Traffic Engineering
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Lecture – 37
Operational Analysis of Signalized Intersection – III

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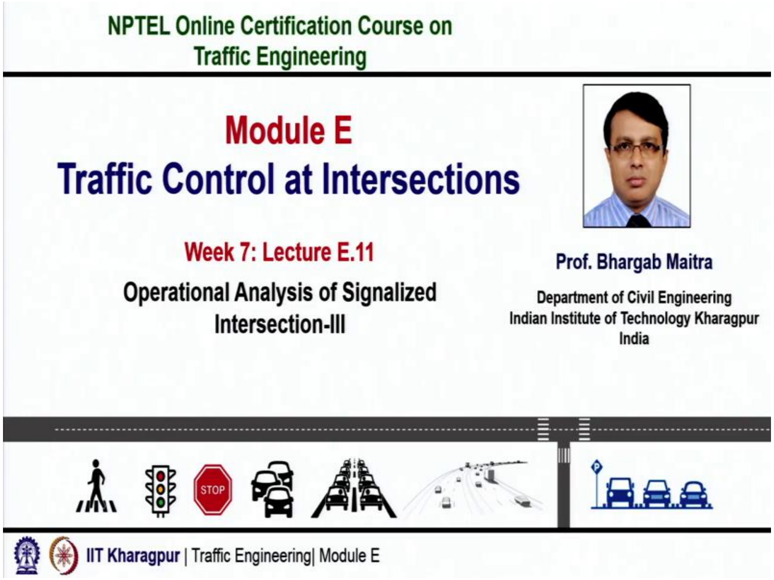

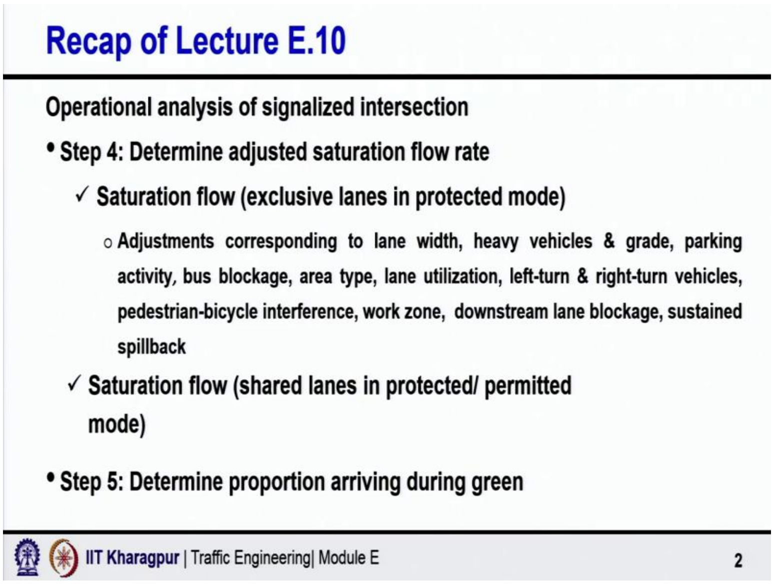

Welcome to module E, lecture 11. In this lecture also, we shall continue our discussion about operational analysis of signalized intersection. In lecture 10, we have spent a lot of time to discuss about step 4, determination of adjusted saturation flow rate. How to get the base saturation flow rate and then do the adjustments corresponding to various factors say lane width to heavy vehicle and grade to parking to various other factors and then how to calculate the shared saturation flow for the shared lane in protected and permitted movement.

How to calculate the saturation flow for shared lanes in protected and permitted mode and finally step 5, how to determine the proportion of vehicles arriving during green. I also mentioned to you about how step 3 and step 4, they work together in an iterative manner. That means, we first try to get the trying to calculate the lane group flow and then somewhere we know what is the percentage of left turning traffic or right turning traffic and other inputs.

So, we come back to step 4, get the values of saturation flow based on the given conditions or under prevailing condition, go back and then do the remaining calculation for step 3, see whether there is any change from one iteration to another iteration and keep on iterating between step 3 and step 4 till we converge and get the lane group flow.

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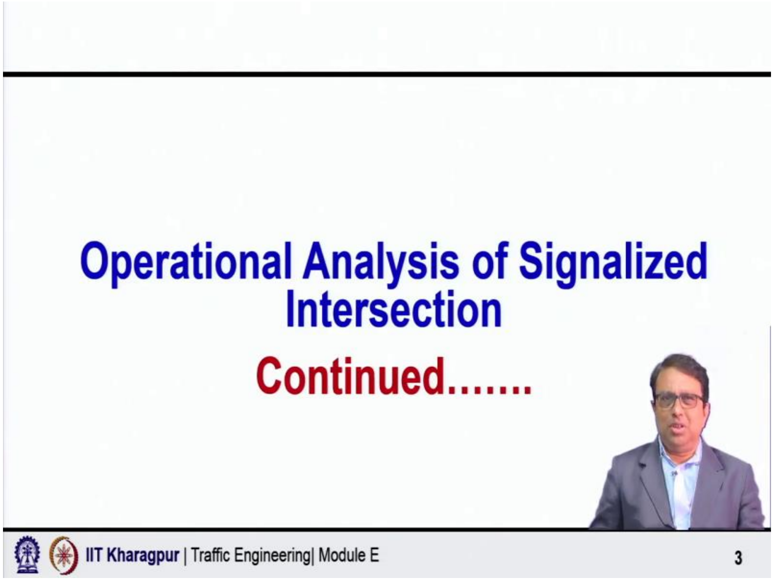

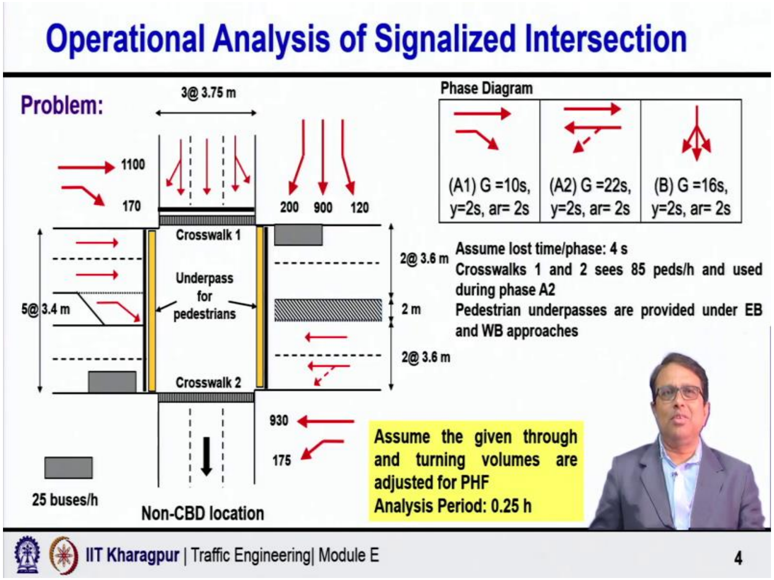

Today, we shall continue as usual and discuss about the step 6 that is basically determine capacity and volume to capacity ratio but before we go to step 6, step 7 and step 8, even step 9 in today's lecture, I would like to remind you about the same problem what we were handling because ultimately we will tell you how to or what to do and how to do it in different steps but then explain you the calculation with reference to the same example starting from step 1, we are taking the same example.

So, just a quick look that it is a four arm intersection, you know that north south road is one way road, south bound east west two way road, the underpasses are there on the east west road and on north south road it is at grade crossing. So, the phase diagram also to just quick recap on the phase diagram straight and right from the east approach, the west approach then the right turn is closed, exclusive right turn is closed, opposing traffic we are allowing, straight and then left under permitted condition because of the crosswalk and then in phase B, the northern approach or the south bound approach is actually taken.

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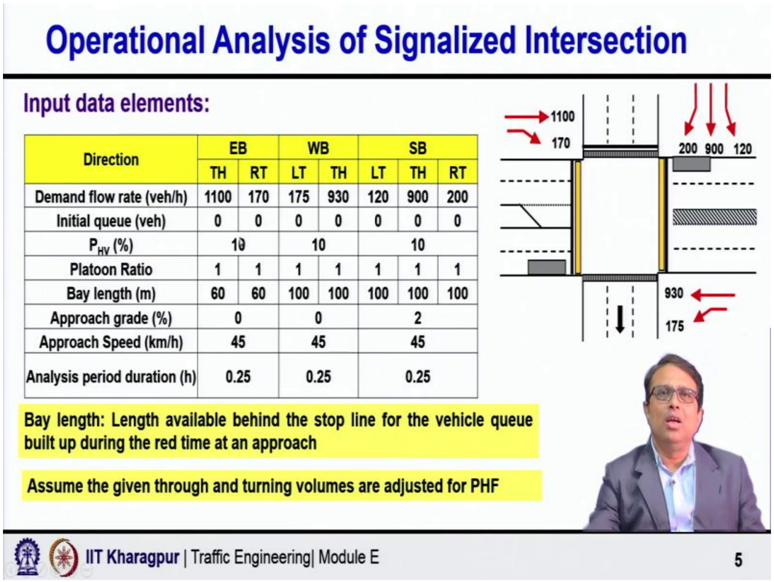

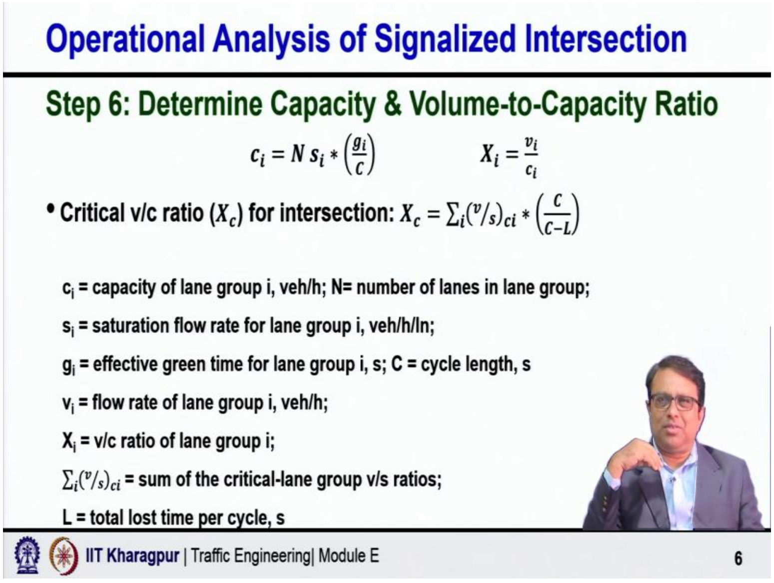

These are the input data, we all used, we all discussed about this input data used many of the data in earlier steps, up to step 5. So, with this background and with this example problem let us now go to the step 6. In step 6, we want to calculate the capacity and volume to capacity ratio.

First of all, how to calculate the capacity of lane group? Obviously, capacity of lane group will be saturation flow rate for the lane group we have already calculated saturation flow. Step 4 was mostly on that, entirely on that not mostly but step 4 was entirely on that and with this saturation flow rate, if there are N number of lanes, so N into Si but the whole cycle time is not available its only gi by C for this lane group how much is the effective green time divided by the cycle time. So, that is taken and that gives you the capacity of the lane group i.

$$c_i = N\, s_i * \left(\frac{g_i}{C}\right) \qquad X_i = \frac{v_i}{c_i}$$

Critical v/c ratio (X_c) for intersection: $X_c = \sum_i (v/s)_{ci} * \left(\frac{C}{C-L}\right)$

Once we know the capacity of the lane group i, we have also calculated the flow rate for lane group i in previous step, step 4. So, then we can calculate Xi that is volume to capacity ratio for lane group i, so very clear cut calculation. Now we also need to calculate the critical v by ratio that we are saying Xc for the whole intersection. How to calculate that? What we are using here v by s flow for a particular lane group i divided by the saturation flow for that critical lane group for lane group i, for the critical lane or critical lane group, for lane group i.

Now, for the critical lane group i, what is the v by s? And it could have been simply v by s, sum over all i but then that means all lane groups together but remember that or note that, we are using here saturation flow not the capacity. We are using the saturation flow, what is the difference between the saturation flow and the capacity? One major difference is this adjustment with g by C ratio effective green to cycle time because the saturation flow is per hour but we do not get green all the time.

Here instead of lane group or considering the g by c ratio for the lane group we are taking the volume to saturation flow ratio and then multiplying it for the overall cycle because we are calculating this critical ratio for intersection. So, what is the intersection cycle time and compared to the overall intersection cycle time, what is the effective green time that means what is cycle time minus the total lost time for the intersection. So, l is the total lost time for the intersection per cycle.

Now here obviously you can see it is g by C multiplied with the saturation flow. Here it is v by s so saturation flow is in the denominator. So, it is multiplied with C by g rather than g by C. As it is done here. So, very similar calculation so we can get the critical volume to capacity ratio.

So, in step 6, we can calculate the capacity of every lane group, once we know that then we calculate the, then we calculate the volume to capacity ratio for each lane group and then with the knowledge of the volume and the saturation flow for the critical lane group in every phase for the critical lane group, in every phase and then sum over i we can do and then multiply by C by C minus l or C by g effective green time.

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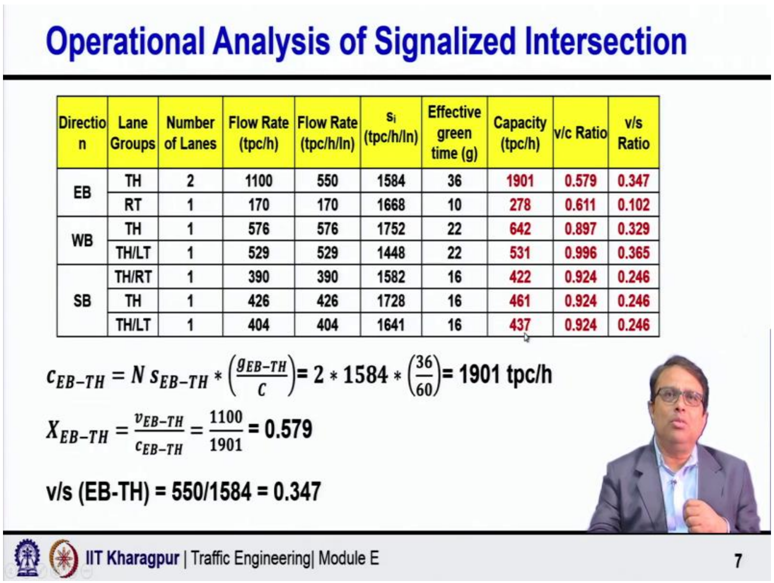

Now coming to this same example problem, we know the direction, lane group, number of lanes, flow rate we have calculated total flow rate and also flow rate per lane, flow rate per lane is simply division of the flow rate by the number of lanes. Here only two lanes so it is becoming half the all the remaining values are same because there is one lane in each lane group.

Then we have also calculated the saturation flow in step 5, step 4, the flow rates are known after iterative procedure in step 3, effective green time is known from the total green time, lost time, amber time, already time all these are known so you know how to calculate.

Now using this formula as shown in this slide 6, we can actually calculate then what is the capacity. For each lane group, we can calculate it. Now we calculate the v by c ratio, volume is known, flow rate is known, total flow rate tpc per hour, capacity is known tpc per hour, so we calculate the v by c ratio. We can also calculate the v by s ratio, volume to saturation flow ratio because in this case we are taking this flow or tpc per hour per lane divided by saturation flow in tpc per hour per lane. So, you can get this v by c ratio.

I have shown one calculation for east bound through movement in number of lane two multiplied by saturation flow for the east bound through movement, it is 1584, so multiplied by 1584 into g by C, effective green time in 36 seconds, cycle time we know is given as 60 second. So, you calculate this capacity as 1901 and once you know the capacity, we know the flow is 1100 tpc per hour. So, 1100 by 1901 .579. We can also calculate the v by s ratio volume is 550 tpc per hour per lane divided by 158, you can see here tpc per hour per lane.

So, you can definitely see here as we expect our v by s ratio will be lower than v by capacity ratio because capacity will be less than the saturation flow due to this effective green time availability within the whole cycle time not the whole cycle time is available for green, it is only the effective green times and the effective green time to cycle time ratio, that is what will come so accordingly this will be different.

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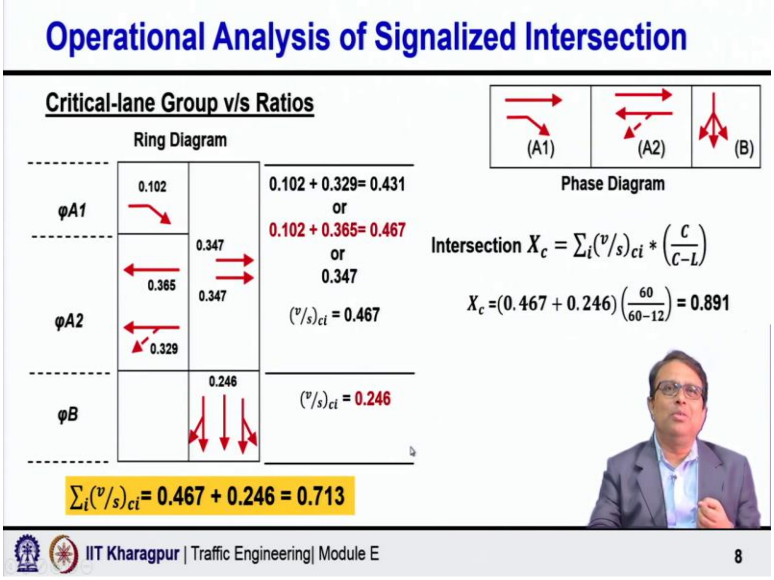

Now as we have got the critical ratio critical flow ratio, say for example, this right turn straight left turn, left turn shared. Now phase A1 2, the common is the through movement east bound. That will continue. So, I have written here the v by s ratios, so you can get it there. So, all these ratios are given here. So, we can calculate actually then what is the sum of v by s ci, why we are taking v by s ci because we want to calculate the critical v by c ratio for the intersection.

So, that is our objective. So, that is why we are calculating because individual flow rate what is Xi volume to capacity ratio and volume to saturation flow rate that we have calculated. Now you want to identify what is then v by s for the critical one ci, critical one. So, sum of critical lane group v by s ratio. So, what is the critical lane group? Now how to calculate critical lane group? How to calculate the critical lane group? Here I have shown you the phase diagram, so what we want to do because the straight is continuing.

Now here for phase A1 and phase A2, the sum of critical lane group ratio v by c ratio, how we calculate v by s ratio, how we calculate we can take either 0.102 plus 0.329 because there are two movements which are happening to 0.102 plus 0.329 in the shared lane or 0.102 plus the straight lane, straight exclusive lane 0.365 or point maximum of 0.102 and 0.347. So, now out of all these whichever will be the maximum that will be the critical volume to saturation flow ratio critical v by s ratio.

So, I repeat again 0.102 plus 0.329, so we are taking the right turn in phase A1 plus the shared through and left in Phase A2 or phase 1 right turn plus phase 2 or A2 straight through lane, through lane exclusive or maximum of right turn and through. All these combinations are valid.

So, out of that we know the 0.467 that means 0.102 and 0.365 this summation is maximum. So, v by s critical for phase A1 and A2 together why we are calculating together, you should be clear because the straight is you know continuing in both phase A1 and A2. So, you get this v by s ci and for phase B, all 0.246. All the cases, if you go back you can see here through right 0.246 through 0.246 through left also 0.246. So, anyone we take it is 0.246.

So, then what will happen 0.467 plus 0.246 that sum over v by s ci, multiplied by c by effective green time. So, 60 divided by 60 minus 12. So, you can calculate Xc, so, I have also now calculate Xc, so I could calculate ci, I have shown you how to calculate Xi and also calculate then Xc. How to identify with this individual v by s, how to then identify the critical one and then using that how you can calculate the intersection wise v by c ratio. So, that completes step 6.

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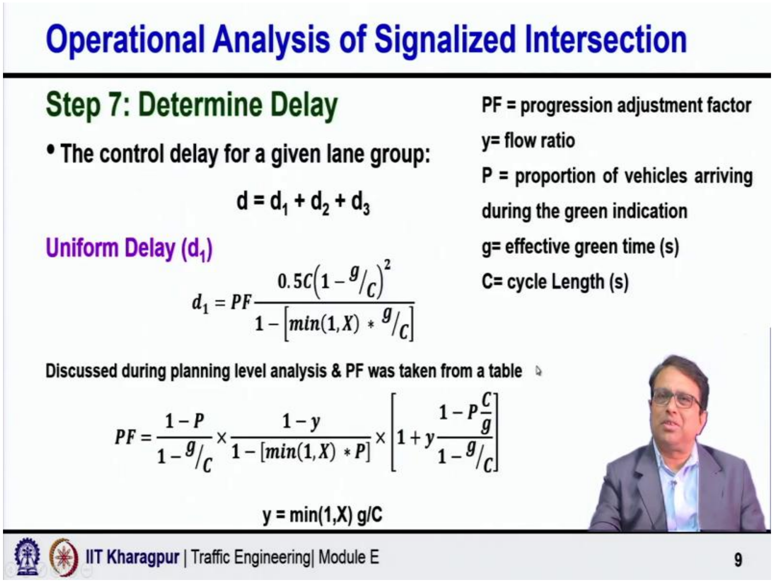

Now going to step 7, here we try to determine the delay. Now this is control delay and I have told you earlier that there are three components d1, d2 and d3 and the total control delay will be d1 plus d2 plus d3. What d1 gives? d1 gives uniform delay, please recall our discussion about the uniform delay and the assumptions what we made uniform arrival then d2 takes care of the incremental delay because in reality it will not be uniform arrival.

So, because of that some cases some of the cycle may fail or even for a longer time also there could be sustained cycle failure because volume to capacity ratio will be higher in general and the third to account for initial queue delay.

Now to explain or discuss this further, first about the uniform delay you are again familiar with this equation, I have used this equation when I mentioned to you earlier about the control delay and showed you the planning level analysis.

$$d_1 = PF\frac{0.5C\left(1-{}^{g}/_{C}\right)^2}{1-\left[min(1,X)\ *\ {}^{g}/_{C}\right]}$$

Only thing that they are from a table we picked up the value for this PF which is the progression adjustment factor but in this case since it is operational level more detailed analysis, there is an equation which may be used to calculate the progression adjustment factor for a given situation and it all depends on various variables as you can see here, all the variables are known to you. So, I need not explain to you again. So, a equation is given and using that equation you can calculate the PF.

$$PF = \frac{1-P}{1-{}^{g}/_{C}} \times \frac{1-y}{1-[min(1,X)\ *P]} \times \left[1+y\frac{1-P\frac{C}{g}}{1-{}^{g}/_{C}}\right]$$

y = min(1,X) g/C

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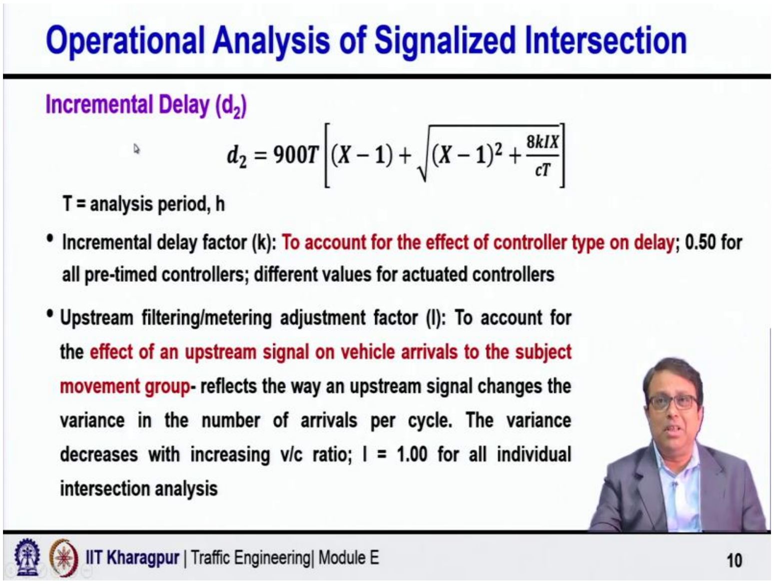

Second part is incremental delay, this also you are again familiar with this component d2, the basic equation is very similar. Of course, there are some changes like they are always we consider as T, the analysis period has 15 minutes so 900 into 0.25 that value directly was mentioned here and in this case also it was simplified.

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right]$$

The whole overall equation was used in a simplified form, the basic equation is same but it was used in a simplified form. We did not have this two variables one is k another is I. So, the they were not present there in that equation, you can check the previous lecture and once again try to refresh your understanding.

So, what are these two factors k is actually called incremental delay factor. Now why we are considering this? This is considered because we want to account for the effect of controller type on delay and you remember there are different controllers that could be used, so it could be a pre-timed controller, it could be actuated controller depending on what kind of operation you are aiming for.

So, or what is the existing operation, how presently the intersection is operated. So, generally the value is 0.5 just for example for all the pre timed controller highway capacity manual tells you more details about how to get the values under for actuated controller and some of the discussion probably we will also make, when we talk about actuated signal control.

So, to account for the effect of controller type on delay. Now what is I, I is something again interesting, it is called upstream filtering, upstream mean what? It will control arrival pattern it will control. So, upstream filtering or metering adjustment factors? Why we use this factor? To account for the effect of an upstream signal, what it will control? It will control the vehicle arrival to the subject movement group.

What is the effect of upstream signals on vehicle arrival of the subject movement group and this reflects the way an upstream signal changes that will impact the variance in the number of arrivals per cycle. So, how the discharge is happening from the upstream signal and how the vehicles are actually arriving.

So, obviously the effect of upstream signal will have impact or reflection on the way an upstream signal changes and its impact on variance in the number of arrivals per cycle, in the intersection we are trying to analyse. Now this variance obviously will decrease with the increasing v by c ratio because heavily loaded intersection this variance will decrease obviously and you can take it simply as one for all individual intersection analysis. In this case let us use that.

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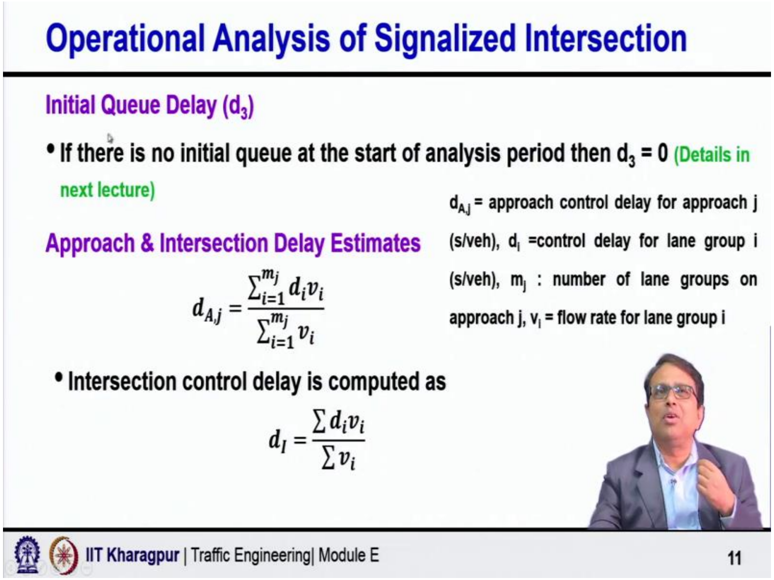

Now the third part is to account for the initial queue at the start of analysis period. Remember that what we said that when you are starting the analysis that time also the queue may not be 0, you may have some queue from the previous analysis period, end of the previous analysis period or when you was just starting your analysis period for the present work. So, if there is any initial q that effect we need to take care through this d3. But for the moment at this stage let us assume that there is no initial queue at the start of analysis period. Again, we will discuss this more how to calculate this d3, what are the consideration in the next lecture. So, for the moment just assume it as 0.

So, theoretically now you know how to calculate d1, d2 and d3 that means how to calculate uniform delay, incremental delay and then initial queue delay. Now once you know that, then the next step is we want to calculate the approach and intersection delay, how the delay will happen approach wise and also for the overall intersection. So, if you take a particular approach dAj, then that will be sum over di vi what is i? i stands for lane group i, and sum over so all lane groups we are considering.

$$d_{A,j} = \frac{\sum_{i=1}^{m_j} d_i v_i}{\sum_{i=1}^{m_j} v_i}$$

If there are mj number of lane groups then i, equal to sum over i equal to 1 to mj di vi that means what is the control delay for lane group i? Multiplied by what is the volume in lane group i, sum overall lane groups so that gives you the aggregate delay divided by flow rate for lane group i and sum over again all i, so i will be 1 to mj, so that will give you average delay. Average delay obviously, if we are using control delay it will be average control delay per approach.

Now once you know that, then how the overall intersection delay can be computed? Overall the intersection delay will be di vi that means control delay for lane group i, vi is the flow rate for lane group i divided by sum over vi. So, the first one for approach delay for approach j and the second one is actually for the intersection control delay. All the volumes and overall intersection we are considering.

$$d_I = \frac{\sum d_i v_i}{\sum v_i}$$

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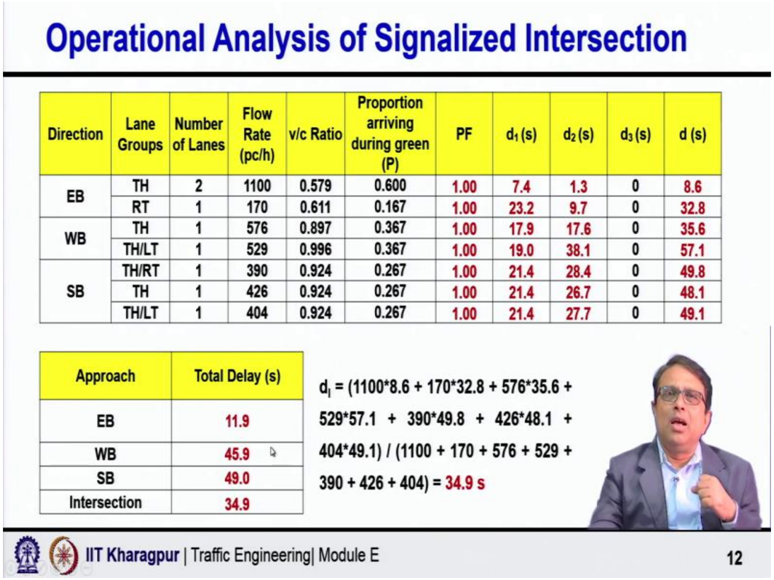

So, overall intersection we are considering. So, now coming to the application I have told you then how to calculate d1? How to calculate d2, d3 for the moment we will assume as 0. Then how to calculate this approach and overall intersection delay using this two equations as given here.

So, going to the example again, going back to the example again. Directions known lane group, number of lane flow rate, v by c ratio also known, platoon arrival during green that is also known, step 5, now we are assuming that PF equal to 1, PF actually you can it is not an assumption you can calculate for the given data in all cases we got it as finally value minimum of 1 or x either 1 or x minimum of into g by c. So, we got actually the overall PF value in all these cases as one we calculate d1 as I have shown you here using this equation once you know the PF then c g by c is known X is known so everything you know it.

Similarly, you can calculate also the d2 and d3 you take as 0 and then the approach or lane group wise, you can find what is then the delay. So, lane group wise if you know then using that you know approach wise, number of lane groups on approach j, you take and here it is the overall intersection di. So, here I have shown you the lane group wise delay and here I am showing you how you can actually calculate the overall delay for the intersection. Say for example 8.6 into 1100 plus 170 into 32.8, 576 into 35.6 like that you do it, you sum it over and you get for the overall intersection delay that is 34.9.

And how you get this eastbound delay? It is again the you only take the lane groups which are east bound. How you calculate the west bound? You take only the lane groups which are westbound and whatever how you calculate here considering all the lane groups and volume and the corresponding lane group delay. So, you can also calculate it and then I have shown it here. So, you know now eastbound, westbound, south bound and for overall intersection what is the control delay, total delay per vehicle.

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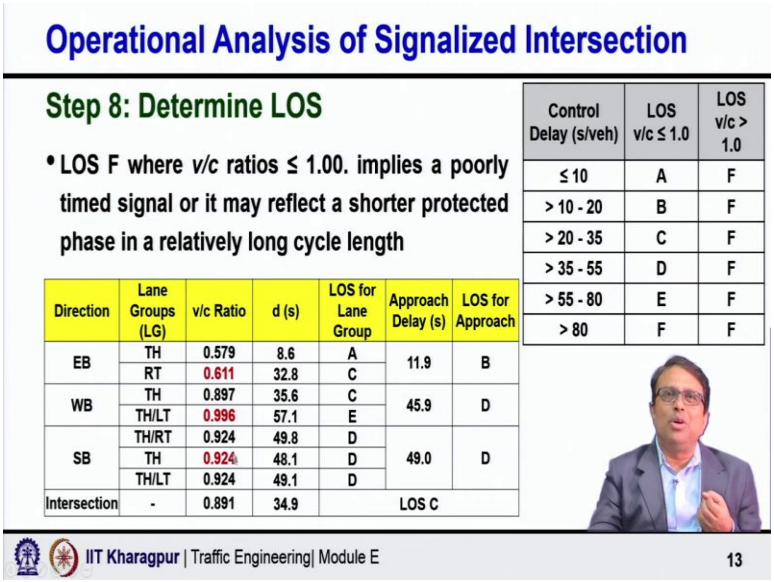

Now once you know that the next step is determine level of service. How we determine the level of service? Already you know, one condition is if the v by c is greater than one then it is definitely f level of service f, the worst one. When v by c less than equal to one then depending on how much is the control delay accordingly we can calculate the level of service.

So, here this is the table which is given. Now what we do, for each direction each lane group we know the v by c. We know the control delay we have calculated from the previous step and simply comparing the delay with the table we can find out which lane group is operating with what level of service.

Then we can also calculate what approach considering the lane group within its this approach. How the overall level of service for the approach and once we know the approach wise thing, approach wise level of service we can calculate and we can also calculate considering the overall intersection. What is the delay and therefore what is the overall intersection level of service?

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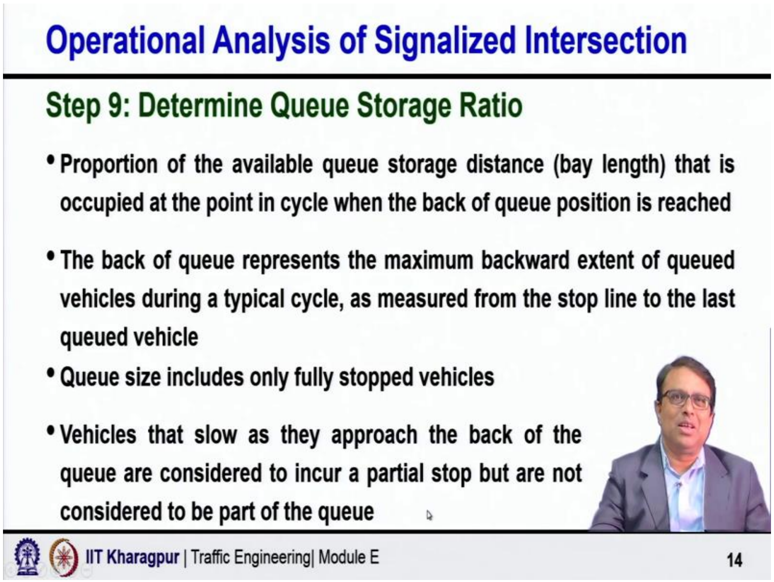

So, that up to the level of service. Next step 9, determine queue storage ratio. Here again it is something interesting and you have to be careful to understand it clearly. What is the queue storage ratio? You remember that earlier we discussed and told you whenever I was talking about the inputs, I told you something about the bay length or how much, how long storage is acceptable. That means when you are designing, operating an existing signal you are carrying out operational analysis you want to know that how long the queue can go.

That is the bay length, storage distance, queue storage distance so proportion of the queue storage distance that is occupied at the point in cycle when the back queue position is reached. So, you have so much length available and what proportion of that length is actually occupied by the queue storage. 70 percent, 80 percent, fully. The back of the queue represents the maximum backward extend of queued vehicles during a typical cycle and you can measure it from the stop line to the last queued vehicle.

So, queue size includes obviously fully stopped vehicle because two types of thing that a vehicle two types of thing may happen, some vehicles obviously all vehicles will decelerate and stop if the vehicle is stopping for all stopped vehicle there will be deceleration component, a stopped component and an acceleration component. But there could be some vehicles which will not have this stop, fully stopped vehicles but simply may be some deceleration and then acceleration. No fully stopped condition.

So, some vehicles will have experience of full stop, some vehicle may not really stop fully but may have only acceleration deceleration, fast deceleration and then acceleration and anyhow all the stopped vehicles fully stopped vehicles will definitely have a deceleration and acceleration. Now vehicles that slow as they approach the back of the queue are considered to incurred a partial stop but are not considered to be part of the queue because they are not stopped vehicle. So, there is a difference.

So, if the vehicle is slowing down and then accelerating without fully stopped condition, then that will not be considered to be part of the queue but does it mean that unless it is 0, we will consider that the vehicle is not stopped, no. Sometimes people use yes, that could be a possibility I am saying fully stopped means it has to be 0. So, the time distance diagram may show exactly horizontal portion but some cases a small speed is also taken as a threshold value maybe 5 kilometre, 6 kilometre, very low.

So, if a vehicle is travelling as 5 kilometre, so once the speed becomes below the threshold limit and as long as it will be below the threshold limit it may be 0, it may be two, it may be four, it my threshold is 5 as long as the speed is less than 5 kilometre per hour any value between 0 to 5, it will be considered as a stopped vehicle. So, people use many analysis is carried out considering a threshold value but what we are saying not be considered as a part of the queue, in that case even with deceleration, acceleration all these.

The speed is not going anytime below this threshold value. So, that is the difference between stopped vehicle and vehicles which are incur a partial stop. We are saying partial stop means not really stopping but they are slowing down in a way using certain deceleration.

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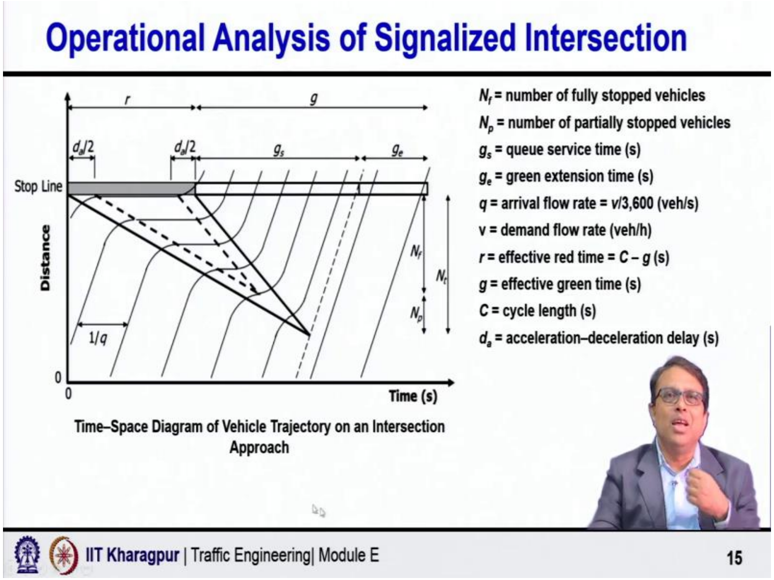

Now let us look at this diagram, this is very interesting this is a time distance diagram you have already studied shock waves, so you know how the shock waves are created once the signal becomes green. How the recovery shock wave is also created when the signal turns from red to green and then after some time the queue will dissipate depending on the how much storage has happened and how much is the green time whatever is the discharge rate. So, I am showing something similar here.

Here the X axis is the time, y is the distance and let us consider, I am talking about 1, 2, 3, 4, 5, 6, 8 vehicles I am talking. So, I am talking about 8 vehicle trajectories that is what is shown here. Now first 1, 2, 3, 4 vehicle 5 vehicle, first 5 vehicle in all cases there is either a small one or a reasonable longer one, is this horizontal portion or as I said that even below a threshold value also.

So, even though there is a little bit of movement but it is below the threshold still it will be considered delay. So, 1, 2, 3, 4, 5, 1, 2, 3, 4, 5, first 5, vehicles all these 5 vehicles actually stopped considered as stopped, that means they eventually came to a speed level below this small speed which is the threshold value and eventually also you got a flat curve showing that vehicle is fully stopped.

Now the sixth vehicle and also up to any vehicle suppose there if there would have been a vehicle up to this dotted line. Actually vehicle is slowing down, you can see here, it is not going straight there is a curve but the speed never came below the threshold limit so yes there is an impact, partial stop, partial slow down whatever you want to say whatever way you want to say some impact is there but the speed never went below the threshold limit what we consider to define fully stopped, partially affected but then seventh eighth cycle out of this even the solid triangle, no impact just travelling and traveling exactly in the same speed without any deceleration, acceleration anything just clearing seventh vehicle, eighth vehicle same. So, no impact now, no impact of queue.

So, generally this dotted line, this triangle what it is showing? It is showing actually the stopped vehicle as per our definition. It will be here we have considered a small threshold value. So, maybe even just before it even becomes fully horizontal, we have marked that as stopped. So, this is the, this part of the triangle side or this line showing when the vehicle just stopped and the other line on the other side of this one, this is showing when the vehicle just came out of the stopped condition. Just reached above that threshold value. So, this dotted triangle is actually representing the stopped vehicle.

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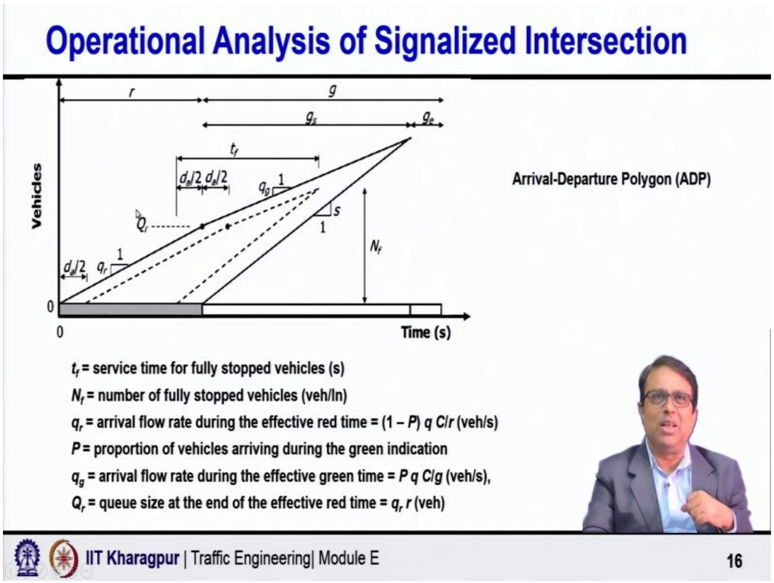

Now with this let us go to the next one. Here the y is the vehicles, not really much difference here we talked about the distance and obviously here you can calculate if we that for how long is the stopped vehicles are there, fully stopped vehicles. It will be from this line to this line and Np is number of partially stopped vehicle, some impact but not stopped fully.

That will be this line, so this to this, so that is what is shown as Np and the total number of vehicle experienced any kind of impact either fully stop or partial stop, that will be fully stopped vehicle plus partially stopped vehicle. So, together whole maximum distance considering the solid triangle. Now with this we go here, here we are showing vehicles, this is a time and vehicle the left line solid line, it is showing how the vehicles during the red time, how the vehicles are arriving. This is the arrival line vehicle arrival representation. Obviously, with time, it will grow and cumulative number.

So, even when the signal becomes green, then also there will be arrival but the arrival during red and during green may not be same. You know it depends on the arrival type, so it may not be same, it may be same, it may not be same. So, it is shown as Qr and Qg respectively and some cases Qr and Qg may be same as well. So, this solid line it represent vehicle arrival first portion showing during the red time and the second portion showing during the green time.

Now what is the departure one, departure is when there is red then the departure is 0. So, it is flat horizontal then here the signal turns into green. Now obviously, this point where the flow rate changes from Qr to Qg, if I draw a vertical line it will coincide with the start of green, this is the point which is getting represented. Now discharge start, so discharge will happen and this is showing the cumulative discharge and in this case within the green time the cumulative discharge and cumulative arrival, they are catching up. So, that means there is all the vehicles are cleared.

Now this is actually known as arrival departure polygon. Earlier case I have shown you only an example of a triangle but here the arrival rates are different. There could be various other conditions initial q and so many other possibilities could be there. So, it may give different shape but there is always one arrival, another departure with some additional considerations. So, generally we can call it as arrival departure polygon. Within this there is a dotted polygon also. What that represents? Stopped vehicle, that is the representation of stopped vehicle as exactly here you found, there is a solid triangle but within that there is a dotted triangle.

So, here you have a solid polygon within that there is also a dotted polygon, dotted polygon indicates the stopped vehicle, represent the stopped vehicle. All the vehicles which are arriving during red or during green may not really stop. So, it will be a separate one, a smaller one. How much will be this distance? Like this point to this point or this point to this point, even in the previous case also, this to this or this to this, how much will be the timed gap.

Time difference here also it is a time access. So, what will be the time difference? It is taken as da by 2, what is da? da is the, I have shown here acceleration deceleration delay. First deceleration and then acceleration. Remember these vehicle trajectories. So, it is basically called as Xda is acceleration deceleration delay, half of that, this side half of that on the other side as you have seen here, here also it is da by 2, there also it is da by 2. So, that is what is shown here.

Now with all this representation then what will be the number of fully stopped vehicle? Up to this tip of this dotted triangle that is the number of fully stopped vehicle. What is the rate time?

This is the rate time up to this. What is the green time? The next one? Within the green time, there is one component is called gs which is going up to this plate starting from this point up to this point, this point is what here.

What is the meaning of gs? gs is the green time to clear all the queued vehicles or all the vehicles, I mean now there is no impact, no effect of queue because the departure and the arrival and the departure car, they are meeting.

So, this point onwards in the green, it is only the vehicles which are arriving in the green extension time, just clearing it. So, that is g, total time to required to calculate the fully stopped vehicle? All these parameters you can calculate. So, what is the tf? tf is service time for fully stopped vehicle that is shown here. What is this that? What is that? This time, so you can see going here starting of green and taking up to this time, this dotted triangle.

How much time, so that much time it will take to take away all the vehicle from stopped condition. That means when signal turns into green after so much time, tf time there is now no vehicle which will be, so tf time is starting from here, you take look at this position carefully. So, from this time da by da by 2 here, da by 2 on the other side and this one is basically the green time.

So, it is starting from the green time, that is what it is. The gs and g but tf is starting from da by 2 on the left side so it is actually starting from this point, carefully observe that, it is not at the starting of green because at the starting of green means it will be this position not this position. But this is the time, so from this point up to this point because the stopped vehicle starts moving from this point and then finally up to this point or up to this time, all the stopped vehicles start moving there is no stopped vehicle anymore. So, that is what it is.

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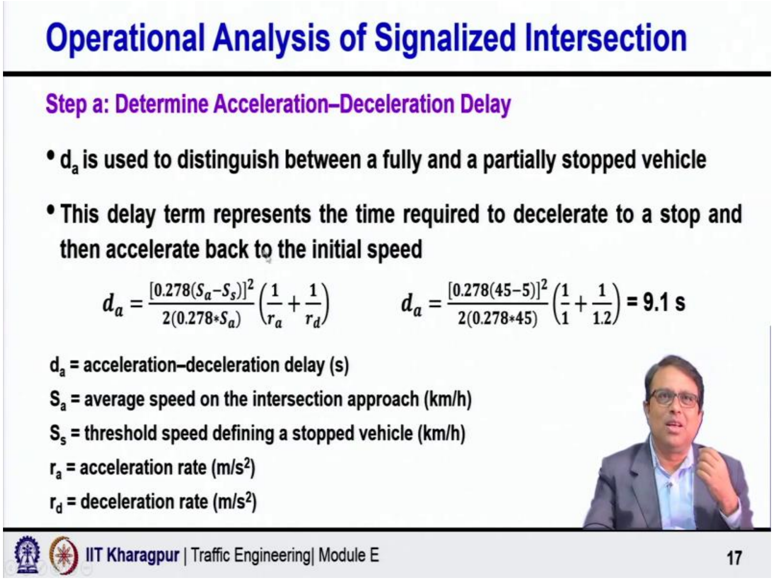

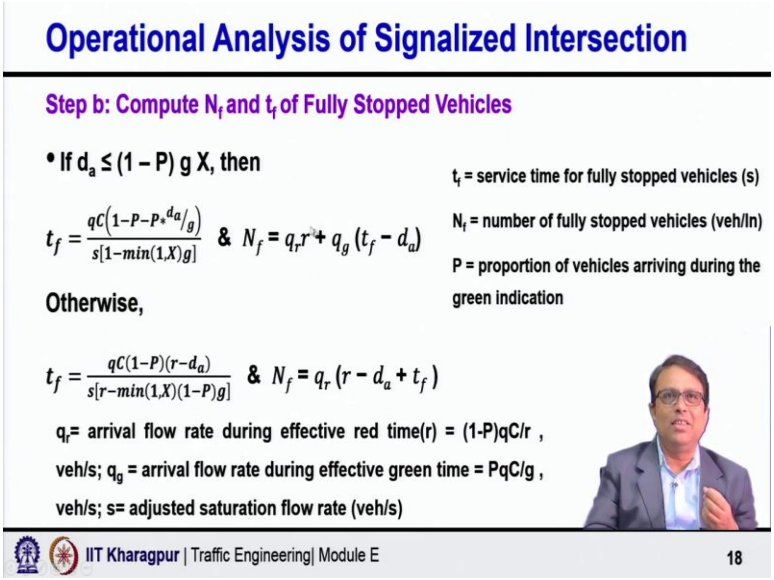

So, how to determine the acceleration deceleration delay? It depends on the average speed of the intersection approach, the threshold speed what I said and obviously the acceleration rate deceleration rate. So, this is a simple formula which is given you can apply that and we have applied it to our given problem to calculate the da value and then once the da is there, how you can calculate the tf? My main intention is to calculate tf and Nf? How much time to serve the stopped vehicle and Nf, number of stopped vehicles, fully stopped vehicles?

$$\boldsymbol{d_a = \frac{[0.278(S_a - S_s)]^2}{2(0.278 * S_a)}\left(\frac{1}{r_a}+\frac{1}{r_d}\right)}$$

So, there are two formulas given if da is less than one minus p into gx then there is one formula for tf otherwise there is another formula for tf. So, similarly the tf and Nf both cases you can calculate depending on whether da is less than one minus P into gX or otherwise. So, this formula is given here.

If $d_a \leq (1 - P)\, g\, X$, then

$$t_f = \frac{qC\left(1-P-P_*{}^{d_a}/_{g}\right)}{s[1-min(1,X)g]} \quad \& \quad N_f = q_r r + q_g\,(t_f - d_a)$$

Otherwise,

$$t_f = \frac{qC(1-P)(r-d_a)}{s[r-min(1,X)(1-P)g]} \quad \& \quad N_f = q_r\,(r - d_a + t_f\,)$$

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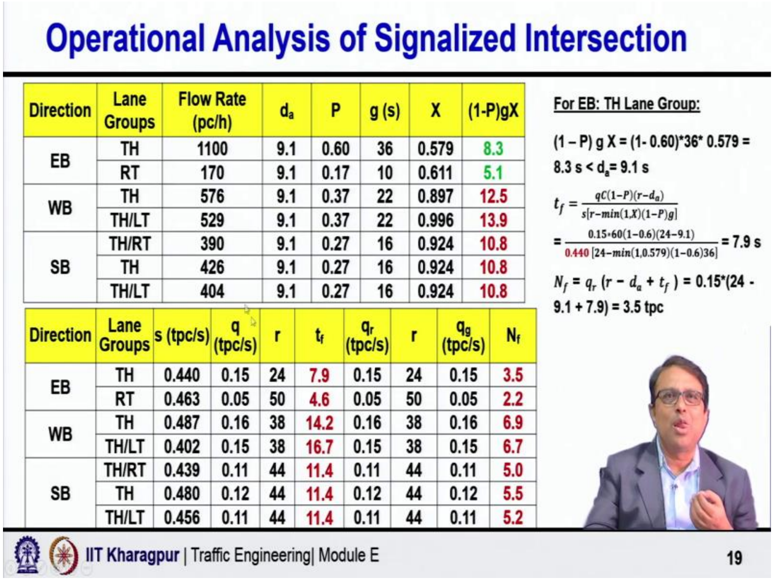

Accordingly, I have shown here, the calculation east bound every land group flow rate, what is the da known, P known, gs known, X also known. So, I have calculated one minus P into gX, you are seeing two colours because some cases the first condition is getting satisfied this one da less than equal to one minus P gX. Some cases this condition is not getting satisfied so some cases you are using this set of equation; other cases you are using this set of equations.

That is what I have done, we have calculated it and here I am showing one minus P into gX up to this calculation and once we know that then we calculate accordingly tf and Nf value appropriately depending on this 1 minus P into gX whether it is less than greater than equal to da or otherwise.

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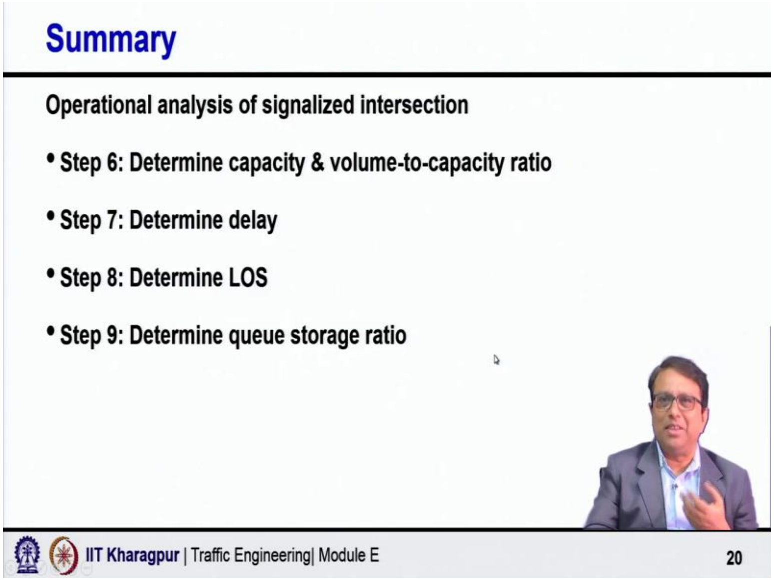

So, that is what, I have shown the calculation here and that completes my lecture. So, what we discussed here basically step 6, how to determine capacity and volume to capacity ratio. Then step 7, how to determine the delay, 8 with that control delay measurements how to determine the LOS and step 9, how to determine the queue storage ratio, particularly the Nf and tf, number of fully stopped vehicles and as I said, that how much time it takes service time for fully stopped vehicle. So, with this I close this lecture. Thank you so much.