Traffic Engineering
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Lecture 34
Pre-Timed Signal Design - II

Welcome to module E, lecture 8. In this lecture, we shall continue our discussion about pre-timed signal design.

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In lecture 7, I mentioned to you about Webster's method for design of pre-time signal estimation of flow ratios, lost time, calculation of green times and cycle length also mentioned to you how to identify critical lane and what is really the time budget concept and how it can be applied to get the minimum required cycle length and also that desirable cycle length. The difference between the minimum cycle length and the additional considerations for getting the desirable cycle length.
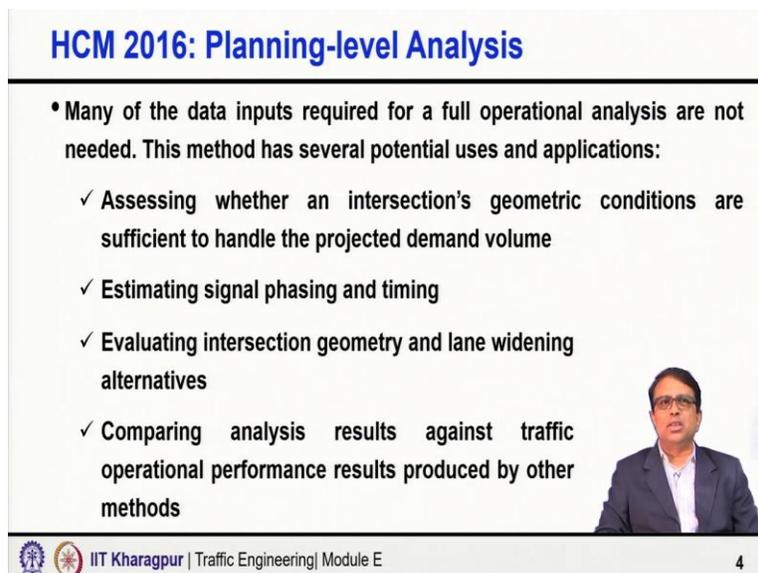
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Now, today, we shall focus entirely on planning level analysis and of course, the design of signals following highway capacity manual 2016 approach. So, this is planning level analysis. Subsequently, we shall have several lectures to cover operational level analysis.

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The planning level analysis many data inputs which are actually required for full operational level analysis are not needed in this case relatively simple and this has several potential uses and applications. For example, assessing an intersections geometric conditions whether those are sufficient to handle the projected or forecast traffic volume. Also for estimating signal phasing and

timings, evaluation of intersection geometry and lane widening alternatives and also for comparing analysis results against traffic operational performance results produced by different data methods.

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Now, this planning level analysis is carried out primarily in two parts. So, if I come to methodology, I should tell you the steps which are followed for part 1 and part 2. In part 1, what we try to do is intersection sufficiency assessment. The second part once that is done the second part is on delay and level of service analysis.

What do we do in the first part? The step one is determination of right turn operation as you understand by this time that it could be permitted or protected right turns. So, how to take a call and we need to take a call first at this stage. Second convert movement volumes to through passenger car equivalent. Because you know there are left turning movements, right turning movements also you have presence of commercial vehicles or heavy vehicles then several other things which are important and based on with the connections are to be applied.

So, equivalent factors are to be used to convert the traffic volume what you have obtained to equivalent through passenger car movement equivalent through passenger car movement. So, all movements will be converted duly considering all the necessary correction factors I shall discuss in details in today's lecture only. And then we get the equivalent through passenger car volumes. Then we have to assign flow rates to lane groups. Here in a simplified way, the lane group and

movement group concepts we will use. In fact, the lane groups will be taken similar to movement groups for this simple type of analysis.

Then, the next step includes determination of critical lane groups that means identify critical lane groups and calculate the sum of critical flow rates. There are multiple phases which will be there in a signal design. So, in each phase we have to consider identify the critical lane groups and thereby, subsequently we have to calculate the sum of critical lane flow rates.

Then in step 5, we will do assessment of intersection sufficiency that is one approach and here listen carefully, that there are two ways we can do, one we can do we can assume a cycle length and then check how the design has come up in form of assessing the intersection sufficiency. That means, what is the intersection capacity and compared to that how we have designed our signals or how much loading is actually coming, what is the volume to capacity ratio based on that the intersection sufficiency as well.

Or alternatively what we can do, we can actually decide the target v by c ratio, how much loading we can do at what v by c we want the intersections to operate. So, the target v by c we can decide first and accordingly decide the design the cycle, cycle length, phasing, everything can be decided.

So, once we are targeting or designing with respect to a target v by c ratio, that means, we are targeting in a way the intersection sufficiency. We know what intersection sufficiency we want. So, accordingly we are designing the cycle that is the estimate cycle length that part or the first one as I said we assume cycle length and then we check what or how the cycle length is working for a given or expected to work for a given intersection.

And with what volume to capacity ratio, how much loading we are doing that is in a way the intersection sufficiency. So, either we can assume a cycle length and check the intersection sufficiency or we can decide a priori target a particular volume to capacity ratio that is relates to intersection sufficiency only and we can accordingly estimate the cycle length in that way.

So, both are possible. Then, in part 2, once that is done, the next part of analysis relates to delay and level of service. So, in step 6 we calculate effective green times and then once the effective green time is known with all other relevant parameters, we can calculate the capacity and again volume to capacity ratios and finally, determine the delay that is the control delay I introduced this

concept of control delay in my earlier lecture and then calculate also the level of service. So, that is the part 1 and part 2.

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Now, there are various input datas that are required in the process of this planning level analysis. I have mentioned here what all data items are required in part 1 and part 2 also given the comments that how and what is the real use of that, how we can get that or whether in can some case we can estimate it.

So, I will not read these items, each and every item in details, but generally say what are the kinds of inputs we required, they may include the number of lanes and lane use, the turn movement volumes, the intersection peak hour factor, what is the percentage of heavy vehicle, on street parking present.

Now, these are all the thing see intersection peak hour factor, percentage heavy vehicle, on street parking, level of pedestrian activity all these will be used eventually to convert movement volumes to through passenger car equivalent all this will be used. Then right turn operation and phase sequence. This is also to be decided and you know some of the inputs, traffic volume and other things will be used.

Then the base saturation flow rate, this can also be estimated cycle length can be estimated or even maybe assumed as I told there are two alternative methods go back here, as I said in 5 case, assess intersection sufficient to based on assumed cycle length, in that case cycle length is an input or

estimate cycle length, in that case we have a target v by c ratio and accordingly we calculate the cycle length. Similarly, for part 2 the effective green time, progression quality, these are the inputs that are used.

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Now, to explain each of the things in more details or each step in more details, let us go through an example. So, we shall explain you each and every step through this example problem and it will be very clear to you. Let us, take this example. This figure shows the intersection of two four lane arterials with significant demand volumes and an exclusive right turn lane provided on each approach as an additional lane.

So, let us take this figure which shows the intersection of two four lane arterials with sufficient are significant demand volumes and an exclusive right turn lane. That means, you can see it is basically 2 plus 2 four lane on each approach divided road, two lane each side, but they are intersection we have an additional lane for right turn and that is an exclusive lane.

So, you can see here each case the left lane left and through movements that is catered and then middle lane only through movement and the right lane exclusive lane for right turning movement. Now, here various inputs are given, peak hour factor, target v by c ratio, heavy vehicle on each approach, what is the start-up loss time, what is the end gain time all this terminology is unknown to you I have already discussed about all these. Then pedestrian volume on each approach this will

again determine the equivalency, then or why even the permitted or protected or permitted turn that will be decided based on this and what is the lost time per phase.

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So, with all this and data and with the given traffic volume and for the given intersection, what do you want now, the first step for this planning level analysis is to determine the right turn operation that means, we have to take a decision whether we shall go ahead with protected movement or permitted movement for the right turn.

Now, there are three conditions which are given in highway capacity manual any one of the following conditions are met that means, we have to go for protected operations and if none of this condition is satisfied, in that case, we can go ahead with permitted operation. What is the first condition? Right turning volume greater than 240 vehicle per hour, right turning volume multiplied by opposing through movement flow product of that, right turning movement and opposing through movement the product of that 50,000 should be greater than 50,000 for one opposing lane.

If there are two opposing lane,, then 90,000. If there are 3 or more, then 110,000, that is the condition 2. Condition 3 is there is more than one right turning lane as in condition 2 we have we mentioned to you different threshold values depending on the number of through lane or opposing lane.

Condition 3, there are more than one there is more than one right turning lane. So, if there are there is there are two lanes or more than that, then anyhow we have to go for protected operation. So,

this is another condition there is more than one right turn lane. So, based on these we can decide or take a call if we can go ahead with protected operation or permitted operation.

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So, let us go ahead with this example problem. So, here for each approach in the right side I have again reproduced the turning volumes through left turning, straight all volumes are given. For each approach we are now saying what is the right turning volume. Say if I take eastbound approach, the right turning volume is 25 that is written here. For the westbound volume, 35 you can say this is the right turn volume 35.

For southbound approach, right turning volume is 250. For the northbound approach, the right turning volume is 220. So, what was the first condition that RT VRT volume of right turning traffic should be greater than 240. So, only in one case, which is shown in red, this condition is satisfied, that means based on the right turning traffic volume only, we know that we need protected operation for southbound approach.

For all other is fine can be permitted as per this condition. Second VRT into VO greater than 90,000. Since, it is a two opposing lane. So, through movement is happening through two lanes. So, accordingly here we have taken 90,000 for two opposing lanes. So, with 90,000 we have now multiplied so, say for eastbound traffic 25 and what is the through volume.

So, this is the 25 and what is the through volume from the opposite direction it is 610. So, 25 into 610. Similarly, westbound approach right turning volume is 35 and what is the through volume

500. So, 35 into 500. Like that we calculated and here we find both southbound and northbound approaches the values are actually higher than the threshold values, indicating that for both these approaches, we need actually protected movement protected right turn.

And then in terms of number of right turn lanes in all these all the approaches you have only 1. So, as per right turn number of right turn lane, we do not need actually protected operation, but then southbound as per the first criteria and south and north both as per condition two, we need protected turns.

So, what we decide or conclude that we need right turn and movements of both northbound and southbound requires protection. Therefore, exclusive therefore, exclusive right turn phase on north south arterial both for northbound approach and southbound approach. So, we said north south arterial may be provided.

And in other cases, since the, we do not need any protection or protected moments. So, they may be permitted. One more interesting thing here as you can see here 175,000 and 176,000. So, actually the indicate that the turning volumes in northbound and southbound approaches are somewhat similar. So, similar green time may be provided for both right turning moments. Because the volumes are very similar.

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So, considering all these, we actually now decided the signal phase plan. So, what we give we give an exclusive right turn phase A for northbound and southbound then other movements straight and

left, left, why is shared left? Because pedestrians are there. So, the traffic has to yield to pedestrians so that why it is shown in dotted line rather than a solid line. And for east west movement, we need only phase.

So that straight left right from each west west west and eastbound approach we can use a single phase. So, phase C is for east west arterial both for eastbound approach and westbound approach and here the dotted line for right turn, why dotted? Because they are actually permitted. In the phase 1, it is protected so solid line and here it is dotted line because it is permitted.

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Now next step 2, conversion of volume to through vehicle equivalent volume as a mentioned earlier also. So, now a number of corrections are to be considered in terms of equivalency factor. So, to account for say effect of heavy vehicles variation in the flow during the hour that means, so far we have taken hourly volume, but we want to consider peak 15-minute hourly flow rate.

So, the peak hour factor will come into picture impact of opposing through vehicle on permitted right turn vehicles. So, higher the vehicles the right turn equivalence will be higher impact of the pedestrians on left turn vehicles. If pedestrians are there, then again the left turn equivalence will be higher. Impact of parking maneuvers, if parking is there again it is, the factor will be equivalency factor will be more than one.

Lane utilization, what is the lane utilization? If there are two or more lanes, then volume on each lane may not be exactly same. So, volume is adjusted to reflect the performance of the heaviest travel lane. So, some equivalency is also used not exact same per lane, but using the lane utilization corrections or equivalency to adjust the volume and reflect the performance of the heaviest travel lane. Because equally utilization may not happen. There are also other factors for which we can apply equivalence factors to take into account the lane width, the bus blockage, the work zone and such factors.

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Now, adjusted volume then will be the movement volume what we have calculated so, far since so, far, multiplied by EHV into EPHF into ELT into ERT into EP into ELU into E other indicating that these are equivalency factor accounting for different factors such as heavy vehicle, parking characteristics, right turning lane or right turns, left turns, parking activity, lane utilization and other factors.

$$v_{adj} = V E_{HV} E_{PHF} E_{LT} E_{RT} E_p E_{LU} E_{other}$$

Now, highway capacity manual provides corrections how and what corrections to be applied. See for example, adjustment of heavy vehicle you can use this formula it is a function of EHV is nothing but proportion of heavy vehicle and the value of ET that means equivalent number of cars for each heavy vehicle as per highway capacity manual you can take 2 or even you can take a specific other value as well.

$$E_{HV} = 1 + 0.01P_{HV}(E_T - 1)$$

Then adjustment for variation in the flow during an hour or during the hour as we said that we want to consider the peak 15 minute hourly low rate. So, here the equivalency is 1 by PHF and the PHF peak hour factor may vary between 0.25 to 1

$$E_{HV} = \frac{1}{PHF}$$

HCM 2016: Planning-level Analysis

Adjustment for Right and Left Turning Vehicles

Equivalency Factor for Right Turns, E_{RT}

Right-Turn Operation	Total Opposing Volume V_o (veh/n)*	Equivalency Factor
Protected right-turn phase	Any	1.05
Protected-split phase		
Permitted right-turn phase	<200	1.1
	200-599	2.0
	600-799	3.0
	800-799	4.0
	≥ 1000	5.0
Protected-permitted right-turn phase	Refer to HCM 2016	

*Includes the sum of through and left-turn volumes on the opposing approach, regardless of whether the left-turn volume is served in an exclusive left-turn lane

Equivalency Factor for Left Turns, E_{LT}

Level of Pedestrian Activity (p/h)	E_{LT}
None or low (0-199)	1.2
Moderate (200-399)	1.3
High (400-799)	1.5
Extreme (≥800)	2.1

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Then adjustment of right and left turning vehicles equivalency factor we are giving. Now for right turn operation it depends on several factors. For example, protected right turn phase or protected split phase for all conditions the value is 1.05. But permitted right turn phase it depends on what is the total opposite traffic volume, because the vehicle is taking right turn against the opposing volume.

Now, interestingly here I have written in the note below the opposing volume includes sum of through and left volumes both, sum of through and left volumes on the opposing approach. Now different values higher the values higher will be the equivalency factor. So, it may vary from 1.1 may go up to 5 if the total opposing vehicle volume is more than 1000. There is significant interference in that case.

So, the equivalence will be higher. Similarly, the equivalency for left turn lanes are also given depending on the here traffic has to yield to the pedestrian volumes or to the pedestrians. So, the pedestrian volumes are higher means higher will be then the equivalency for the left turn vehicles. So, you can see if suppose, 0 to 199 pedestrians per hour, then it is 1.2 as it goes from 200 to 399 1.3, 400 to 799 1.5 and greater than 800 2.1. So, these factors are also there.

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HCM 2016: Planning-level Analysis

Equivalency Factor for Lane Utilization

Movement	No. of Lanes in lane group	E_{LU}
Through or Shared	1	1.00
	2	1.05
	≥ 3	1.10
Exclusive Right Turn	1	1.00
	≥ 2	1.03
Exclusive Left Turn	1	1.00
	≥ 2	1.13

Equivalency Factor for Parking Activity

On-Street Parking Presence	No. of Lanes in lane group	E_p
No	All	1.00
Yes	1	1.20
	2	1.10
	3	1.05

Adjustment for "Other" Conditions (E_{other})

✓ This factor allows to further adjust the movement volume for conditions that are not captured by any other adjustment factor

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Then equivalency factor for lane utilization I explained already, why we consider it, because we want to consider the heavily loaded lane and then it need not be just 50-50 distribution in case of two lane or equal distribution in case of multi lane. So, the through or shared lane, if it is one lane obviously, there is no question of sharing. So, it is 1, 2 lane 1.05 greater than 3 1.1, exclusive right turn again the values are given exclusive left turn again the values are given. So, depending on what is the type of movement and what is how many number of lanes are there in the lane group accordingly equivalency factor.

Same way the correction factors or equivalency factors are given for the parking activity, when there is no parking activity, it is always 1, the same value will be there. And parking level activities there, then the number of lanes in the lane group depending on that and here it is reverse. As the number of lane in the lane group is increasing, the equivalency factor becoming lower. Because as you saw there are multi lane, so, not all lanes will be affected by parking.

So, that is why if it is a single lane, obviously, it is worst affected, if there are 2 lanes, the second lane which is on the inner side not adjacent to the parking lane will not to be affected so much. So, the overall equivalency is lower. If there are 3 lanes then only 1 lane adjacent to parking will be affected more. So, the equivalency factor is even lower. And similarly, there are other conditions are there and which we are not considering in this case.

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Conversion of Movement Volumes to Through Vehicle Equivalents

Approach	Movement	Volume (pc/h)	E_{HV}	E_{PHF}	E_{RT}	E_{LT}	E_p	E_{LU}	E_{other}	v_{adj} (tpc/h)
EB	LT	50	1.03	1.09	1.00	1.30	1.00	1.05	1.00	76
	TH	500	1.03	1.09	1.00	1.00	1.00	1.05	1.00	588
	RT	25	1.03	1.09	3.00	1.00	1.00	1.00	1.00	84
WB	LT	70	1.03	1.09	1.00	1.30	1.00	1.05	1.00	107
	TH	610	1.03	1.09	1.00	1.00	1.00	1.05	1.00	717
	RT	35	1.03	1.09	2.00	1.00	1.00	1.00	1.00	78
SB	LT	175	1.03	1.09	1.00	1.30	1.00	1.05	1.00	267
	TH	800	1.03	1.09	1.00	1.00	1.00	1.05	1.00	940
	RT	250	1.03	1.09	1.05	1.00	1.00	1.00	1.00	294
NB	LT	185	1.03	1.09	1.00	1.30	1.00	1.05	1.00	283
	TH	700	1.03	1.09	1.00	1.00	1.00	1.05	1.00	823
	RT	220	1.03	1.09	1.05	1.00	1.00	1.00	1.00	259

Calculation for EB-LT:

$$v_{adj} = V\,E_{HV}\,E_{PHF}\,E_{LT}\,E_{RT}\,E_p\,E_{LU}\,E_{other}$$

$= 50*1.03*1.09*1.00*1.30*1.00*1.05*1.00$

$= 76\ tpc/h$

So, considering all these factors, the way I have explained for each approach, each movement, we want know the base volume, what is the actual hourly volume that we have taken. So, the first three columns are known. Now, we are calculating this factor EHV, EPHF, ERT, ELT, EP, ELU like that and then we are multiplying this volume with all the factors or the equivalency values to get the equivalent flow rate through vehicle equivalent. So, I have shown here one calculation say for the first case eastbound approach left turning 50 into 1.03 into 1.09 into 1 into 1.3 into 1 into 1.05 into 1. So, you get 76 the same way all calculations are made.

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Step 3: Define Lane Groups & Assign Flow Rates to Lane Groups

- For simplicity, lane groups are assumed same as movement groups

  ✓ **Exclusive turning lanes**: Left-turn only or right-turn only lanes are separate lane group(s)

  ✓ All **remaining lanes are combined**, including all through-only lanes and shared lanes (mixed lane group)

- Note: Shared lane may be considered as exclusive turn lane when the turning flow rate is high or impeded by the opposing movement

Now, third is defined lane groups and assign flow rate to lane groups. Here for simplicity, the lane groups are assumed same as the movement groups. I would like to remind you that I have discussed this concept of lane group and movement groups earlier. So, I hope you remember and you could connect it well.

Now, as I said earlier in the beginning there are one thing is exclusive. So, what we are doing here exclusive turning lanes. So, left hand only or right turn only lanes are separately and group and all remaining lanes are combined including all through lanes and shared lanes which are in the mix lane group. That way the lane grouping is done actually.

Now, here I must mention that the shared lane may be considered as exclusive turn lane it will be considered as exclusive turn when the turning flow rate is high or impeded by the opposing movement. In that case, you have to consider even the turning flow rate the shared lane also may be considered as exclusive turn lane.

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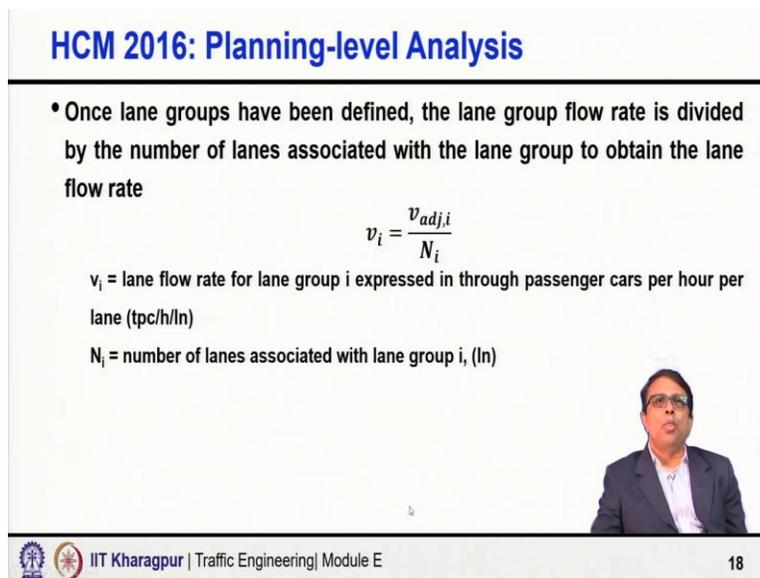
Now, once the lane groups have been defined, the lane group flow rate is divided by the number of lanes associated with the lane group. So, you know that what is that adjusted volume divided by number of lanes in the lane group so you get actually lane flow rate for group i expressed in through passenger car per hour per lane.

$$v_i = \frac{v_{adj,i}}{N_i}$$
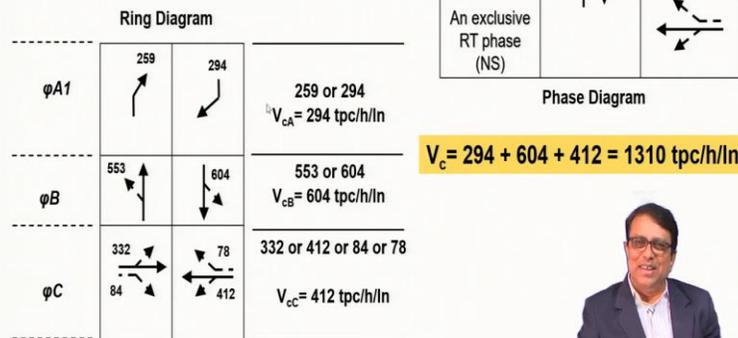
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Now we apply that. So, we have we know the approaches what are the movement, what is that adjusted vehicle volume, how we get that adjusted vehicle volume? It is that last column. So, this column we have taken now. So, we know that adjusted volumes and then the lane group accordingly is defined.

So, through and left turn lane for eastbound through and left lane and right lane, each cases for westbound through and left turn lane right lane southbound northbound in the similar manner and then these are the number of lanes right turning lanes always we have 1 lane and through and left we have 2 lanes. So, what is the total lane group volume and then accordingly what is then the volume per lane for this lane group. Fine?

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HCM 2016: Planning-level Analysis

Step 4: Determine Critical Lane Groups

Ring Diagram

φA1 — 259 or 294, $V_{cA} = 294$ tpc/h/ln

φB — 553 or 604, $V_{cB} = 604$ tpc/h/ln

φC — 332 or 412 or 84 or 78, $V_{cC} = 412$ tpc/h/ln

An exclusive RT phase (NS)

Phase Diagram

$V_c = 294 + 604 + 412 = 1310$ tpc/h/ln

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So, once we have done that, then we can determine in step 4 the critical lane group, how to identify the critical flow? Again, I have discussed it earlier. So, for example, phase A we have two right turn lane group one is 259 and other is 294. So, higher of these two is 294. So, VcA the critical volume is 294. In phase B, you have 553 and 604 lane group volumes.

So, which one is critical 604 and in phase C we have eastbound and westbound movement in each case straight and left shared and permitted right from the exclusive lane. So, we have 2 plus 2 4 values out of this for four 412 is the maximum. So, what is the total then critical volume? Critical volume is total critical volume is critical volume for phase 1 critical volume for phase 2 and critical volume for phase 3. So, 1310 tpc per hour per lane through volume we are considering equivalent through volume per hour per lane.

Then, next is step 5 is assess intersection sufficiency or estimate cycle length. I told you already there are two approaches here the first approach we can assume a cycle length and as far as highway capacity manual, we can assume 30 seconds for each critical phase. And then finally, we can judge the intersection sufficiency in terms of, what is then the volume to capacity ratio and how compared to capacity, we have designed the signal system, or we can actually estimate the cycle length for the target v by c ratio. Once I am saying target v by c ratio I know then what intersection sufficiency I am actually trying to achieve. Because intersection sufficiency will depend on what is the v by c ratio.

So, first case assumed cycle length and then you check what is then the v by c ratio and accordingly judge the intersection sufficiency. In the second case, you actually first target have a target v by c ratio. So, you know what intersection sufficiency were trying to achieve and accordingly estimate the cycle length. First first approach that is approach 1. Here we calculate the cycle length as I say 30 seconds for each critical phase and this is 3 phase signal. So, total cycle length is 90 second.

Once we have calculated the 90 second then next step is to calculate the intersection capacity and volume to capacity ratio. So, how we collect the, calculate the intersection capacity, the intersection capacity is saturation flow multiplied by effective green time. What is effective green time? Cycle time minus total loss time. So, how many phases are there and what is the last time per phases?

$$c_I = s_o \frac{C - (n_{cp}l_t)}{C}$$

So, accordingly you can calculate the capacity and once you have capacity is known and we know what is our critical volume and what is the capacity. So, we can calculate Xc which is nothing but critical intersection volume to capacity ratio, this eventually will be used to judge the intersection sufficiency.

$$X_c = \frac{V_c}{c_I}$$

So, for the given example, our saturation flow is 1900 no adjustment to be done in the saturation flow because the volume itself we have adjusted. So, 1900 into cycle length 90 seconds, there are three phases each phase lost time is 4 seconds. So, accordingly you calculate the capacity and you can calculate the, what is the value of Xc that is the volume to capacity ratio and you know it is 0.8.

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So now, HCM provides a table for different Xc values, what is the conclusion? Now, the conclusion is what actually because, what we are trying to judge? We are trying to judge whether an intersection is operating under, near, or over its available capacity. So, clearly anything below 0.85 means the intersection is operating under its available capacity.

If it is near, that is what we want and overall so is problematic, we do not want that. So, you can judge, then if it is not up to your satisfaction that means, if it is under or over, what we can do? We can go for a different trial of cycle length. Which were modify? You will understand from the subsequent slides.

Now, going to approach 2, here we are targeting v by c and accordingly designing the cycle length. So, step 1 is compute a flow ratio and identifying the critical flow ratio from the lane groups serve, during a common phase as usual. Then in step b if signals-system constraints do not dictate the dictate the cycle length. If signal system constraints do not dictate the cycle length that means, suppose if you are doing a coordination obviously, your cycle length determination will be dictated by the requirement of coordination because you need common cycle length.

$$C = \frac{LX_c}{X_c - \sum_i y_i}$$

So, such kind of things are not there, if such kind of things are not there, then you can estimate the minimum cycle length using this formula as it is giving by setting Xc equal to 1 or by substituting a target Xt for the critical ratio Xc that means, I can assume Xc as 1 and as you have seen here that Xc always need not be 1 we can target a different value also. So, either you can take 1, in that case v by c ratio will be 1 that is your target value, or you can assume as per your requirement what you want accordingly you can assume a Xc value that you can target.

So, here in this case, we can target something, then the Xc will not be 1 Xc will be equal to Xt and Xt value will be that target v by c value. Now, I have also shown the Webster equation here just to indicate that this cycle length calculation and Webster calculation, some there are some kind of similarities. It is not exactly same, but some similarities is there.

For example, here even you take Xc as 1, then it is simple L total last time whereas, it is 1.5 L plus 5 and here it is 1 minus sum over Yi which is very similar to here whatever is written. But it will be different if you consider Xc different take your Xt values that means what is the target volume to capacity values.

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Now, coming back to this same example problem following this approach, we know approach wise what are the lane groups and we know in which phase we are operating which lane group. So, the number of lanes are also known, lane group volumes are known. So, lane group volumes are known so per lane volume also we can calculate and accordingly we can also calculate the Yi.

How we are calculating? I have shown here suppose it is 664 and then there are 2 lanes. So, 664 divided by 2 into 1900 is the saturation flow. So, we get 0.175 similarly, here you get 0.044. So, like that for all other we can calculate. Now, we have to identify the critical volume for each phase.

Now, if you consider phase A, then it is a comparison between 0.155 and 0.136. Which one is higher? 0.155 is higher. So, 155 is selected 0.155 is selected. Similarly, for phase B, it is a choice between 0.318 and 0.291. So, obviously 0.318 is selected and in phase C it is a choice among these 4 lane groups moment volume. So, 0.175, 0.04, 0.217, 0.041. So, you have picked up 0.217.

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Cycle Length Calculation

- Target v/c ratio (X_t) is given as 0.92, therefore replacing X_c with X_t

$$C = \frac{LX_t}{X_t - \sum_i y_{c,i}}$$

Total lost time = Number of critical phases x Lost time/phase

$$= 3 \times 4 = 12\ s$$

$$C = \frac{12 * 0.92}{0.92 - (0.217 + 0.318 + 0.155)} = 48\ s$$

$$C_{min} = \frac{12 * 1}{1 - (0.217 + 0.318 + 0.155)} = 38.7\ s$$

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So, what is then the cycle length? How we can calculate? We know that our target volume to capacity ratio is 0.92 that is what is the target value taken for this example calculation. You can select a different value also. So, with the target value of 0.92, then now we will replace Xc with Xt, and what is the Xt? Xt value is 0.92. What will be when it will be Xc that means it is 1.

$$C = \frac{LX_t}{X_t - \sum_i y_{c,i}}$$

Any other target if we have then that will be Xt considered as Xt and it will be taken an appropriate value. In this case we have taken it 0.92. So, now, the total last time 3 phases 4 seconds is 12 second lost time and you can calculate the C value cycle length using which formula as I have shown here, this is the formula that we have used.

So, Xc is replaced by Xt and taken as 0.92. So, you get a cycle length of 48 seconds. I wanted to show you that if you take the value as instead of 0.92 1, then whatever cycle length you will get it will be lower because you are actually accepting you are considering the signal to operate with volume to capacity ratio 1. So, you will have minimum cycle length, but then what is the problem that again has been discussed earlier that if we designed it with volume to capacity ratio 1, what will be our problems? Remember our discussion about the lecture on delay, there, we mentioned it.

Now, once we are done, then go to step 6 the next part here we calculate effective and actual green time this is very easy, what is the total then effective green time is the cycle length minus the lost time. So, that is the effective green, how we will distribute it to each phase according to the critical volume the Vci divided by Vc.

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

$$g_i = g_{TOT} * \left(v_{ci} / V_c \right) \quad \& \quad G_i = g_i - Y_i + t_{Li}$$

So, Vci we know, Vc also can be calculated some of that. So, accordingly the you distribute the green time and once you have you know the, what is the effective green time for a phase, then the actual green time for that phase will be effective green time minus yellow time for that phase plus the total lost time for that phase. So, you can calculate the overall green time.

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Effective Green Times (As per Approach (i) in step 5)

$g_{TOT} = C - L = 90 - 12 = 78 \text{ s}$

$g_A = 78 * (^{294}/_{1310}) = 17.5 \text{ s}$

$g_B = 78 * (^{604}/_{1310}) = 36.0 \text{ s}$

$g_C = 78 * (^{412}/_{1310}) = 24.5 \text{ s}$

$t_L = L = l_1 + y + ar - e$

$y + ar = Y = L - l_1 + e = 4 - 2 + 2 = 4 \text{ s}$

$G_i = g_i - Y_i + t_{Li}$

$G_A = 17.5 - 4 + 4 = 17.5 \text{ s}$

$G_B = 36.0 - 4 + 4 = 36.0 \text{ s}$

$G_C = 24.5 - 4 + 4 = 24.5 \text{ s}$

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Effective Green Times (As per Approach (ii) in step 5)

$g_{TOT} = C - L = 48 - 12 = 36 \text{ s}$

$g_A = 36 * (^{294}/_{1310}) = 8.1 \text{ s}$

$g_B = 36 * (^{604}/_{1310}) = 16.6 \text{ s}$

$g_C = 36 * (^{412}/_{1310}) = 11.3 \text{ s}$

$t_L = L = l_1 + y + ar - e$

$y + ar = Y = L - l_1 + e = 4 - 2 + 2 = 4 \text{ s}$

$G_i = g_i - Y_i + t_{Li}$

$G_A = 8.1 - 4 + 4 = 8.1 \text{ s}$

$G_B = 8.1 - 4 + 4 = 16.6 \text{ s}$

$G_C = 8.1 - 4 + 4 = 11.3 \text{ s}$

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That calculation I have shown here for two scenarios approach a 1 and approach 2. Approach 1 was assuming 90 seconds cycle time 30 seconds for each phase if we adopt that, if we accept that then what will be my effective green time and total lost time and what will be my actual green time and if I do not do that, if I consider by 48 seconds cycle time, where from 48 second has come this one.

If we consider the 48 seconds cycle time with the target v by c ratio of 0.92 in that case, how the effective green time will be there. So, 48 minus 12 second last time 36 will be there now distributed

to gA gB gC effective green time for phase A phase B phase C and then once you know the effective green time for each phase you can calculate the actual green time.

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Now, next step is calculate the capacity and volume to capacity ratio. So, lane group capacity and volume to capacity ratio can be computed as shown here. So, what is ci capacity of a lane group i is the saturation flow for that lane group multiplied that number of lane. So, saturation flow for that lane group multiplied by number of lanes in that lane group into effective green to cycle ratio g ratio C.

$$c_i = s_o N_i * \left(g_i / C \right)$$

$$X_i = \frac{N_i v_i}{c_i}$$

So, that can give you the, what is the capacity for the lane group. Now, you can also then calculate, what is the in volume to capacity ratio for lane group i that can be calculated. So, you know what is the capacity and so that becomes your denominator, what will be in the numerator is the number of lanes associated with the lane group i and then what is the lane flow rate for lane group i.

So, that calculation is shown here shown in the next slide. Then once you know that Xi is known, ci is known, then what we will do we can calculate then the control delay. Remember our earlier discussion about the control delay there were three components here the queuing effect we are not considering, we are not assuming that the queue is 0 from the previous cycle.

$$d_i = d_{1,i} + d_{2,i}$$

So, di is simply d1i plus d2i approach wise group wise say the control delay then di is the control delay for lane group i, you can calculate it the uniform delay part using this formula and calculate the incremental delay part using this next formula. So, how to calculate d1 and d2 for the length group i.

$$d_{1,i} = PF_i \frac{0.5C\left(1 - g_i/C\right)^2}{1 - \left[min(1, X_i) * g_i/C\right]} \qquad d_{2,i} = 225\left[(X_i - 1) + \sqrt{(X_i - 1)^2 + \frac{16X_i}{c_i}}\right]$$

So, exactly once you have done that one important input here is the PF progression adjustment factor for lane group i. You remember our discussion, we talked about various arrival type using platoon ratio and then says that what will be the quality of progression here for the planning level analysis this is considered in a simple form only three groups are made, good progression, random arrival and poor progression.

And if it is good progression, then the progression factor is taken as 0.7 for random arrival 1 and poor progression 1.25. So, with all these you can now calculate the control delay. So, once you have can calculate the control delay for each lane group, then based on the control delay the level of services defined. So, if the control delay that means how many seconds per vehicle if it is less than 10 seconds, then LOS as 10 to 20 as B and so on. And obviously for v by c greater than 1 always it is level of service F.

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v/c Ratio, Delay and Level of Service (As per Approach (i) in step 5)

Approach	Lane Group	Vol/lane (v_i) (tpc/h/ln)	g_i (s)	c_i (tpc/h)	X_i	d_1 (s)	d_2 (s)	d (s)	LOS
EB	TH + LT	332	24.5	1036	0.641	28.9	3.0	31.9	C
EB	RT	84	24.5	518	0.162	24.9	0.7	25.6	C
WB	TH + LT	412	24.5	1036	0.796	30.4	6.3	36.7	D
WB	RT	78	24.5	518	0.151	24.8	0.6	25.4	C
SB	TH + LT	604	36.0	1518	0.796	23.8	4.4	28.2	C
SB	RT	294	17.5	370	0.796	34.5	16.1	50.7	D
NB	TH + LT	553	36.0	1518	0.728	22.9	3.1	26.0	C
NB	RT	259	17.5	370	0.701	33.8	10.6	44.4	D

$$d_{1,EB:TH+LT} = 1 * \frac{0.5*90\left(1-\frac{24.5}{90}\right)^2}{1-\left[min(1,0.641)*\frac{24.5}{90}\right]} = 28.9 \text{ s}$$

$$d_{2,EB:TH+LT} = 225\left[(0.641-1) + \sqrt{(0.641-1)^2 + \frac{16*0.641}{1036}}\right] = 3.0 \text{ s}$$

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v/c Ratio, Delay and Level of Service (As per Approach (ii) in step 5)

Approach	Lane Group	Vol/lane (v_i) (tpc/h/ln)	g_i (s)	c_i (tpc/h)	X_i	d_1 (s)	d_2 (s)	d (s)	LOS
EB	TH + LT	332	11.3	895	0.742	17.0	5.5	22.5	C
EB	RT	84	11.3	447	0.188	14.7	0.9	15.6	B
WB	TH + LT	412	11.3	895	0.921	17.9	16.1	34.1	C
WB	RT	78	11.3	447	0.174	14.6	0.8	15.5	B
SB	TH + LT	604	16.6	1314	0.919	15.1	11.8	26.8	C
SB	RT	294	8.1	321	0.917	19.6	32.9	52.6	D
NB	TH + LT	553	16.6	1314	0.842	14.5	6.7	21.1	C
NB	RT	259	8.1	321	0.808	19.2	19.3	38.5	D

$$d_{1,EB:TH+LT} = 1 * \frac{0.5*48\left(1-\frac{11.3}{48}\right)^2}{1-\left[min(1,0.742)*\frac{11.3}{48}\right]} = 17.0 \text{ s}$$

$$d_{2,EB:TH+LT} = 225\left[(0.742-1) + \sqrt{(0.742-1)^2 + \frac{16*0.742}{895}}\right] = 5.5 \text{ s}$$

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So, now, the application is shown here, I will not go into details if not necessary. So, you have approach, you have lane group, you have volume per lane, you then calculate the effective green time the and all other calculation, calculate the X value then the d1, d2 and the total value of d and based on the total value, you can refer to this previous table and then you can say what will be my level of service.

So, this is the calculation considering the approach 1 value that means, why we consider 90 second cycle. So, parallely two calculations are going is that two alternative calculations. If you consider

30 seconds per phase and accordingly in this case go with a 90 second cycle time, then all the corresponding calculation subsequently as shown as under approach 1.

And approach 2 similar calculation, but here we have actually designed the cycle length 48 seconds we calculated with a target v by c ratio of 0.92, if I remember correctly, let me check just once again yes, so 0.92. So, that calculation also I have shown. So, you can see those calculations and therefore, we can actually calculate in each case the d1, d2 and the total delay and also that level of service.

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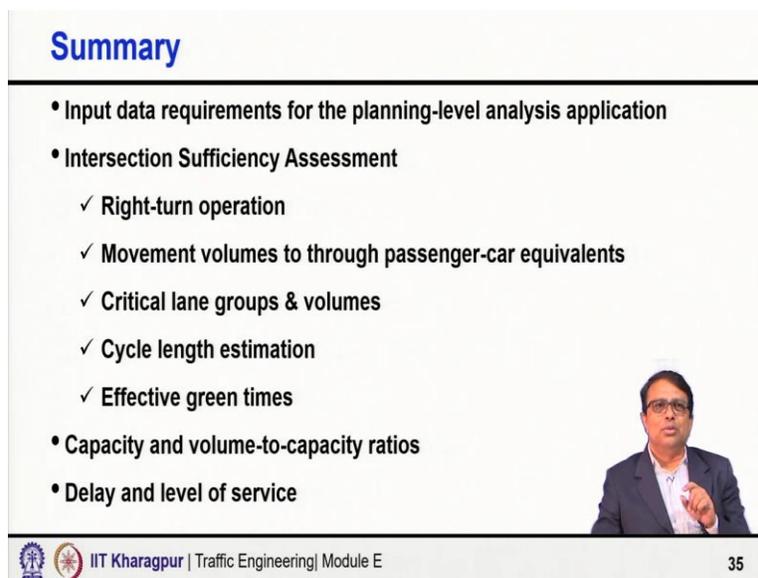
So, what we discussed is input data requirement for planning level analysis and its application. Intersection sufficiency assessment how we do that first decide the right turn operation then movement volumes to through passenger car equivalent, then critical and groups and volume then cycle length estimation, effective green time and then finally capacity and volume to capacity ratios to finally calculate the delay and conclude about the resulting level of service, with this I close this lecture. Thank you so much.