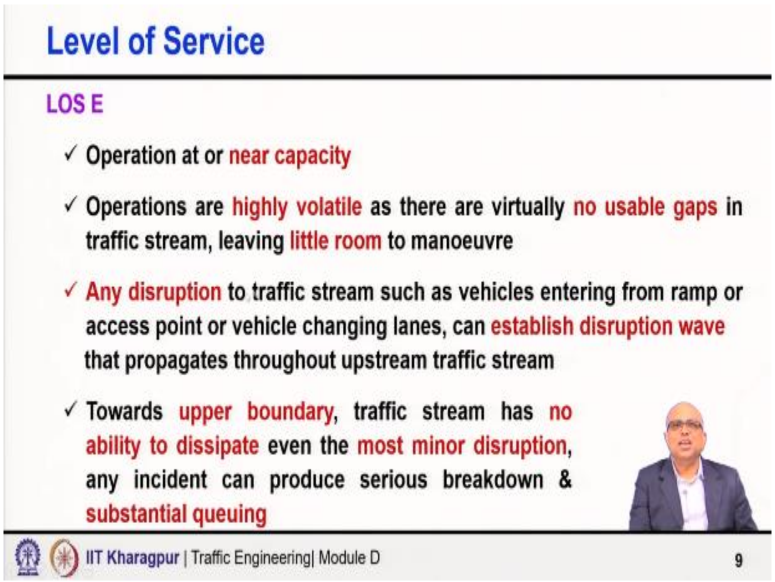

Level of Service E, its operation now at or near capacity that is the range approaching capacity or even up to capacity, operations are highly volatile at this stage as there are virtually no usable gaps in traffic stream leaving little room to maneuver. Traffic starts to follow each other, platoon kinds of movements are more and because at that level high flow level density is also very high.

At any disruption to traffic stream such as vehicles entering from ramp or access points or vehicle changing lane even can establish disruption wave that propagate throughout upstream of the traffic stream and towards upper boundary, traffic stream has no ability to dissipate even the most minor disruption, flow state is going to get impacted heavily and any incident can produce serious breakdown and subsequent queuing.

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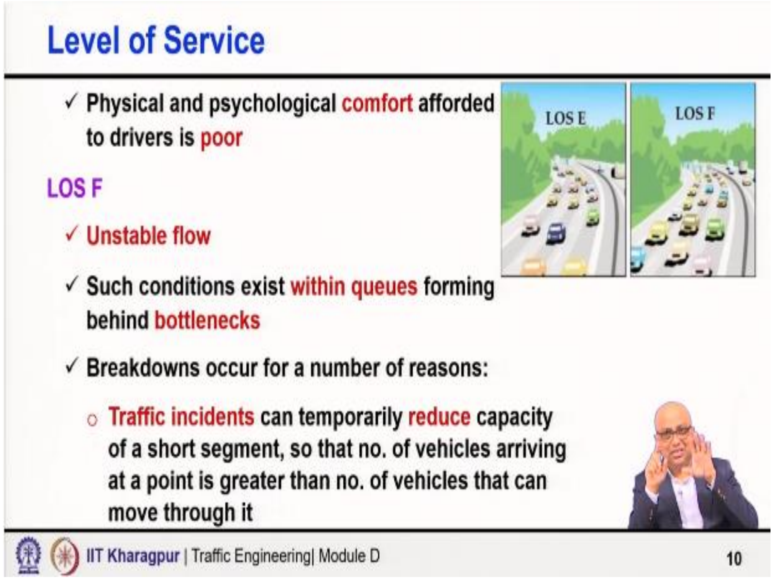

Because of all this and the overall traffic state is such that physical and psychological comfort afforded to drivers is poor, I have also shown every step more or less a kind of pictorial representation to give you a feel about how the LOS is changing, the density is actually changing.

Coming to LOS F as you know that is the unstable flow, no more the flow is in the steady state and such conditions exist within queues forming behind bottleneck as I have given the example earlier, you have a three lane road and then you have a two lane segments because of construction or whatever may be the reason, one lane is blocked.

So, if the demand is more than two lane capacity then obviously upstream of this junction of A and traffic state A and B or segment A and B the queue starts forming and the queue will start propagating upstream, that means within the three lane sections only starting from the junction of two lane and three lane, so unstable flow will occur there and this kind of conditions exist within queues forming behind bottlenecks.

So, bottleneck starts at junction of section A and B, B is two lane capacity, A is three lane capacity and the demand is more than two lane, so within A close to this section B the bottleneck will be there, so there the unstable flow will be there and such breakdowns occur for a number of reasons for example, there may be a traffic incident which can temporarily reduce capacity, a vehicle breakdown has happened or road accident has happened which has temporarily reduced the capacity for a short segment.

So, that number of vehicles arriving at a point is greater than number of vehicles that can move through it, so that is what I said that available capacity may be the number of lane is two lane but the demand is more than two lane that is approaching or trying to go.

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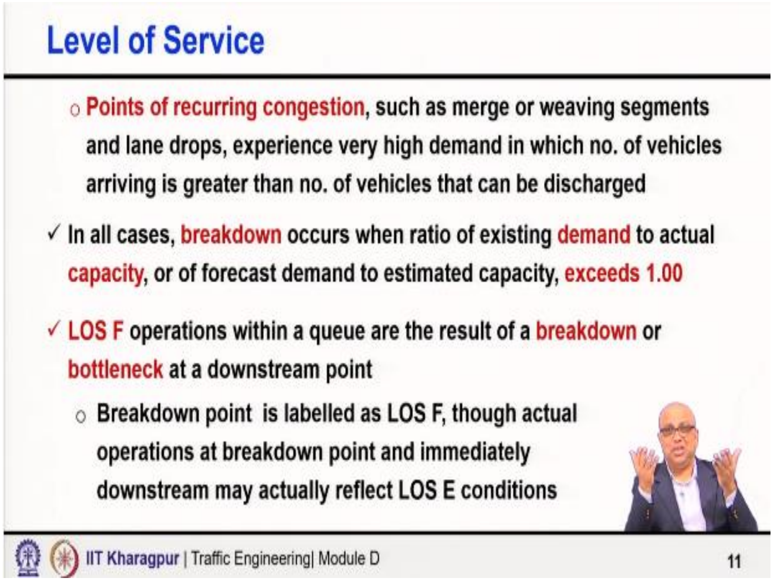

Points of recurring congestion, this is interesting again, such as merge or weaving segments and lane drops, two roads are merging maybe often we do, two plus two not merging to three lane but maybe two lane, two plus two not merging to four lanes but actually leading to three lanes.

But when in the peak hour here also it may be operating with capacity, the other one also might be operating with capacity and four lane traffic is trying to enter whereas that capacity is three lane, optic no problem because collectively the demand will not be more than three lane capacity but in the peak hour both might be operating with capacity level flow and the total flow cannot enter into this stream because there is a shortfall two plus two but then merging into three lanes, so four lane traffic cannot enter into three lane.

So, points of recurring congestion, every day may be in the peak hour for some time one or two hour it might be happening during the peak period, so points of recurring congestion such as merge or weaving segments and lane drops experience very high demand in which number of vehicles arriving is greater than number of vehicles that can be discharged.

And in all cases breakdown occurs when the ratio of demand to actual capacity or if we are trying to forecast, then forecast demand to estimated capacity exceeds one. So, demand to capacity ratio exceeds one means it is a breakdown and going to be level of service F.

LOS F operation within a queue are the result of a breakdown or bottleneck at the downstream point, remember that we are having this LOS state still within section A but upstream of just section B, so the bottleneck is actually at the junction of A and B there the bottleneck starts, so therefore, it is break point LOS operation within a queue is the result of a breakdown or bottleneck at the downstream point.

Breakdown point is leveled as LOS F though actual operations at breakdown point and immediately downstream may actually reflect nearly LOS C, because you have two lane capacity, so two lane flow, nearly two lane and flow is happening of course, the queue discharge as you know is always slightly lesser than the capacity.

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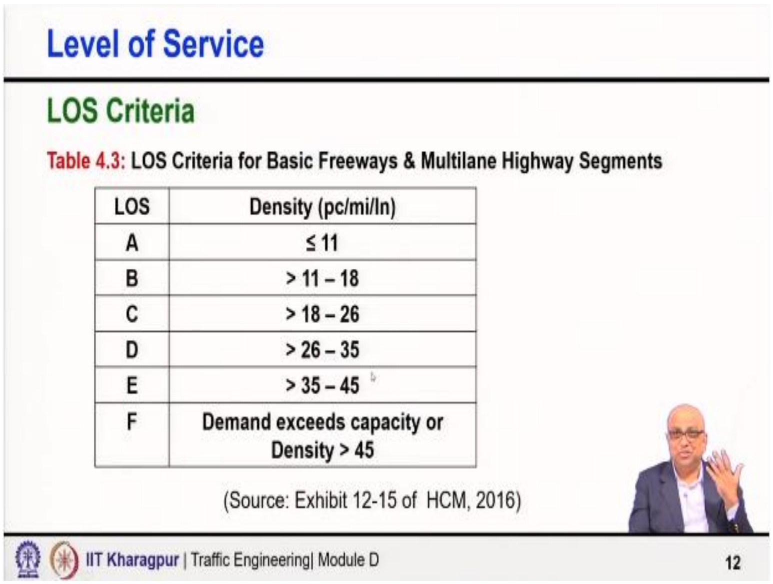

LOS	Density (pc/mi/ln)
A	≤ 11
B	> 11 – 18
C	> 18 – 26
D	> 26 – 35
E	> 35 – 45
F	Demand exceeds capacity or Density > 45

So, based on the density, now the density is going to change throughout this range, so LOS is defined based on the density passenger curve per mile per lane. So, A less than 11, B greater than 11 up to 18, C greater than 18 up to 26, D greater than 26 up to 35, E greater than 35 up to 45 and F you can say when the density is more than 45 or in all such cases where demand exceeds capacity, anyhow it is to be LOS F.

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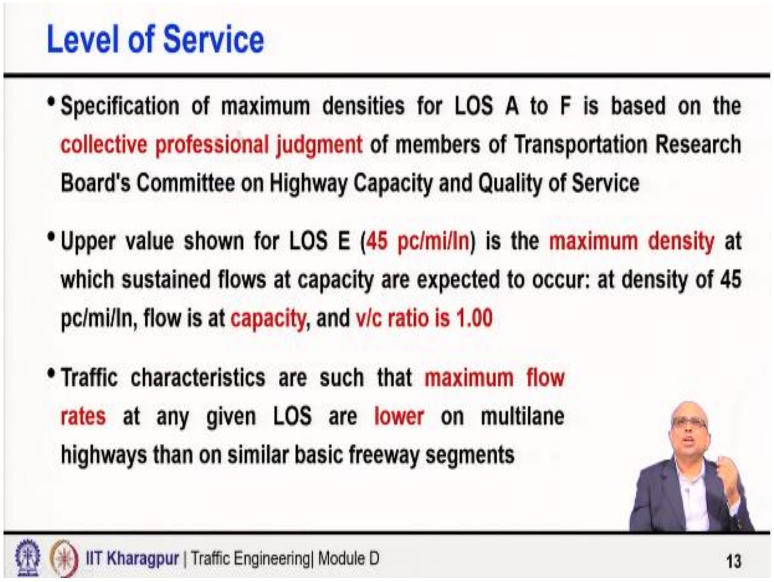

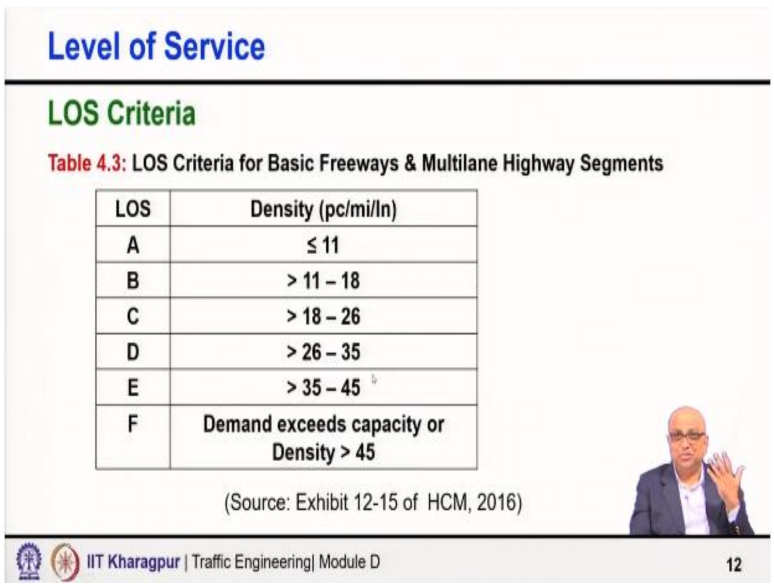

Now, specification of maximum densities for LOS A to F, not in the case of F we are not saying what is the maximum density but practically we are mentioning the threshold values, these threshold values are decided based on the collective professional judgment of members of transport research boards committee on highway capacity and quality of service.

Collectively people decided that this should be the threshold value for here it is 11, 18, 26, 35 and 45 this threshold values are decided collectively. Upper value of LOS E that is 45 passenger car per mile per lane I have mentioned it in my previous lecture also is the maximum density at which sustained flow at capacity are expected to occur, so that means at density 45 passenger car per mile per lane flow is at capacity and v by c ratio is 1.

Traffic characteristics are such that maximum flow rates at any given LOS are lower on multilane highways than on similar basic freeway segments. So, both cases the LOS is defined based on this threshold values of density but if you take the speed flow curve you will always find that the maximum service volumes will be higher for freeway segment as compared to the multilane highway segments that is why this last statement is made traffic characteristics are such that maximum flow rates at a given LOS are always lower on multilane highways than on similar basic freeway segments.

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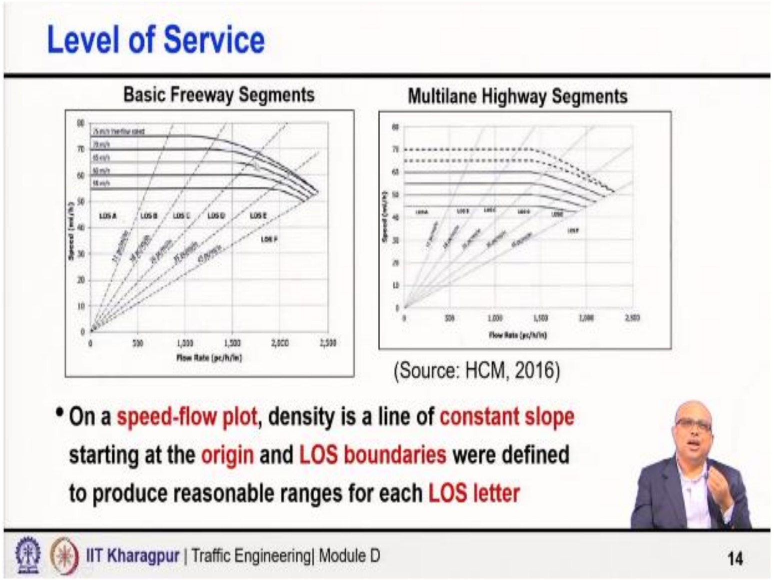

So, here I have shown here, you can see here how the basic freeway segment and multilane highway segments, how the speed flow relationship look like and this is the line 45 passenger car per mile per lane both cases and then based on these threshold values what I have said here how the demarcations are done, this range is LOS A, LOS B, C, D and this is the threshold E and beyond this density it is F.

To remind you that although the flow and the speed are mentioned it is essentially speed flow curve but density can also be mapped because speed flow density are related, density equal to flow by speed, so the densities threshold values can also be plotted, so that is the way the LOS can be represented or LOS boundaries also can be represented in speed flow diagram.

On a speed flow plot density is a line of constant slope starting at the origin and LOS boundaries were defined to produce reasonable ranges of for each LOS letter starting from A to F.

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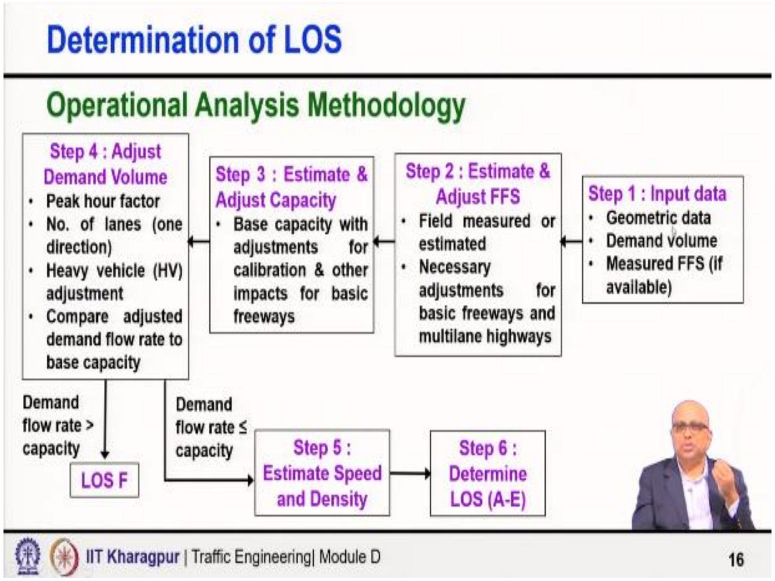

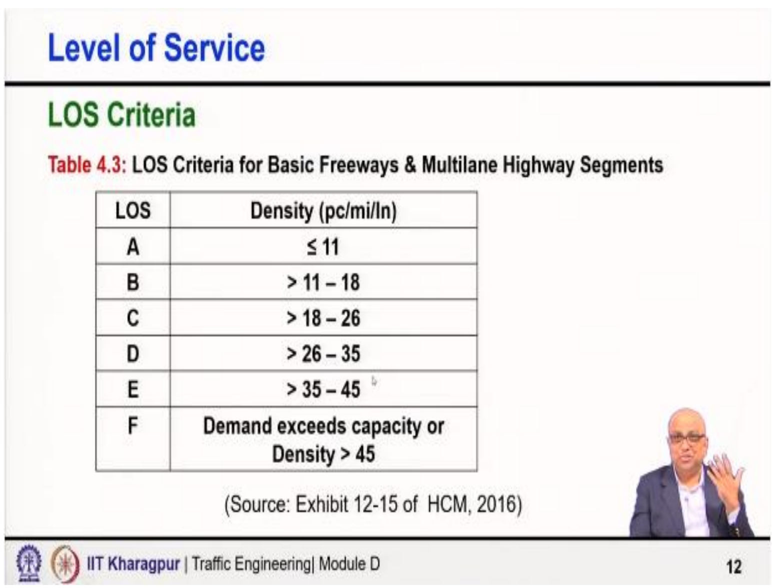

Now, next part determination of LOS. So, we discuss about the concept of LOS what measures we use that is density in these cases, why we do not use volume to capacity ratio or speed specially for freeway segments and multilane highway segments all these are discussed and what are the threshold values and how they are represented. Now, how to determine the LOS, so here is that overall chart that is shown its a six step methodology.

First step with it starts with the input data, we have geometric data because we know what is the lane width, how much shoulder width is available and all other values including the demand volume, measured free flow speed if available if not we can estimate it.

Free flow speed you can measure in the field its possible under a prevailing situation or prevailing condition you can mention it, generally at some low flow state up to some low flow state because the speed is constant, so up to some low flow state we can actually measure the speed and consider that as the free flow speed under prevailing condition or we can estimate it, if field measurement is not possible we can estimate it.

So, first is all the input data and then if required if free flow speed is not measured directly in the field then we need to estimate it and also make necessary adjustment if required to reflect the other conditions, weather conditions and other things. So, field measurements are estimated and necessary adjustment for basic freeway and multilane highways, these adjustments are different for freeway and multilane highway segments, the factors sometimes are same, sometimes are different we will discuss those later.

Then step three we estimate the capacity and also adjust the capacity to reflect for other factors and then adjust the demand volumes because the capacity all what we have said earlier is for the base condition, what is given in the table is the base condition they are all adjusted but the traffic volume also is to be adjusted because heavy vehicle presence is assumed to be zero under base condition, so here heavy vehicles may be there, the peak hour factor needs to be considered.

So, we need to adjust volume to account for peak hour factor, to account for number of lanes in one direction, to capture the presence of heavy vehicles and do necessary adjustment and therefore, compare adjusted demand flow rate to base capacity.

And if we find the demand to capacity ratio is actually more than one, then straight away we conclude that it is level of service F, if not that is demand flow rate is less than the capacity or the flow rate and demand ratio capacity ratio is less than one then we go and try to then use appropriate speed flow curve and then try to estimate the speed and density. Once the density is known we refer back to the table and try to see what density I have calculated and that is corresponding to which LOS as per the table I mentioned earlier, here this table, so accordingly we decide the what should be then the LOS.

Now, we need to understand clearly each of these steps, so here I have shown you all the six steps together just to give you an overall understanding, how we are proceeding further starting from step one to step two, three, four, five and six. Now, we shall discuss little bit in more details about step one and step two only and then we shall continue our discussion in the next lecture about the remaining steps and also shall take some example problems, one example with basic freeway segment and another example with multilane highway segment.

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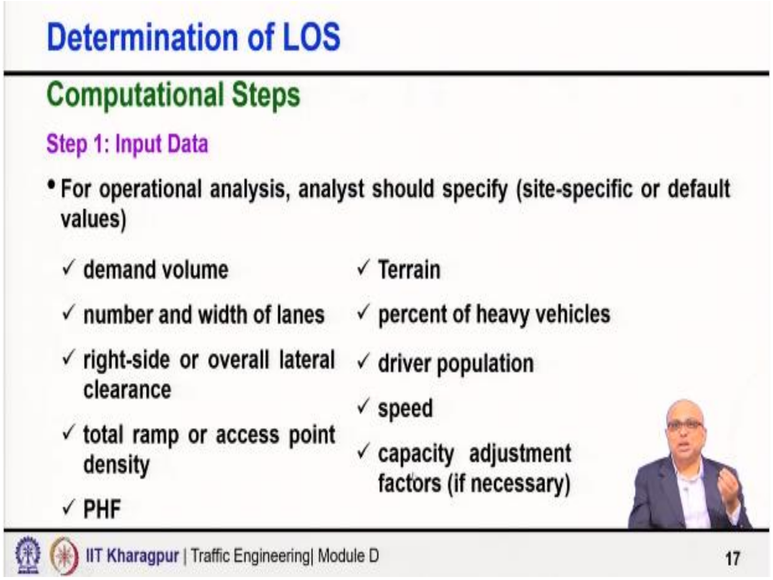

Coming to the first step the input data what all input data we really require for operational analysis, we need demand volume, we need number of lanes and width of each traffic lane, what is the right side or overall lateral clearance, what is the total ramp or access point density.

In case of freeway it will be how many ramps are there for the entire stretch and for multilane highways segments how many access points are there, what is the peak hour factor, what is the type of terrain, what is the percentage of heavy vehicles present in the string, how we define driver population all are familiar with the road and the environment or there are drivers who are not so familiar as well, what is the share then the speed, also the capacity adjustment factors if required, then those also we will require as input so with this input it starts.

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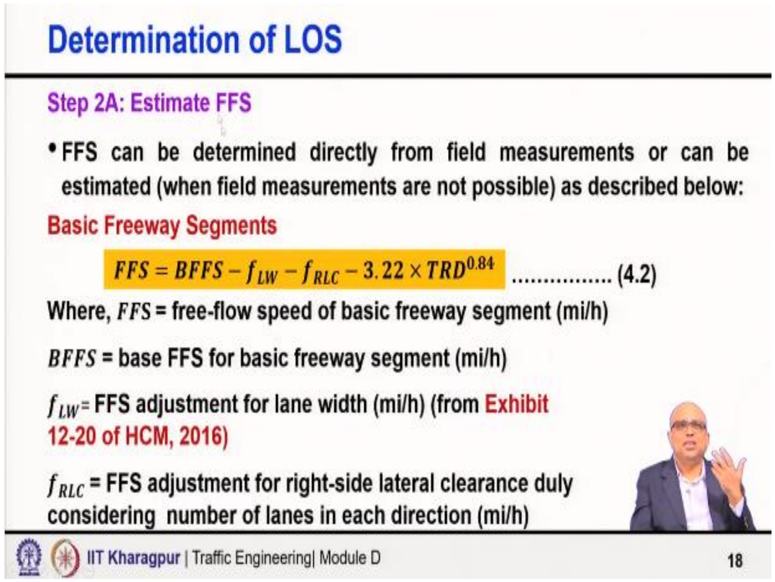

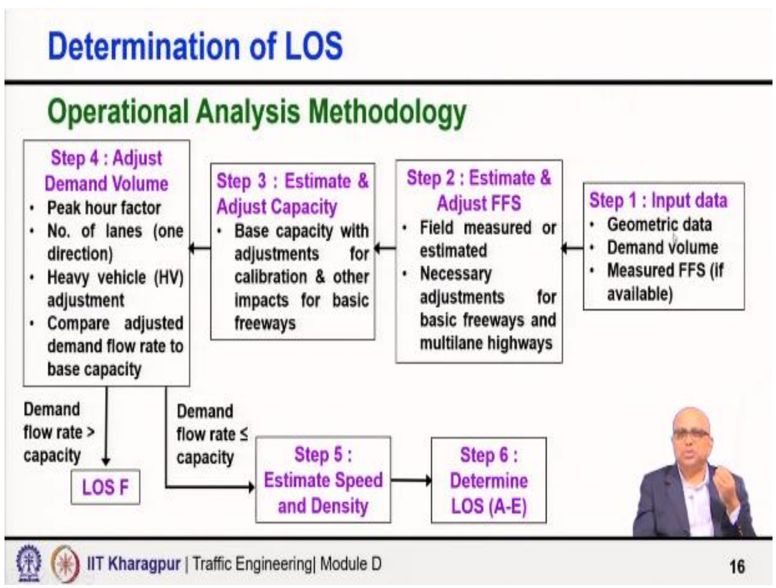

Then we go to step two, step two is actually if you see estimate and adjust FFS. So, when the field measurement is not available, field measurement under prevailing condition is not available then we can estimate. So, here you can see step two estimate and adjust FFS. For the purpose of discussion and better clarity this step we have divided into 2a and 2b, 2a includes estimate FFS, 2b adjust FFS.

So, first estimate FFS step 2a, FFS can be determined as I said earlier directly from the field measurement or can be estimated when field measurements are not possible. So, if we are not able to do the field measurements then we can use this equation as given here 4.2, for basic freeway segment we can get the base free flow speed for basic freeway segment.

And then apply necessary correction as required or if required with respect to or based on FLW, FLW is what? The necessary adjustment for lane width, whatever is the actual lane width assumed under base condition if the road under investigation or which is being analyzed now, per lane width is lesser than that then appropriate adjustment is to be done in the FFS value.

So, these adjustments are done through this factor FLW that means correction factors or adjustment factor for LW is lane width and this corrections how we can get there is an exhibit in highway capacity manual 2016 exhibit 12 to 20 and these exhibits give you, it is a table, so it tells you what is the lane width and what is the corresponding FLW values. So, simply go and pick up the value.

Similarly, the next adjustment is with respect to f, we are saying f RLC that means it is the adjustment of free flow speed for right side lateral clearance, it is considering the US convention lateral, right side lateral clearance. So, in Indian condition based on our driving rule it would be actually mean the left side lateral clearance but since, I am referring to HCM I am always going by the HCM and the US traffic driving rules.

So, FFS adjustment for right side lateral clearance and this is again given in exhibit as I have said here 12-21 in highway capacity manual 2016. So, if you know what is the right side lateral clearance and if you also know how many number of lanes are there in each direction, it depends also on the not only the available lateral clearance, right side lateral clearance but also how many number of lanes are there in each direction, two lane, three lane, so like that if I know the number of lane and if I know what is the available right side lateral clearance I can get this factor.

The next one is TRD, TRD is what? Total ramp density, since it is access control facility we are talking about freeway segments so ramps will be there, so how many ramps average in the segment how many ramps on an average per mile, so once you know that then these two values can be taken from table, it is based on the available lane width and it is based on the available RLC that means right side lateral clearance and also based on the number of lane you can get this and once you know the TRD value how many ramps are there per mile you can get it.

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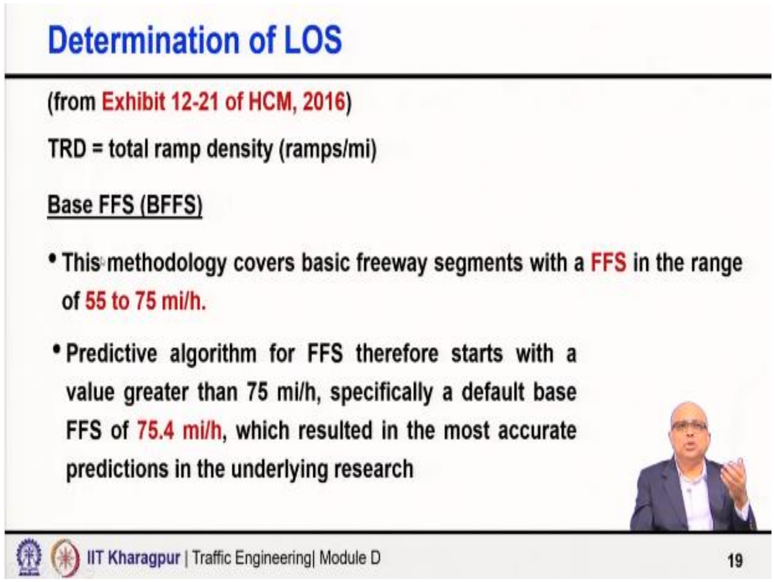

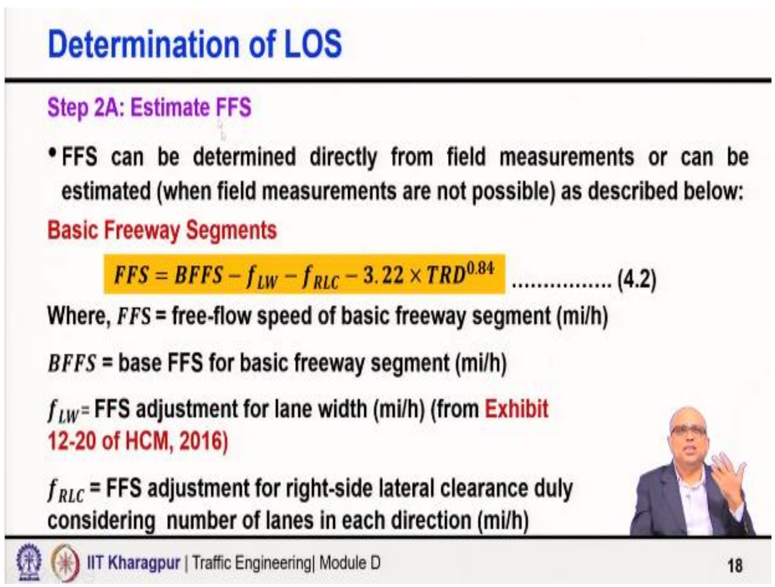

Now, going to two more thing regarding FFS or BFFS, base FFS. This methodology covers for basic freeway segment with FFS in the range of 55 to 75 miles per hour based on that it is developed. So, there are predictive algorithms or equations I have shown it here also equation 4.2 you are calculating FFS from BFFS.

So, here predictive algorithm for FFS starts with a value greater than 75 mile per hour, specifically a default base FFS of 75.4 that may be assumed and in that those are found to give accurate predictions in the underlying research, that means when we are using this equation we must know that this methodology covers FFS in the range of 55 to 75. So, at the predictive algorithm starts with 75 plus precisely default value 75.4 mile per hour.

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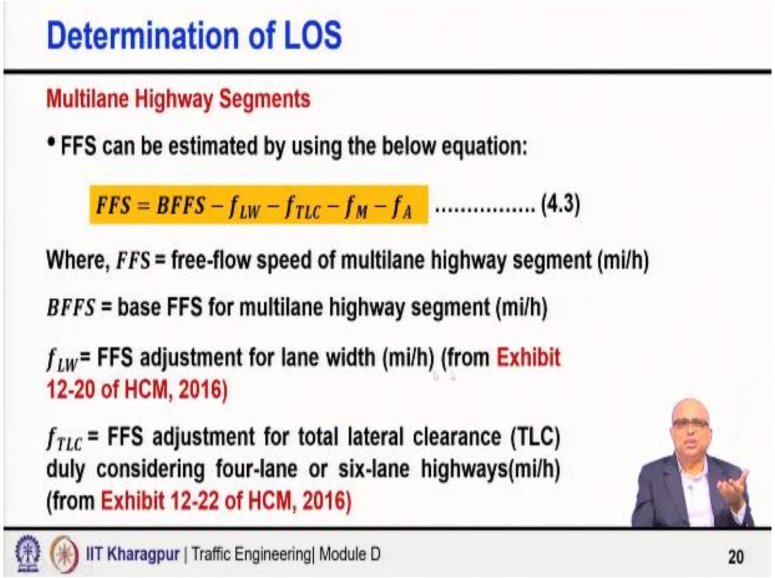

Now, coming to multilane highways FFS can be estimated using this equation here the corrections are with respect to again lane width, but this can be taken from exhibit 12-20 HCM 2016, if TLC, TLC is total lateral clearance, not right side but total lateral clearance and this can be corrections may be obtained once you know what is the available total lateral clearance and also once we know whether it is a four lane highway or a six lane highway because there are separate values for four lane and six lane as given in exhibit 12-22 highway capacity manual 2016.

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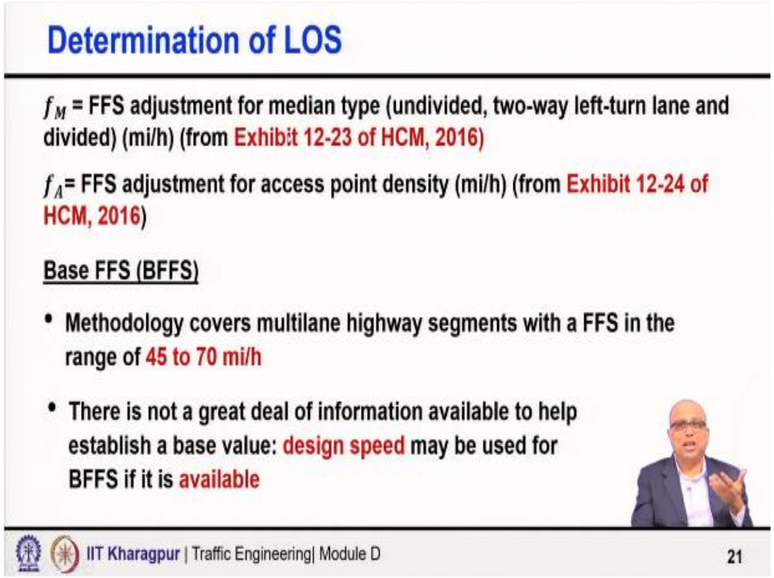

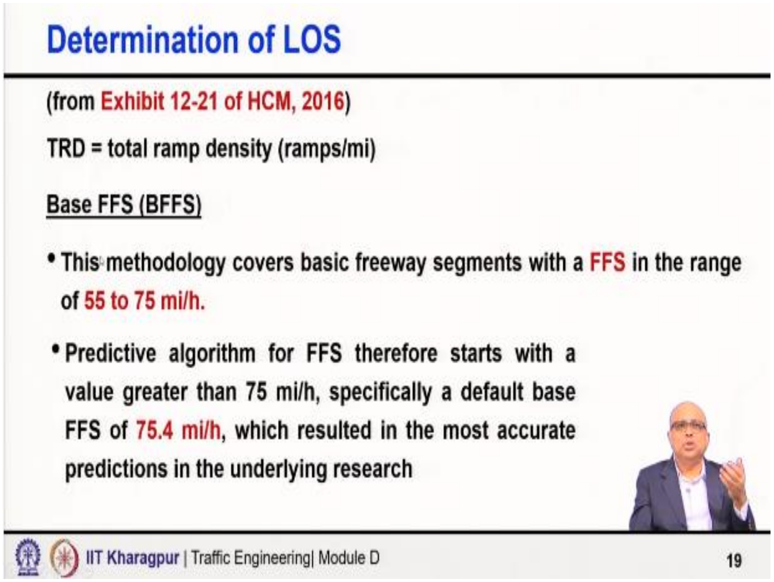

And what is the FM? FM is the type of median based on that what adjustment to be done, may be undivided, maybe two way left turn lane or may be divided accordingly what values we have to take they are again given in exhibit 12-23. And f_A equal to FFS adjustment for access point density, what was earlier the ramp density in case of freeway segment for multilane highway segments it is the access point density, not the ramps, and appropriate correction factors are there in exhibit 12-24.

So, if I know how many access points are there then accordingly the f_A values in mile per hour can be obtained and that will be getting deducted, so BFFS minus this, minus this minus f_M - f_A.

So, here the methodology for the base FFS we must understand that the methodology covers multilane highway segment with FFS in the range of 45 to 70 mile per hour and this is not a great deal of information available, there is not a great deal of information available to help establish a base value how much we should take the base FFS. So, one hint is the design speed may be taken for BFFS if it is available.

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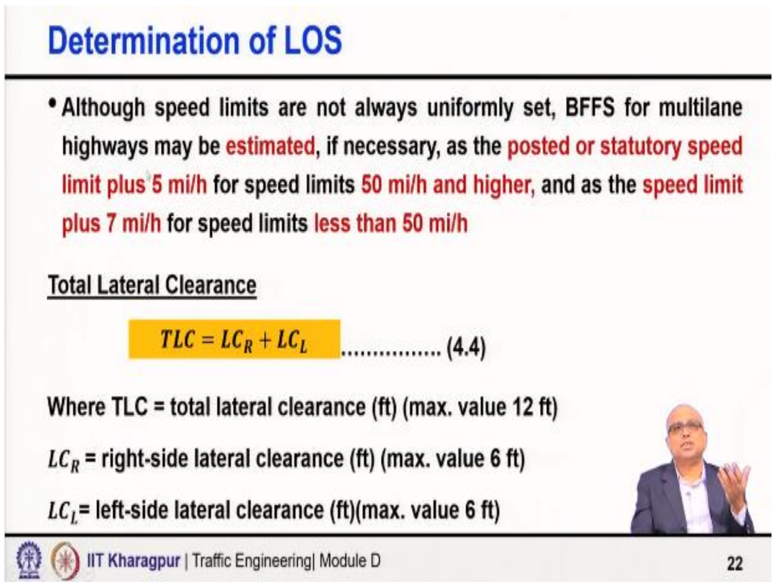

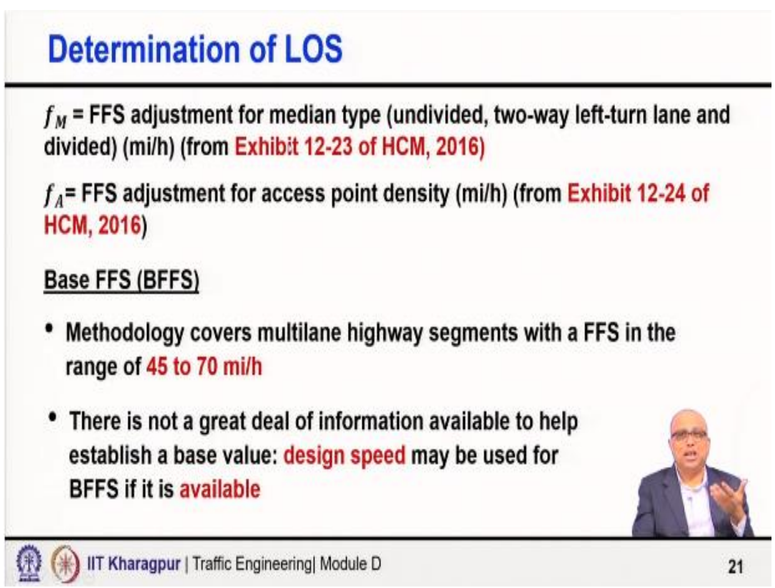

And some cases there may be speed restrictions, although the speed limit are not always uniformly set but BFFS for multilane highway may be established if necessary as the posted or statutory speed limit because this is applicable when you have a separate speed limit, design value is something and but you have a design speed is different but you also have a separate speed limit.

So, if its speed limit is there then that posted or statutory place limit plus 5 mile per hour that may be take as BFFS for speed limits 50 mile per hour and higher and if the speed limit is less than 50 mile per hour then the posted speed limit or statutory speed limit plus 7 mile per hour.

And since we used here total clearance you can see total lateral clearance, so how we get the total lateral clearance I have shown it here you can take it as a summation of right side lateral clearance, maximum value 6 feet and left side lateral clearance again maximum value 6 speed feet, so the TLC maximum value could be 12 feet, so less than 12 feet some corrections.

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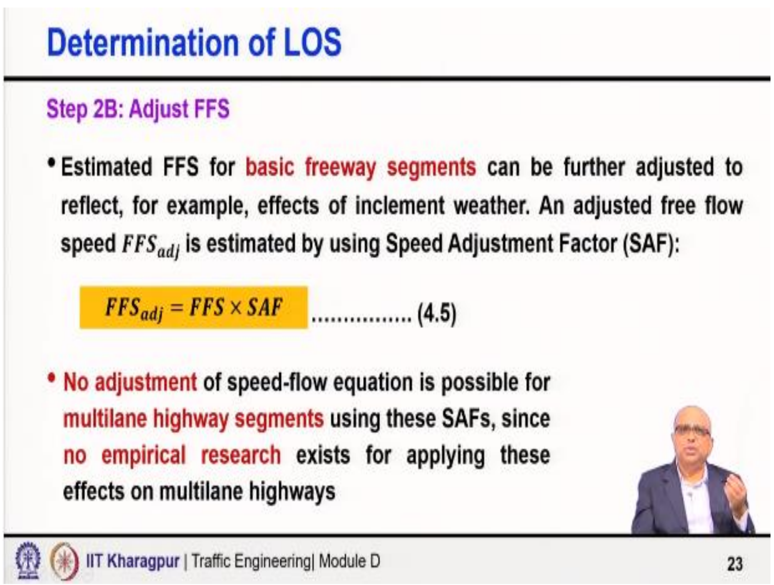

Then step two is adjustment, this adjustment for basic freeway segment can be done further adjustment to consider the effect of other factors, not considered so far for example, effect of inclement weather, so an adjusted free flow speed, free flow speed adjusted may be estimated using the known FFS or estimated FFS and the speed adjustment factor and such kind of adjustment is not possible for multilane highway segment because not sufficient empirical research is available to use such a factor.

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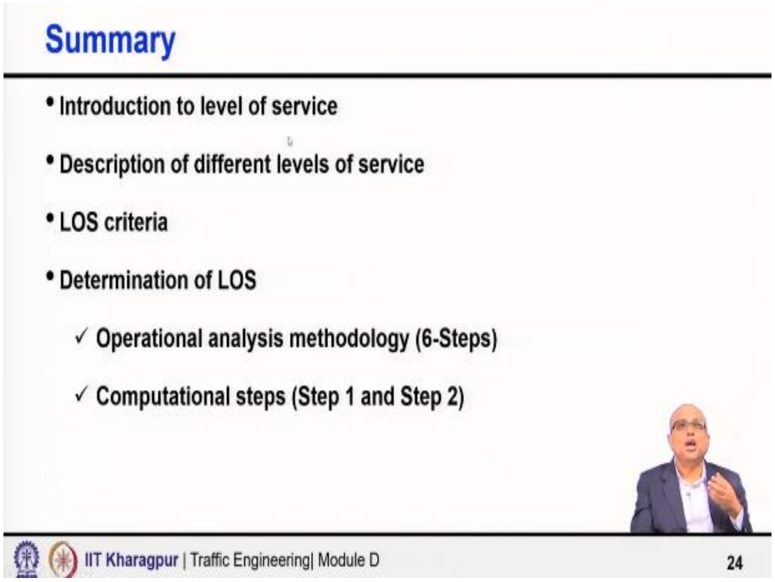

So, in this lecture up to this what we discussed, we introduced you to the concept of level of service for freeway and multilane highway segments, what are the possibilities of LOS and what LOS we use and how the threshold values are taken and how the LOS are described A to F.

And then I told you about the determination of LOS, what is the operation analysis, methodology the six step, step one, two, three, four, five, six and the computational steps little bit in more details I discussed only about step one and step two. So, we will continue this discussion about the other steps and also take some example problem in the next lecture, with this I close this lecture, thank you so much.