Traffic Engineering
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Lecture 33
Pre - Timed Signal Design - I

Welcome to Module E, lecture 7, this is the first lecture in this week. Today, we shall discuss about pre-timed signal design.

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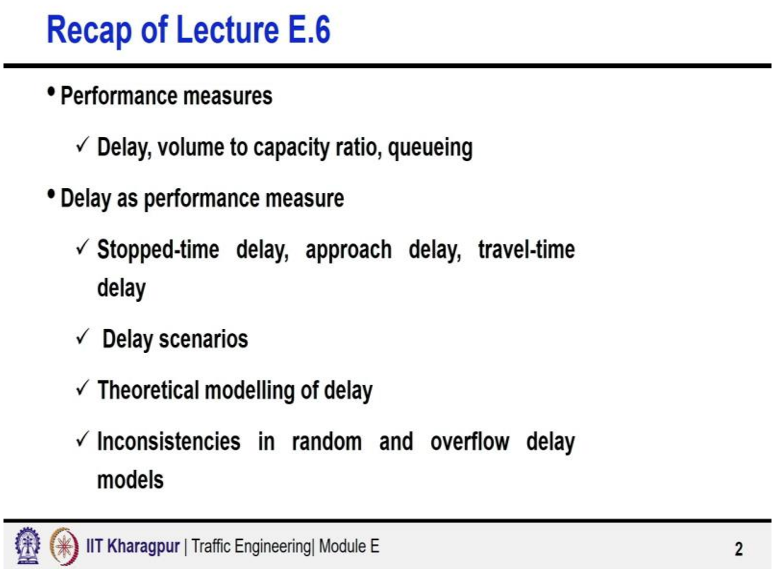

In lecture 6, I mentioned to you about various performance measures. For example, delay, volume to capacity ratio, queuing, and then discussed in details about the delay as performance measures. I mentioned to you about stop delay, approach delay, travel time delay also discussed about various delay scenarios, theoretical modelling of delay and then why the inconsistencies in random and overflow delay models are there and how to overcome that using a different model.

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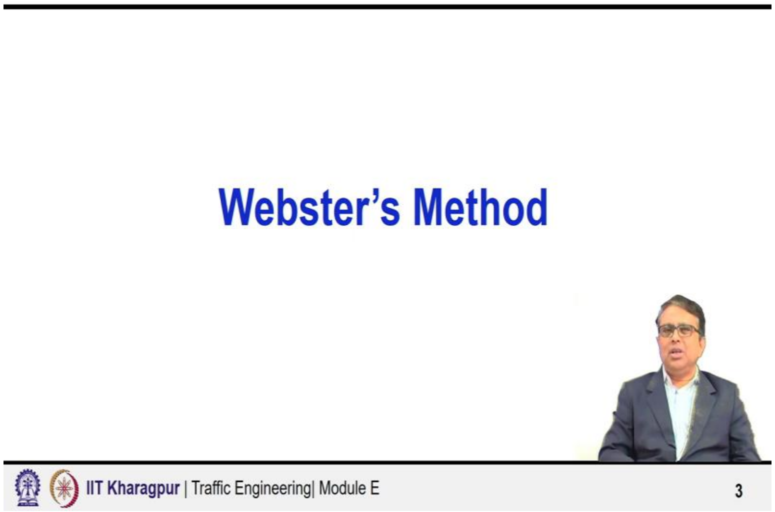

Now, we shall continue our discussion about what I said pre-timed signal design. The first and one of the very popular and well-known method is the Webster's method. So, we shall start our discussion with the Webster's method.

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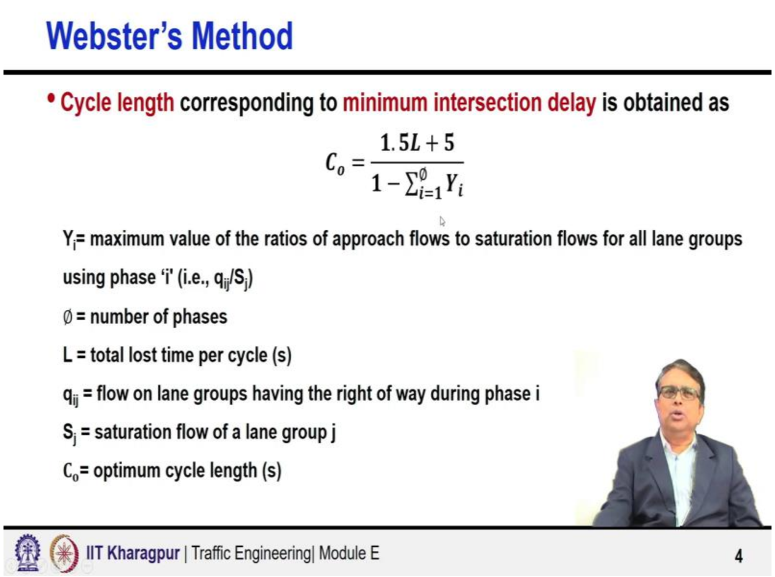

As per Webster method, the cycle length corresponding to minimum intersection delay may be obtained using the formula as shown in the slide. Here we are using L as the total loss time per cycle, Yi is the maximum value of the ratios of approach flows to saturation flows for all lane groups using phase i and like that every phase maximum value of the ratio that we add up for all the phases and then 1 minus some of that or some of Yi, i equal to 1 to phi, phi is the number of phases.

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{\emptyset} Y_i}$$

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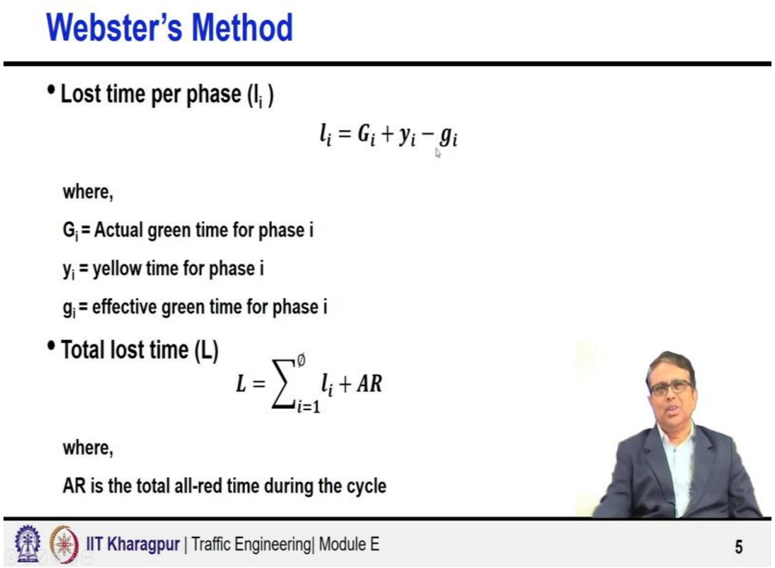

Now, the lost time for phase i as we have discussed earlier is green time whatever is given overall green plus yellow or amber minus the effective green time. So, the actual green time amber and effective green time that way we can calculate the lost time per phase. Now, then what is the total last time? Total lost time is sum over li for sum over all the phases i plus red time.

$$l_i = G_i + y_i - g_i$$

Here in the above equation li equal to Gi plus yi minus small gi effective green time. Here the we only considered yi say yellow time. So, the all-red is not included here in this phase wise lost time calculation. So, when we are calculating the total lost time, we are calculating the lost time plus the all-red time considering all the phases. So, AR is the total all-red time during the cycle. So, all the phases are considered together.

$$L = \sum_{i=1}^{\emptyset} l_i + AR$$

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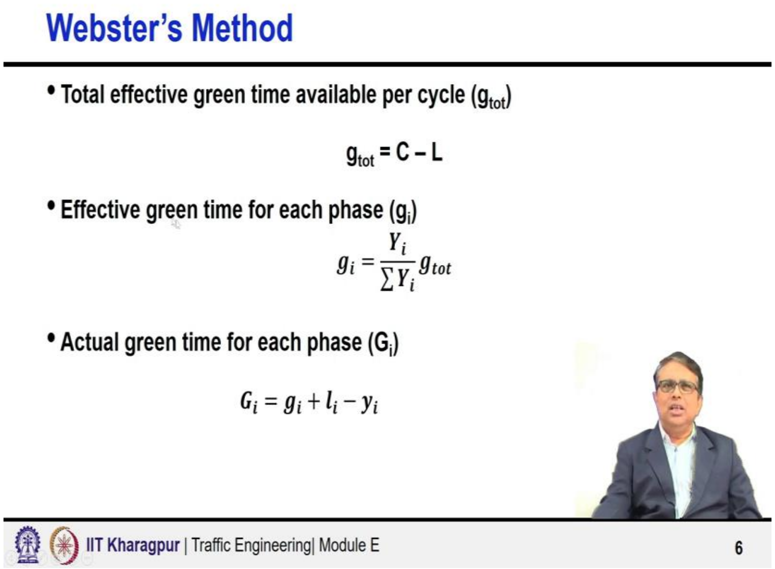

Now, then the total effective green time available per cycle will be how much? Cycle time minus total loss time C minus L.

$$g_{tot} = C - L$$

Then what we are saying effective green time this G total, how we are distributing? We are distributing in proportion of basically Y. So, Yi by sum over Yi. So, how much share one particular phase i will get that is Yi divided by sum over Yi, that way the effective green time is distributed two different phases.

$$g_i = \frac{Y_i}{\sum Y_i} g_{tot}$$

Now, then what will be the actual green time for each phase? Actual green time will be effective green time plus lost time for that phase minus the yellow time or amber time for that phase. So, that way we can get the actual green phase.

$$G_i = g_i + l_i - y_i$$

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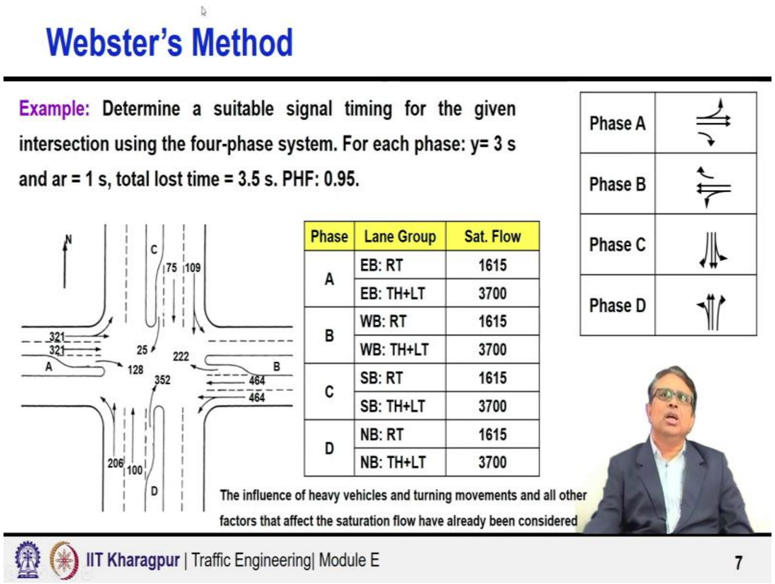

Let us, take an example to understand it even in a better way. Determine a suitable signal timing for the given intersection using the four-phase system and for each phase y equal to 3 seconds, ar this ar is small ar that means, each phase wise ar is 1 second and total lost time is 3.5 seconds and peak hour factor is 0.95.

Now, this is a four-phase system that is what is assumed here, you know there are four approaches to this intersection and each phase we are actually clearing traffic approaching from one approach. So, first maybe eastbound, then westbound, north, southbound, northbound. And you can see here from each approach, there are three lanes, one is a one in an exclusive right turn lane then the left most lane is straight and left shared middle lane is for the through traffic.

So, the saturation flow values are also given from each approach right turn say 1615 through and left 3700 through and left mean it is both the lanes together, where the left lane is through and left and the middle one is only through. So, together the saturation flow is 3700. Exactly in the similar manner for different phases, the westbound, southbound and northbound the saturation flow values for the right turn and through plus left together that are given. So, with this input we need to design a suitable signal timing.

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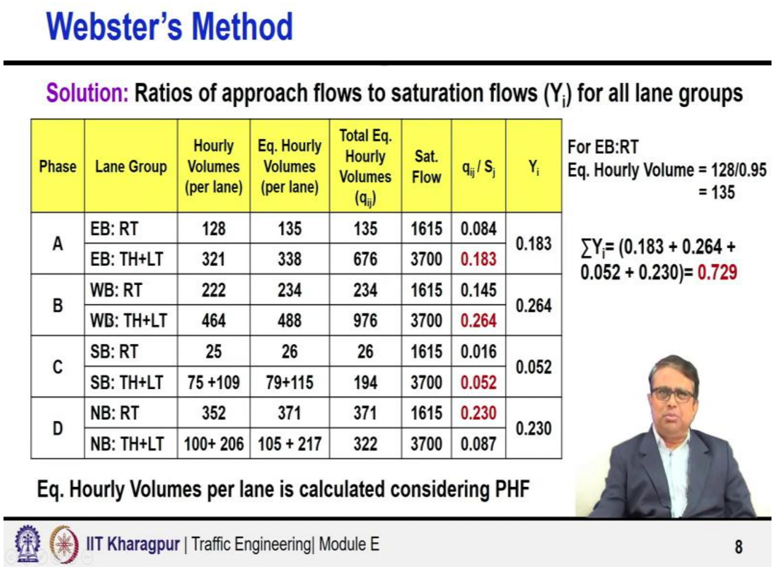

Phase	Lane Group	Hourly Volumes (per lane)	Eq. Hourly Volumes (per lane)	Total Eq. Hourly Volumes (q_{ij})	Sat. Flow	q_{ij} / S_j	Y_i
A	EB: RT	128	135	135	1615	0.084	0.183
	EB: TH+LT	321	338	676	3700	0.183	
B	WB: RT	222	234	234	1615	0.145	0.264
	WB: TH+LT	464	488	976	3700	0.264	
C	SB: RT	25	26	26	1615	0.016	0.052
	SB: TH+LT	75 +109	79+115	194	3700	0.052	
D	NB: RT	352	371	371	1615	0.230	0.230
	NB: TH+LT	100+ 206	105 + 217	322	3700	0.087	

What we are doing here look at this table phase wise we take A, B, C, D four phases. Lane group we consider here eastbound first, then westbound in phase 2 or phase B southbound in phase C and north bound in phase D. In each phase two lane groups we are considering, one is for exclusive right turn, the other through and left together. The left most lane and the middle lane together.

Now, if you take that, then hourly volumes per lane as it is given in the previous page the same values are taken. For example, if you take eastbound right turn it is 128 vehicles eastbound right turn you can say it is 128. Similarly, the straight is 321 straight and left combined or shared lane is also 321. Same way we take the values 321.

Here in phase C through and left the values are not same, like in this case 321 and 321 both were 321. But for eastbound the values are different, 75 is straight and 109 straight and left. So, we add them together and then say this is not volume per lane truly, but these are the volumes in two lanes I should not use the plus sign here. Then what we are trying to get here in the next column is equivalent hourly volume. So, what is the difference between the hourly volume and equivalent hourly volume?

In equivalent hourly volume, we have considered the peak hour factor that means hourly volumes per lane is calculated considering the peak hour factor that means considering the peak 15-minute hourly flow rate rather than the hourly volume, peak 15-minute hourly flow rate. So, you can see the peak hour factor is 0.95. So, 128 by 0.95 you will get 135. Similarly, for each case we calculate the values.

Again, here also not 79 plus 115 in true sense, but what we are trying to indicate that you have one lane where the volume is hourly volume is 75 and when you take the equivalent hourly volume considering the peak hour factor it is 79. Similarly, for another movement it is 109 and the equivalent value is 115.

Of course, eventually these are to be added together when we will consider the hourly equivalent hourly volume not per lane but total. So, here since for the first case phase A eastbound there is only one lane. So, the 135 will remain 135 but through and left in each case 321 the left and straight shared lane is 321, straight is also 321 and the equivalent hourly volumes considering the peak hour factor is 338. So, that total will be 338 plus 338 equal to 676.

Similarly, here it is small lane so, 234 remains 234, 488 again it becomes double because one is through and left shared with 488 equivalent hourly volume per lane in one lane and then another case straight also is 488 equivalent hourly volume. So, together approach wise it is 976, 26 remain and in this case for phase 3 southbound the two values we have to add together so, 79 plus 115 is 194.

Why we are adding them together? Because the left and through combined saturation flow are considering both the lanes, one is a shared lane through and left the other is only a through lane. So, together the saturation values are given. So, hourly equivalent volumes total volumes also yet taking the total volume.

Now, once the saturation flow is known from the previous table inputs given as inputs. So, we can calculate then qij divided by Sj each flow divided by the corresponding saturation flow. Now, in phase A what we said here, if we go back we said, what is Yi, maximum value of the ratios of approach flows to saturation flows.

Maximum value of the ratios of approach flows to corresponding saturation flows. So, if you come here there are two values here one is 0.084 another is 0.183, what is maximum of these two? 0.183. Similarly, 0.145, 0.264, what is the maximum of this? 0.264. Similarly, here it is 0.052 and for phase D, the Yi is 0.230. So, then what is the sum over Yi add all these four values and that becomes 0.729.

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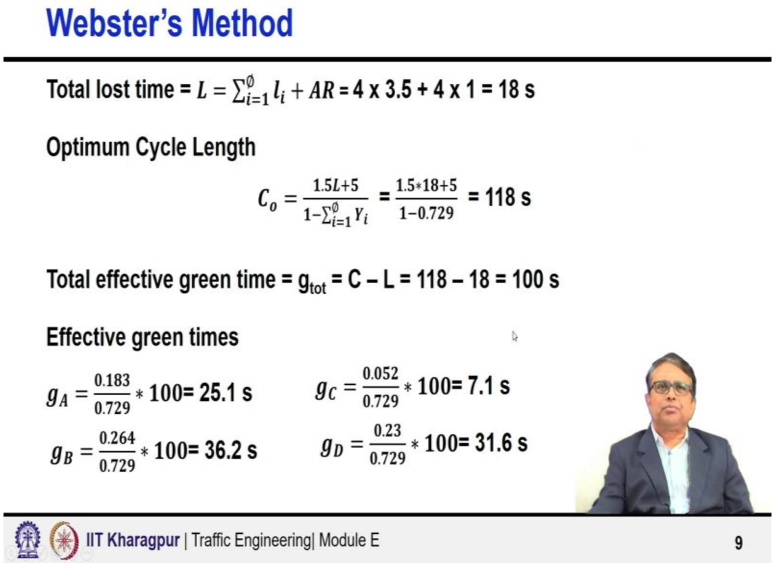

Now, what is the total lost time? Lost time is lost time per phase plus the all-red time for the whole cycle. So, we know there are four phases, each case each phase the lost time is 3.5 seconds giving as input total loss time is 3.5 seconds per phase. So, total loss time is 3.5 plus 4 plus 4 into 1 second. Here, it is also the all-red small ar. So, it is phase wise, so, four phases together is 4 seconds. So, total is 18 second last time.

So, now, with all these values, known value of L known value of sum of Yi we can get the optimum cycle length which we are getting here as 118 seconds. So, what will be then if this is the cycle length then what is the total effective green time is the cycle time minus total loss time cycle time is 118 and total loss time is 18. So, the effective green time is 100 seconds.

Now, these 100 seconds start to be distributed to four phases in what ratio Yi by sum over Yi. So, first phase A how much share will get phase A will get 0.183 divided by 0.729. Phase B will get 0.264 by 0.729 and so, on. So, what we have done here 100 seconds multiplied by effective green time for A is 0.183 by 0.729 so 25.1 second. Similarly, for Phase B the effective green time is 36.2 second, phase C 7.1 second, phase D 31.6 second.

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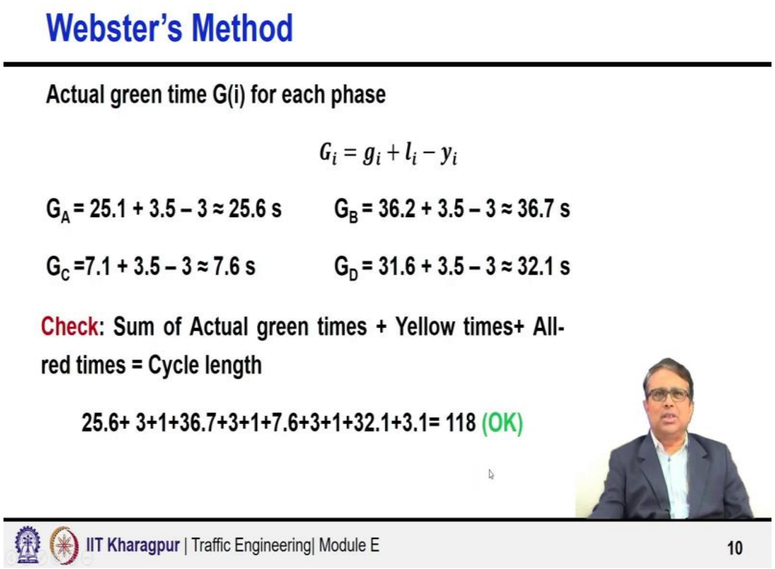

Now, what will be the in the actual green time? Actual green time for each phase for phase A will be effective green time for phase A plus the lost time total lost time is 3.5 seconds per phase. So, that will be there. So, minus 3 is the Yi. So, you take out that it becomes 26, 5.6 again. Similarly, you calculate the total or actual green time for phase B, phase C and phase D. We can also do a check whether we have really distributed it correctly, we can do the check because if you add up GA plus GB plus GC plus GD, it becomes 118, which is exactly equal to whatever you got as the total effective green time.

So, total value that we can see, total not total effective green time sorry so the total cycle length. Because we are getting here the total green time. So, total green time together GA plus GC plus GB plus GD all together plus, you can get all the yellow time add them. So, 25.6, 36.7, 7.6 and 32.1 plus all the corresponding yellow time and all-red time. So, 4 seconds, 4 seconds, 4 seconds, 4 seconds. So, if you get that, what you will get? You will get cycle time.

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Now, going to the next part, critical lane and time budget concept.

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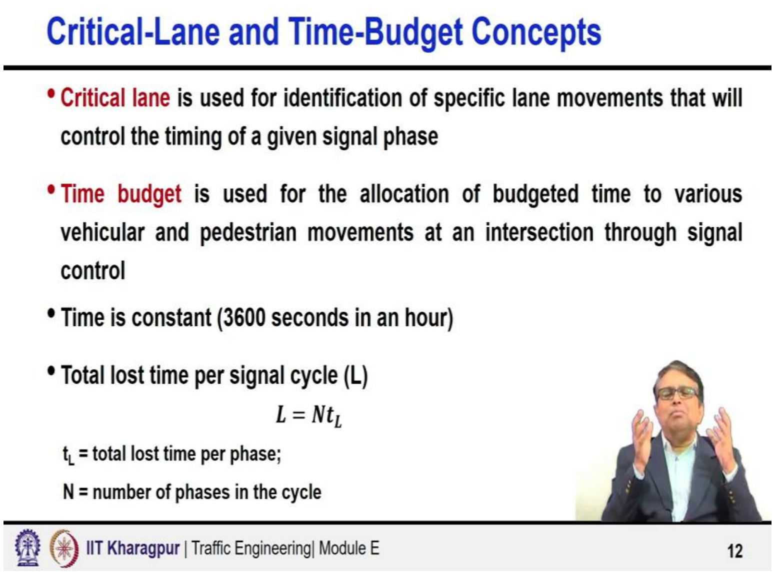

Now, two components we are talking, we are talking about critical lane and also we are telling about time budget. Critical lane is used to identify specific lane movements that will control the timings of a given signal phase. In one signal phase multiple movements are happening. So, we want to find out the critical lane that will control the timings of a given signal phase.

So, that means if the critical lane is served, then obviously all other lanes also will be served and timed budget, time budget is actually used for the allocation of budgeted time to various vehicular and pedestrian movements at an intersection through signal controller. What is the time budget? Because we have total time available per hour is 1 hour or 3600 seconds in an hour.

So, I have all what is available is 3600 seconds. Now, how this 3600 seconds we shall utilize for different things. Now, what is the total lost time per cycle, if there are a number of phases in a cycle and if small tL is the total loss time per phase. So, there are N phases in one cycle. So, per cycle what is the lost time? N into tL easy.

$$L = Nt_L$$

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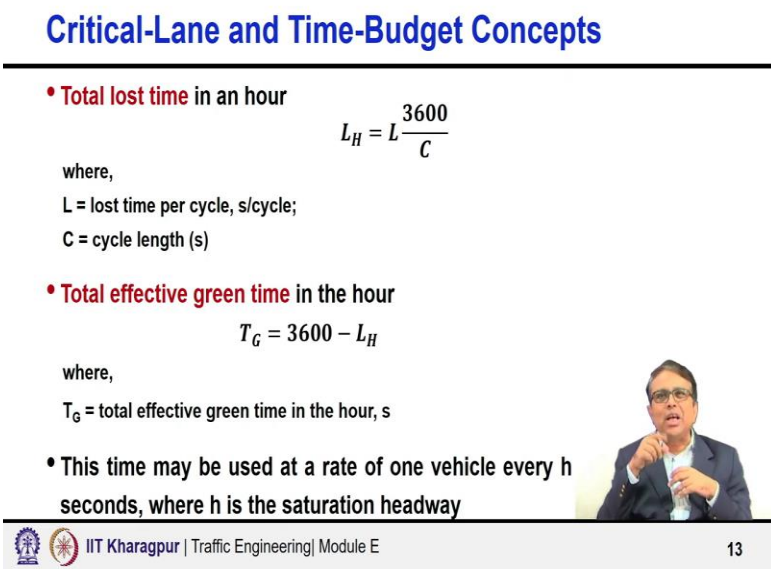

Then what is the total lost time in an hour? That is lost time per cycle multiplied by number of cycle in 1 hour. So, you have 3600 seconds and capital C is my cycle length. So, how many cycles are there? 3600 by C, each cycle what is the last time is L. So, then what is the total loss time per hour LH equal to L into 3600 by C.

$$L_H = L\frac{3600}{C}$$

Then total effective green time in an hour, how much is available then total green time? I have 3600 minus total loss time per hour is LH. So, it is 3600 minus LH. Now, this is the effective green time. So, how many vehicles I can process? It is simply at the rate of h saturation headway. So, this whole TG time maybe used at a rate of 1 vehicle per h second, where h is the saturation headway that much discharge I can do, I can handle, I can process that many vehicles.

$$T_G = 3600 - L_H$$

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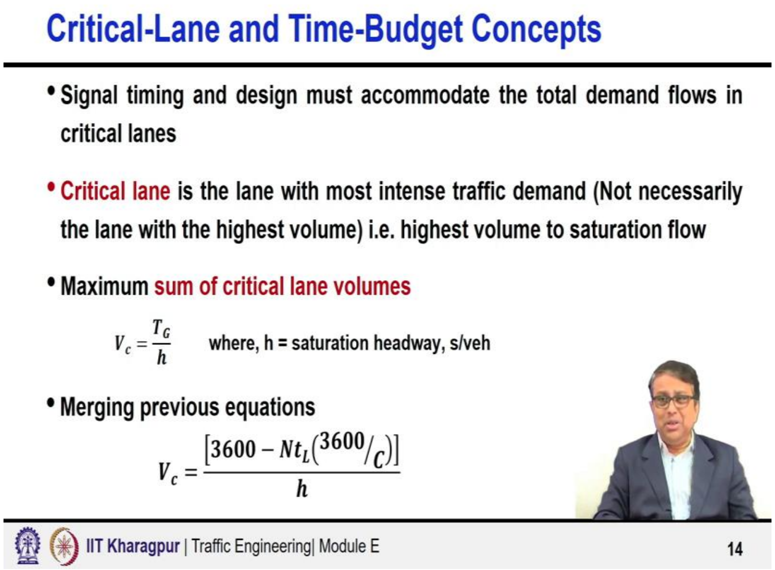

Now, signal timings and design must accommodate the total demand flows in critical lanes that is what is my basis. In every phase I should be able to handle the critical lane. So, critical lane is the lane with most intense traffic demand carefully observe it I am saying most intense traffic demand not necessarily the lane with the highest volume.

So, what on what basis we are identifying the critical lane? It is based on the highest volume to saturation flow. Why this? Because if all lanes are equal. Suppose all are single lane then I can compare only based on the traffic volume. Then highest volume is the critical one, the one which is having the highest volume will be the critical one.

But suppose some one of them is actually having 2 lane, then per lane traffic will be total by 2 and if it is so, I cannot simply compare the volume, but it is volume by saturation flow. So, highest volume to saturation flow that will be the critical lane. I shall also take an example to explain you further.

Now, whatever is this green time available effective green time TG, at the rate of h seconds per vehicle, so, how many vehicle I can handle? Vc, the critical vehicle volume or critical lane volume

TG by h. Now, if you take then VC equal to TG by h, what is TG? TG is 3600 minus LH. So, 3600 minus something, what is LH? LH is L into 3600 by C. So, L into 3600 by C and what is L? L is N into tL. So, with all the substitution, how much you get? You get that VC equal to actually 3600 into N into tL, within bracket 3600 by C the whole thing divided by h that is the critical volume that can be handled.

$$V_c = \frac{\left[3600 - Nt_L\left(3600/_C\right)\right]}{h}$$

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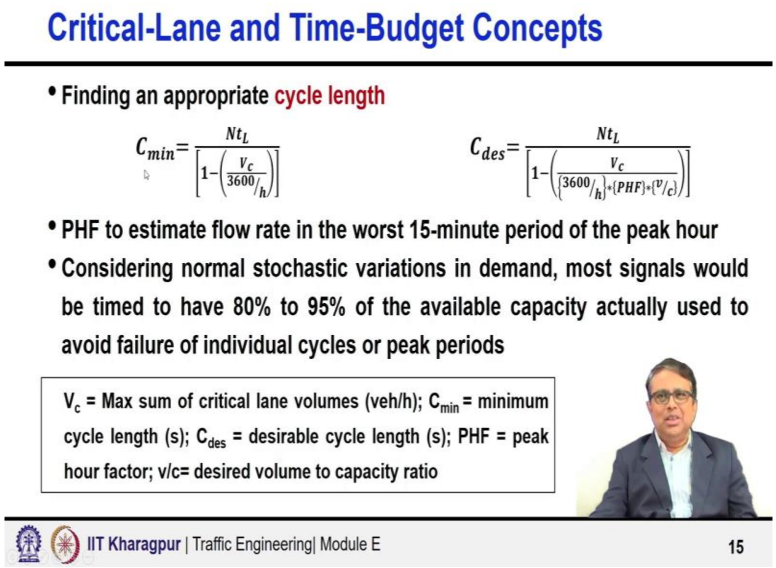

So, if this is the critical volume, then what is the minimum cycle length? Just from this equation only we can get. We can get here then what is C in terms of Vc, N, tL and h that is what exactly I have done it. So, that is the minimum cycle length required N as a function of N, tL critical volume and h.

$$C_{min} = \frac{Nt_L}{\left[1 - \left(\frac{V_c}{3600/_h}\right)\right]}$$

Now, this gives you the minimum cycle length. But when we are proposing we will propose something what we will call as design cycle length. Now, critical minimum cycle length to design cycle length two more additional considerations. First, we now bring here peak hour factor, why we are bringing the peak hour factor? Because, so, far you have considered hourly volume in the calculation.

$$C_{des} = \frac{Nt_L}{\left[1 - \left(\frac{V_c}{\left\{3600/h\right\} * \{PHF\} * \{v/c\}}\right)\right]}$$

But what we need to do, we need to consider peak 15 minute hourly flow rate rather than the hourly volume. So, peak hour factor is used introduced here to estimate the flow rate in the worst 15 minute period, worst in this sense is the maximum flow rate of the peak hour. So, that is why the peak hour factor is coming this is one change from the C minimum to C design.

The other consideration here you can see I have written here something called v by c ratio, what is the v, v by c ratio is the desired volume to capacity ratio, why this one? Because, if you consider just do not consider this thing, then how we shall consider the normal stochastic variation in demand.

Most signals would be time to have 80 percent to 95 percent of the available capacity not 100 percent of capacity. So, we do not use v by c as 1, which is there somewhere other in the C minimum calculation, why we do not use it? Because there will be normal stochastic variation in demand. So, if we consider it only 1, v by c as 1, then how we will handle this stochastic variation?

Because in that case, you are taking v by c as 1 but due to stochastic variation, there will be individual cycle failure and also multiple cycle failures or several cycle failures such such failure may happen during the peak periods. So, considering normal stochastic variation in demand most signals would be actually time to have 80 to 95 percent of the available capacity that means, it will be designed considering v by c as 0.8 to 0.95 so that the normal stochastic variation in demand in cycle to cycle can be handled properly to avoid failure of individual cycles or peak periods.

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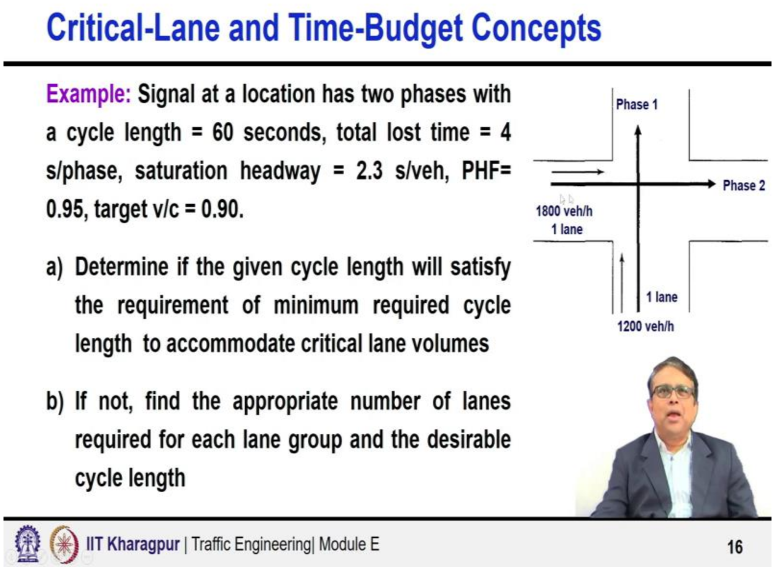

Now, let us take an example, signal at a location has two phases with a cycle length of 60 seconds a very simple one, a two phase signal. No other movements are allowed. So, the straight and this straight. So, one is that is eastbound another is the northbound and suppose, the cycle length is 60 second, somebody has proposed that okay let us use cycle length of 60 second.

Now, if the total lost time is 4 seconds per phase saturation headway is 2.3 seconds per vehicle and peak hour factor is 0.95 and target v by c is 0.9, I said there 80 to 95 percent. So, here it is considering say 0.9. Then what we want, we want two things here. First, determine if the given cycle length will satisfy the requirement of minimum required cycle length to accommodate critical volume. So, we want to see whether it is satisfying the requirement of minimum required cycle length C minimum whether it is satisfying or not. Second, if not find the appropriate number of lanes required for each lane group, and then what is the desirable cycle length?

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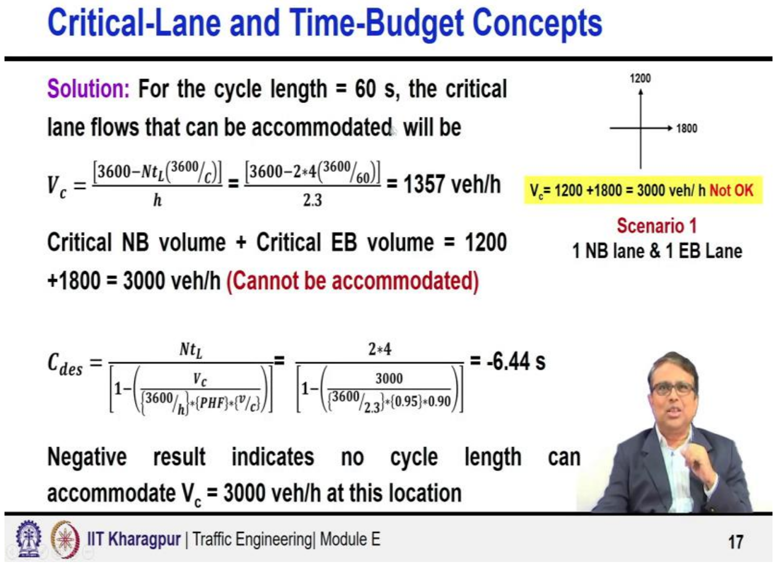

So, what we do first for the cycle length of 60 second the critical lane flows that can be accommodated we can calculate it Vc. How we are calculating? Let us, go back again to remind you this one TG by h essentially. So, here, based on that, we are calculating the value of Vc, how much critical volume that the intersection we will be able to handle given the cycle length giving the lost time, number of phase and saturation headway. So, that we are calculating and in this calculation, it is C minimum, we are not using the peak hour factor and target v by c value.

Because that those two will come when we will talk about Part B that is the desirable cycle length or design cycle length. So, here you can see V critical is 1357. So, that means, with that cycle length, if that is the minimum we considered, then we can maximum handle 1357 vehicle per hour.

Whereas, our present volumes are how much it was given here also reproduced here 1800 plus 1200, 3000 vehicle per hour. Whereas, with the given cycle length even if we considered the minimum required that as the minimum required cycle length then we can maximum handle 1357 vehicles. So, it will not work.

So, the critical northbound volume and critical eastbound volume together is 3000 vehicles higher than Vc. So, it cannot be accommodated the first question is answered. Then second what we are trying to do we are trying to see, let us see then if my critical volume is 3000 vehicle per hour. Then what will be my design or desirable cycle length? You calculate it you get a value negative minus 6.44.

What this negative value is indicating that no cycle length this cycle length you cannot get a cycle length which can accommodate this critical volume of 3000 vehicle per hour at this location with this many number of lanes and with this all other parameters saturation headway 2.3 seconds, total lost time 4 second phase, peak hour factor 0.95, target v by c as 0.9 with all these it cannot you cannot get a cycle length which will be able to accommodate this critical volume. So, now what we do?

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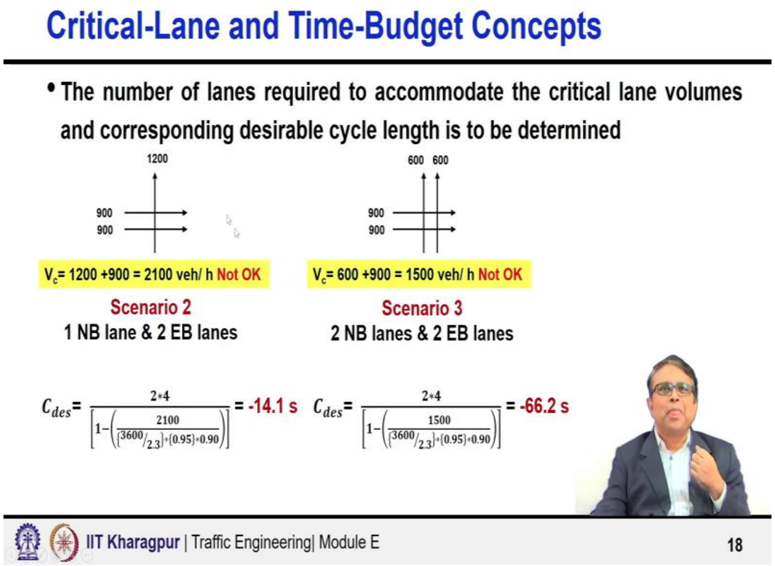

Let us, go step by step we know that the maximum volume here it was eastbound which is 1800 maximum. So, we say instead of 1 lane should we have 2 lane there. Let us try with that. So, if we give 2 lane then each lane will have 900 volume then what will be the critical volume 2100 vehicle per hour. Le us, try to calculate again the C design or desirable cycle length can we get, what we get still it is negative indicating still it is not working fine.

Next we thought that okay let us try we made there is 2 lane the other movement also let us have 2 lane. So, the 1200 also will get distributed to 600, 600. Now there will be 2 lane. So, now with 2 northbound lane and 2 eastbound lane, what will be my critical volume? Critical volume will be 1500 vehicle per hour with that again calculate C design still it is minus 66.2.

So, the desirable cycle length still we are not getting it is still showing still the even if with 2 lanes on the northbound 2 lane in the eastbound with all other things and the given traffic volume. We cannot get a signal cycle design signal cycle or desirable cycle length which can handle this traffic at this intersection.

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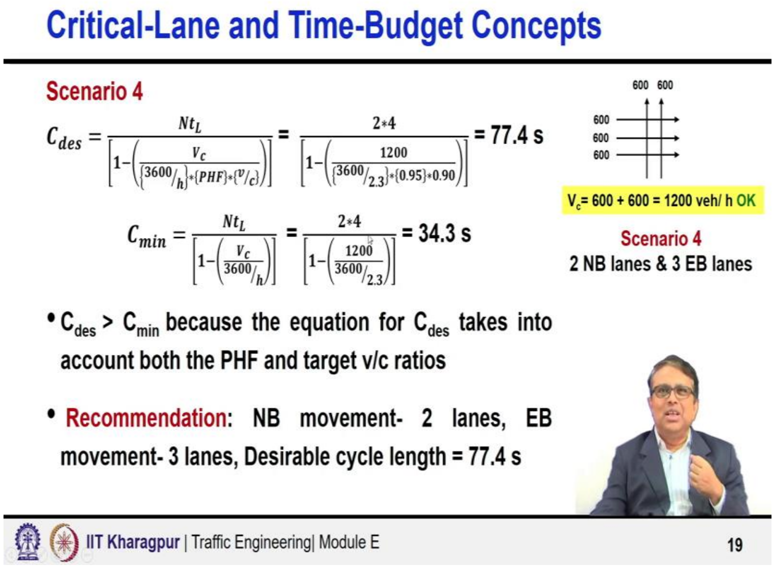

Go for further trial. Here, we consider 2 lane, northbound and 3 lane eastbound. Then what is happening? 1800 divided by 3 lane 600, northbound 1200 divided into 2 lanes 600 in each. So, my critical volume becomes 1200 vehicle per hour. Now, let us see what happens. Now we when we calculate C design or desirable. We get the cycle length as 77.4 positive value and we are able to get it.

So, that means it will work. I also wanted to calculate here the C minimum and you know with this configuration that means 2 northbound lane and 3 eastbound lane your total minimum cycle length will become 34.3. You can clearly see that the desirable cycle length when you consider the peak hour factor and v by c ratio lower than 1. Then your actually desirable cycle length will be much higher. So, the well the minimum cycle length requirement is 34.3 the desirable cycle length is 77.4.

So, altogether what it shows. C design is greater than C minimum because of the equation C design takes it into account both the peak hour factor and target v by c ratio and how for what is going to be our recommendation from this one. That okay, you widen the northbound movement, widen it to 2 lane and eastbound movement to 3 lane accommodate this eastbound in 3 lane accommodate northbound movement in 2 lane have a desirable cycle length of 77.4 seconds or 75 78 seconds, that is what is our recommendation.

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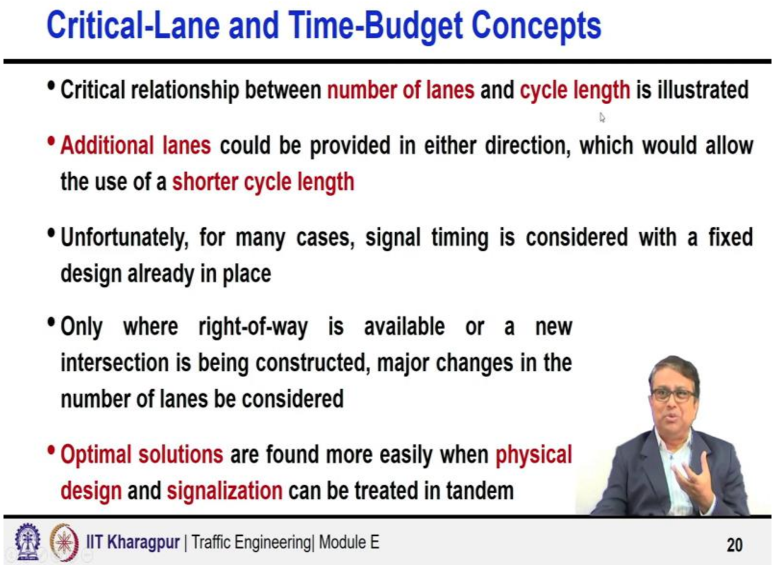

We see a few important observations here critical relationship between the number of lanes and cycle length is illustrated. Because if you are increasing the number of lanes in the approach, then your traffic is actually demand is getting distributed. So, the critical volume that the signal has to handle that becomes very different and easy.

Additional lanes can could be provided in either direction, which would allow use of a shorter cycle length. Unfortunately, in many cases, signal timing is considered with a fixed design already in practice and only where right of way is available most urban areas you do not get land, where is your land? So, you cannot really widen but if you can widen, you can handle larger volume of traffic.

So, only where right of way is available or a new intersection being constructed major changes in the number of lane can be considered. Otherwise what I have shown here, make it 3 lane make it 2 lane, this may not be possible in reality in all the cases that is a constraint. And finally, the optimal solutions are found more easily when physical design and signalization both are treated together.

So that is one very important. Wherever there will be an opportunity the physical design physical infrastructure intervention and signalization together can produce better results. Of course, always it may not be possible to have physical design changes or physical infrastructural intervention in that sense.

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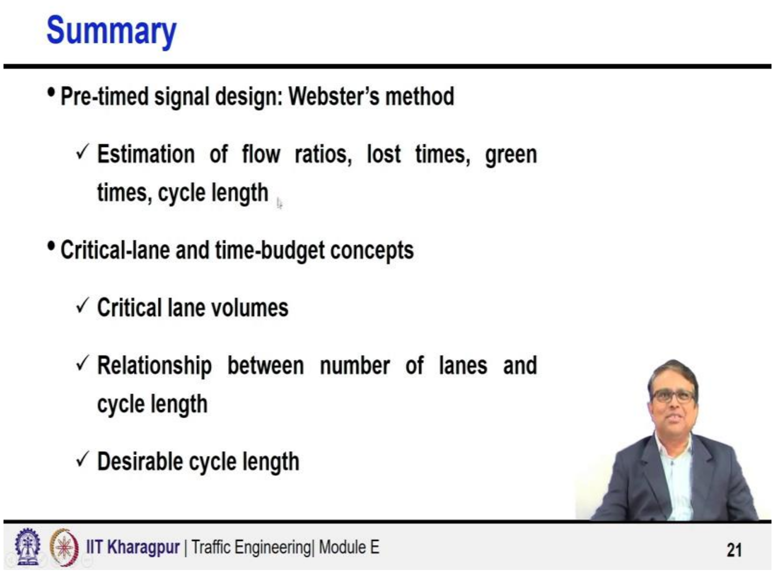

So, altogether, we discussed here about the pre timed signal design using the Webster's method shown that discussed with you about the estimation of flow ratios, lost time, green time, calculation of cycle length all this. Then the concept of critical lane and also the concept of time budget, how to calculate the critical lane volumes, relationship between number of N lanes and the cycle lengths how the whole thing can change and how you can calculate the desirable cycling, with this, I close this lecture. Thank you so much.