Traffic Engineering
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Lecture 31
Intersection Control & Critical Aspects of Operation - V

Welcome to Module E, lecture 5. In this lecture, we shall continue our discussion about Intersection Control and Critical Aspects of Operation.

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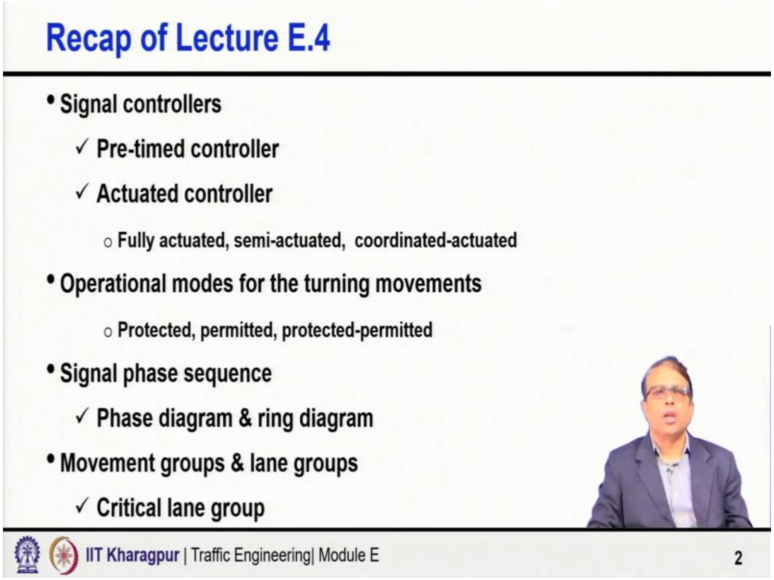

In lecture 4, I introduced you about 2 types of signal controller, pre-timed controller, actuated controller could be fully actuated, semi actuated, coordinated actuated. Also introduced to you operational modes for the turning movements, the turning movements could be protected, could be permitted or protected permitted combination. Also mentioned to you about phase diagram and ring diagram and we discussed how we can identify the critical lane group and critical volume.

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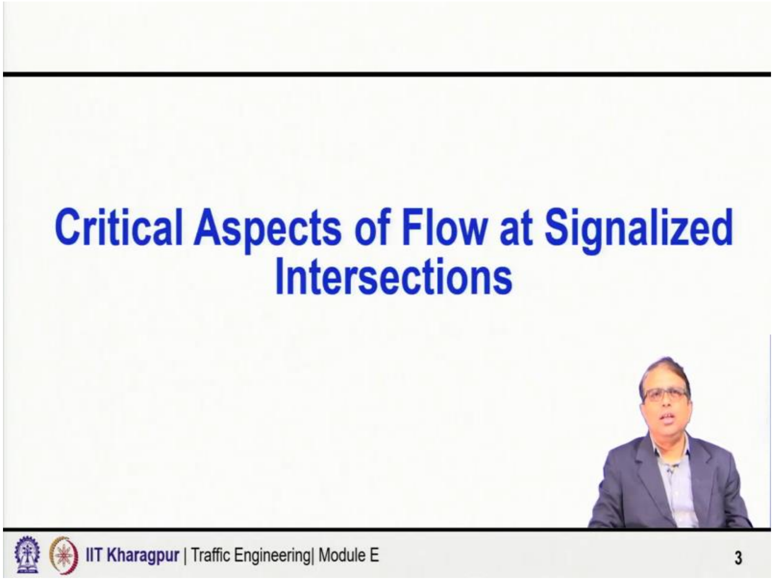

With this background, today, let us try to identify and understand a few critical aspects of flow at signalized intersections. So, we are talking about how the flow happens and some of the critical aspects related to the flow at signalized intersections.

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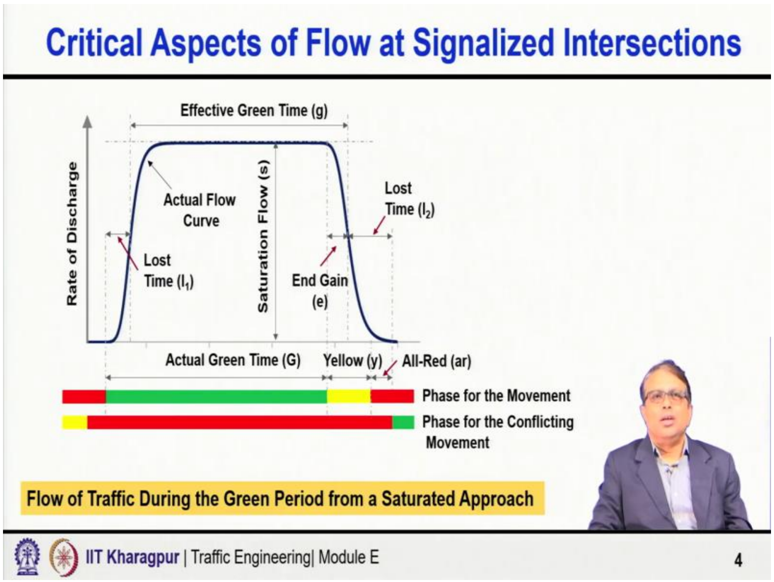

Look at the graph, this is very fundamental and very important how the flow happens when the signal turns from red to green, and also again, eventually go back to red. So, look at this curve, the x axis indicates the time you can see below up to this point it is red. So, the y here is the rate of discharge. So, you have 0 discharge till the time the signal indication is red. But then the signal turns from red to green. You can see here in this curve, the rate of discharge does not go to its maximum here it is the maximum rate of discharge, which we call it as saturation flow.

So, that immediate discharge does not happen at the rate of saturation flow, because it takes some time for vehicles to proceed through the stop line and eventually the operation will be in such a manner that the flow will be equivalent to saturation flow or discharge. So, that is the way the rate changes starting from 0 to gradually going up over a few seconds and eventually reaching to a maximum beyond which it cannot go for a given situation.

Then as signal becomes green to amber or yellow, once the green is completed in the signal turns into Yellow before giving red. So, when the yellow is initiated, after that also it is not a machine like you turn into from red to green, immediately discharge will be at its peak or you turn from green to directly we cannot do but if you suppose you turn from green to red discharge will immediately become 0. It does not happen because the behavior of vehicles, behavior of drivers there are several other aspects which are involved. That is what we are going to do are going to discuss today.

So, when the signal a green is completed and the yellow is initiated, Yellow tells precisely the drivers that stop unless stopping is unsafe. So, what is the message that you are always trying to say stop unless stopping is unsafe. So, obviously first few vehicles immediately the signal turns from green to amber, they cannot stop all of a sudden. So, the flow happens but flow happens now at a lower rate. Then the maximum discharge gradually coming down and eventually becoming 0.

And then you can see after Yellow there is something called all-red a small portion of the red. And when the all-red is over, then that conflicting movement is given green. So, the green line here as I am showing, it does not start immediately after Yellow. This portion is called all-red that means all approaches this movement also is getting red conflicting movement also is getting red it is only after all-red time the conflicting movement is giving green. So, with these basics about this figure, let us go for further discussion.

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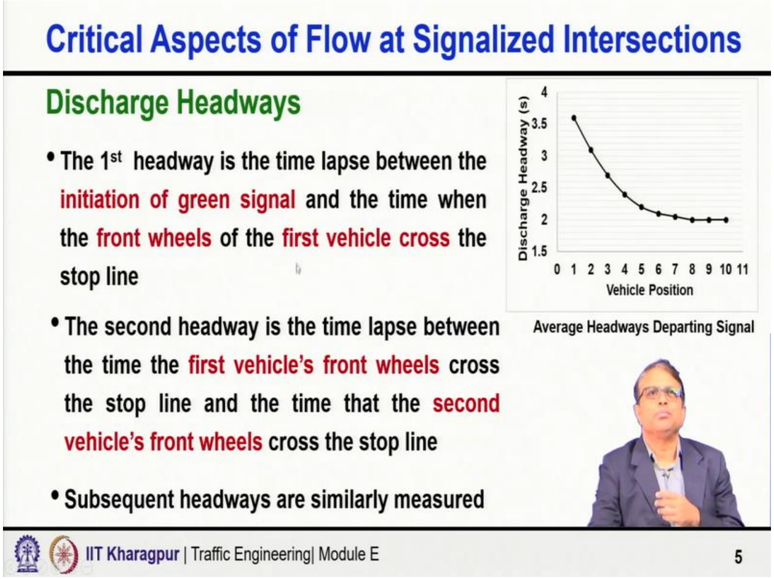

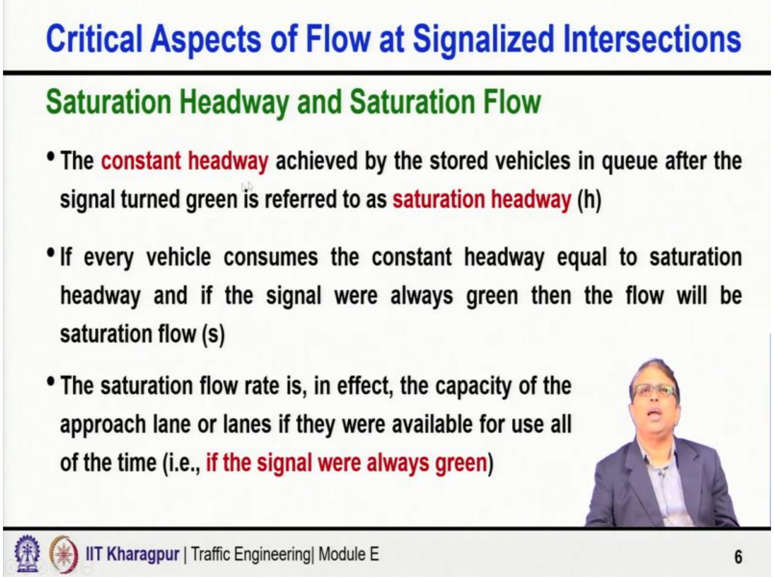

First, the concept of discharge highways, the first highway is the time lapse between the initiation of green signal and the time when the front vehicle or the first vehicle and its front wheels cross the stopline that is the headway, first headway. Then second headway is the time lapse between the time the first vehicles front wheels crossed the stop line and the time the immediate next vehicle that is the second vehicle front wheels again cross the same step stop line the time gap is the second headway.

Now, here I am trying to show you how the headway changes depending on the vehicle position or over time you can call it both. So, the you can see clearly the headway will be higher for the first few vehicles gradually coming down and then become almost like steady. So, if I consider homogeneous vehicle, perfect Lane discipline, all I say cars same characteristics then gradually it will come down and reach to a steady state. So, that steady state headway that the steady state headway is called the saturation headway obviously, discharge will be maximum when the headway is saturation headway.

So, by the time it is reaching to saturation headway if I now go back you are actually now started getting the rate of discharge with that saturation headway or the discharge is actually saturation flow the maximum discharge that is possible. But as I said that it is not that green red it becomes green and immediately the you start getting discharged at a rate of saturation flow that does not happen. So, first few vehicles taking longer time. So, your discharge is not in the beginning at the rate of saturation flow.

But over a period of time a few segments a few vehicle moves then the it becomes steady the headway becomes steady and the corresponding discharge become this saturation flow rate or the maximum flow rate. So, here is the concept of saturation headway and saturation flow as I said the constant headway achieved by the stored vehicles in queue after the signal turns green is referred to as saturation headway. Eventually the headway becomes stable and constant more or less and that time it is called saturation headway.

So, every vehicle now if every vehicle can consume the constant headway equals to saturation headway and the if the signals are always green, then the flow will be saturation flow. That means the flow what you will get corresponding to saturation headway is the maximum flow that is possible and that is called as saturation flow. The saturation flow rate in effect the capacity of the approach lane or lane groups if they were available for use all the time, that means the if the signals are always green, that means what we are trying to indicate that suppose you have enough vehicles approaching the intersection and the signal is always green then what is the maximum discharge he will get? You will get discharged at a rate of saturation flow. So, it is almost like capacity of the approach lane or lane group.

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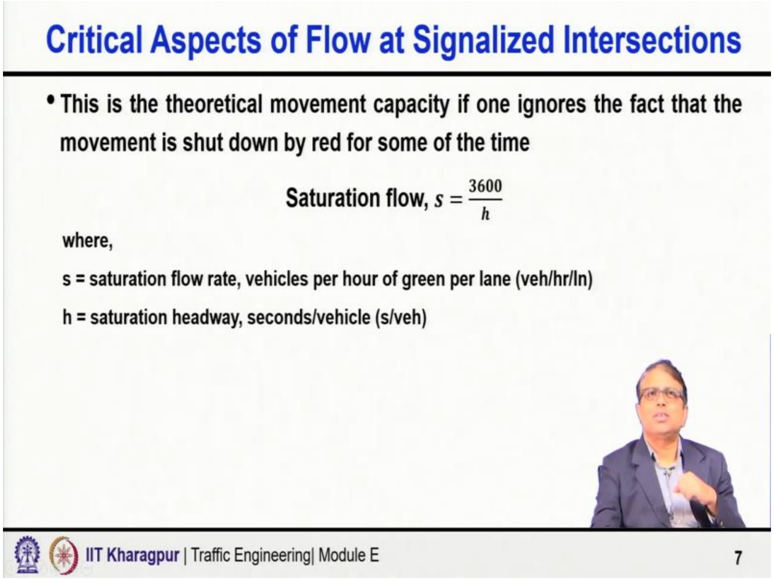

Now, this is the theoretical movement capacity if one ignores that the fact for the fact that the movement is shut down by rate for some of the time, but what I said is steadily it is green that does not happen because it is signalized intersection the conflicting movements we are segregating by time. So, obviously, if there is a green after some time it will become red. Again, after some time it will become green. So, continuous green will not happen. So, it is some kind of indication that what maximum discharge is possible at what rate the discharge is possible from the approach lane or lane group.

$$\textbf{Saturation flow, } s = \frac{3600}{h}$$

Saturation flow obviously is 3600 by h if we can say saturation headways in second part vehicle then how many vehicles can be discharged in 1 hour? 3600 by saturation headway that is the number of vehicle that can be discharged per hour and per lane let us consider the lane grouping. So, this is the way we can get the saturation headway.

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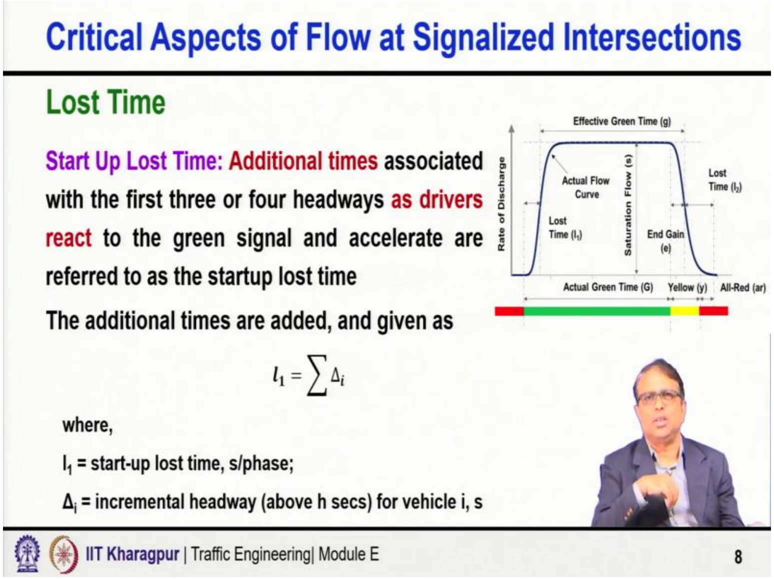

Now, the concept of lost time what we have said that the reasons are known that the first few vehicles the headway will be higher gradually that headway will come down and then becomes stable headway. So, you get the saturation headway that time but initial few vehicles take longer time. So, the incremental headway above the saturation headway. Suppose the saturation headway is x again and you have got the headway as x1 second.

So, x1 minus x is that additional time or additional headway over and above this in saturation headway. So, for the first few vehicles if this additional incremental headway or additional headway if you add together that is the lost time because that time is that additional time over and above the saturation headway and why that time is lost? That time is lost simply because the signal turns from red to green. Because of this change from red to green, this startup lost time is happening this is also called startup lost time.

$$l_1 = \sum \Delta_i$$

Now, in this figure we can represent it like this that the way the discharge happens some vehicle are already discharged listen carefully, some vehicle are discharged but only thing it is not at the rate of saturation flow. So, whatever total vehicle number of vehicles or total vehicles are discharge during this time, if I consider discharge at the rate of saturation flow, then what is the time that time is actually not lost because what I got is the saturation flow, what I got is equivalent to saturation flow for that period of time.

So, the remaining time is the lost time that is what is shown in this figure. So, you can see it is something like at this point only it becomes steady. So, till this time whatever vehicles are discharged as if it is equivalent to sometime at the rate of saturation flow and therefore this initial time is lost, why it is lost? This is lost because of the transition of the signal from or change of the signal indication from red to green. And how we can quantify this how much is lost?

The first few vehicles the additional headway time over and above the saturation headway because our expectation is saturation headway we get the maximum discharge there with that headway, but it is above the more than the saturation headway. So, you add up for the first few vehicles all this delay and that gives you the startup lost time.

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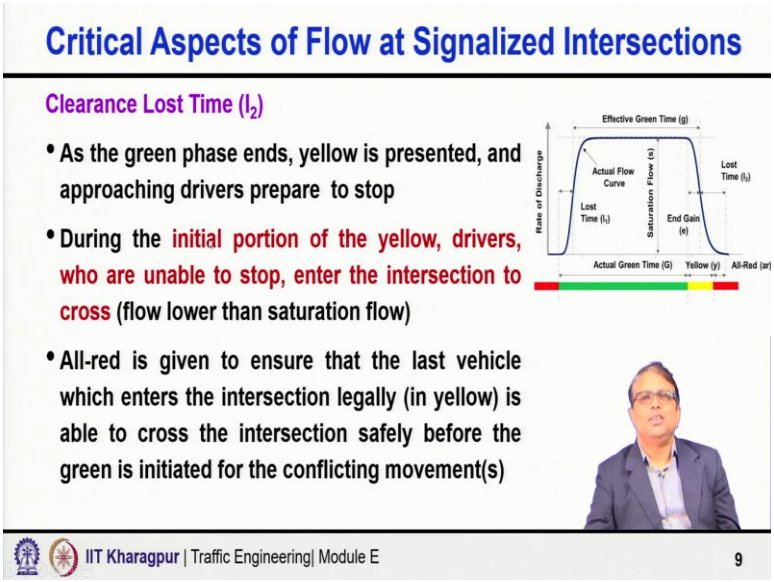

Now, there is also something happening at the other end when the signal or the green time ends. Now, as the green phase ends, yellow is presented and approaching drivers prepared to stop, why we are giving yellow or amber just imagine as I said it is not a mechanical system that you change the switch and immediately things will discharge will stop it cannot happen. Vehicles are approaching it was green suddenly it becomes red.

So, what will happen? Vehicles many vehicles will not be able to stop safely because all of a sudden you cannot stop and even if you stop there may be crash because of that the vehicles which is following you may come and crash may happen or he will cross it you are crossing it in red, which is again not permitted which is not legal in a sense. So, the yellow is presented before it comes to red. So, during the initial portion of the yellow drivers who are unable to stop safely enter the intersection to cross that means it is not illegal to cross the stop line in yellow.

But remember that, that does not mean that I should drive aggressively and try to cross the intersection of stop line in yellow time that is not right and that is in fact answer. The spirit or the reason for giving this yellow must be understood correctly. As I said if you are approaching suddenly the green time ends and you were traveling at a certain speed maybe closer to the stop line. And that time if you want to really stop you probably cannot stop because the distance is too short for you to come to a stop safely or even if you do that the vehicle which is following you may crash with your vehicle.

So, that is the reason the green the amber is given. So, that the first few vehicles who cannot stop safely can cross the stop line and cross the intersection legally without any issue. But if you can stop safely, if you are at that distance, you should actually stop. So, that is what I say for them, but tells you amber tells you stop unless stopping is unsafe. Then once that green after that it is green or amber. After that it already is also given, what already is also given? Just imagine the last vehicle which enters legally in the intersection by crossing the stop line enters when the signal is yellow.

And now the signal just turns green. So, the last vehicle which is entered illegally in the intersection in yellow time should be able to cross these intersections before a conflicting movement starts otherwise what will happen? You just yellow is terminated it becomes red and immediately the conflicting movement you give green. So, the lost vehicle is still in the intersection it has not been able to clear the intersection and the conflicting movement is also allowed.

So, the crash may occur high chance of crash. So, to avoid that, there is an all-red time that means this movement is stop; giving red, so no more vehicle can cross legally enter the intersection. But the other movement is also not giving green for a few seconds, which is the all red time to ensure that the last vehicle which is entered the intersection, it crosses the intersection safely before the conflicting vehicle starts moving.

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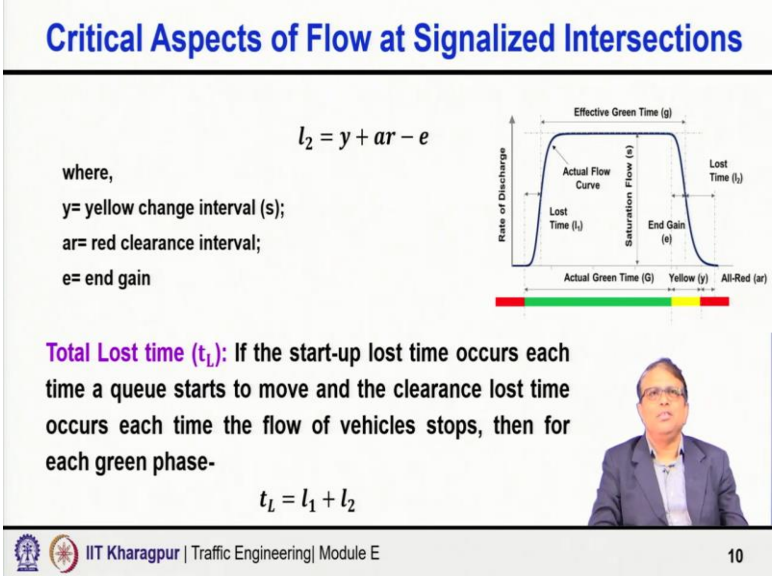

So, if we consider all these then what is the lost time? Lost time is actually yellow plus all-red, but is it that the whole yellow and all-red is lost? Answer is again no. Because when it was yellow of course, the discharge was not at the rate of saturation flow, but some vehicle crossed. So, if I consider how many vehicles crossed and then what is the saturation flow rate that means, the number of vehicle crossed once the green is terminated how many vehicle are crossed, that is equivalent to what time at the rate of saturation flow.

Now, that time is actually then not lost because whatever discharge you got some vehicle crossed the stop line once the green is terminated, so what is the equivalent time at the rate of saturation flow. So, that time is actually called end gain because you have not plus the time. At end gain that amount of time e you actually got discharged equivalent to effective green time equivalent to discharge saturation flow rate. So, that is not a part of the lost time. So, yellow plus all-red minus, since these vehicles have gone and it takes time e to discharge these vehicles at the rate of saturation flow. So, minus e, e is called the end gain.

$$l_2 = y + ar - e$$

So, the total loss time is how much? Total loss time is then startup lost time plus end lost time. As the startup lost time is happening because the signal is changing from red to green the same way end lost time is happening because the signal is changing from red and again going back to green changing from green and again going back to red.

$$t_L = l_1 + l_2$$

So, the startup lost time and end lost times both are happening because the signal indications are changing, it is not always green, it is coming from green, red to green and again going back eventually to red with amber or yellow in between. So, the startup lost time and end lost time every time the cycle every cycle you have to face this.

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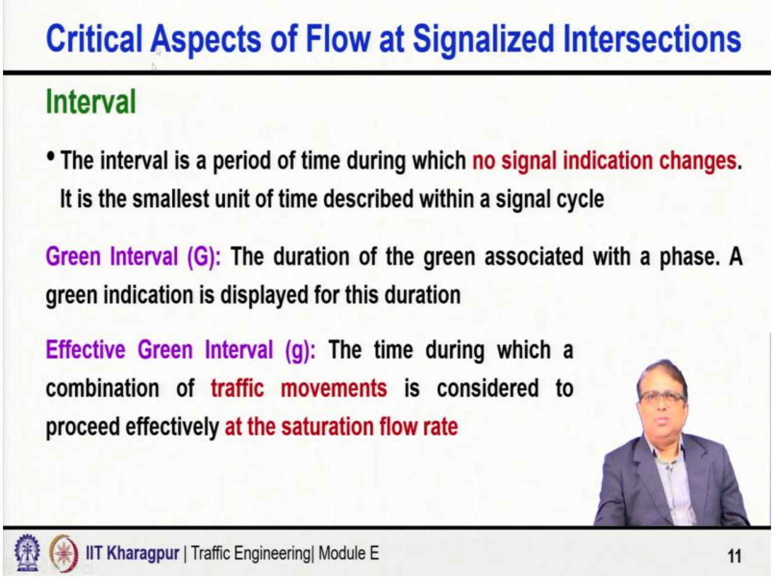

So, now, coming to the concept of interval I have already told you what is interval? Interval is a period of time during which no signal indication changes that means, if a movement is getting green, it will continue to get green. If it is getting red, it will continue to get red for some time and that period of time is called interval.

So, the interval could be green interval, it could be red interval. So, what is the green interval? Green interval is the duration of green associated with the phase, a green indication is displayed for this duration that means, we are designing the signal take your particular phase, the particular moment you are giving green indication for that movement for some time.

That is the green interval. But then, it is equally important now, to understand the concept of effective green interval, why it is green interval and different from effective green interval. These 2 are not same, why they are not same. Go back to this figure again. This is the whole green time that is given.

Now, out of this green time because of the and also considering the amber and all-red whole period, how much you were actually getting discharged at the rate of saturation flow that is not same as the given green time, that means signal will be green for certain seconds, but you are not getting discharge at the rate of saturation flow for all that green time what you are giving as signal indication because of startup lost time because of clearance or end lost time.

So, it is important to understand the concept of effective green. So, what is the effective green? The time during which a combination of traffic movement is considered to proceed effectively at the saturation flow rate. That means, for example, if 60 second is the green, but I could get equivalent discharge at the rate of saturation flow for 50 seconds, then my green time is 60 seconds, my effective green time is 50 seconds example only.

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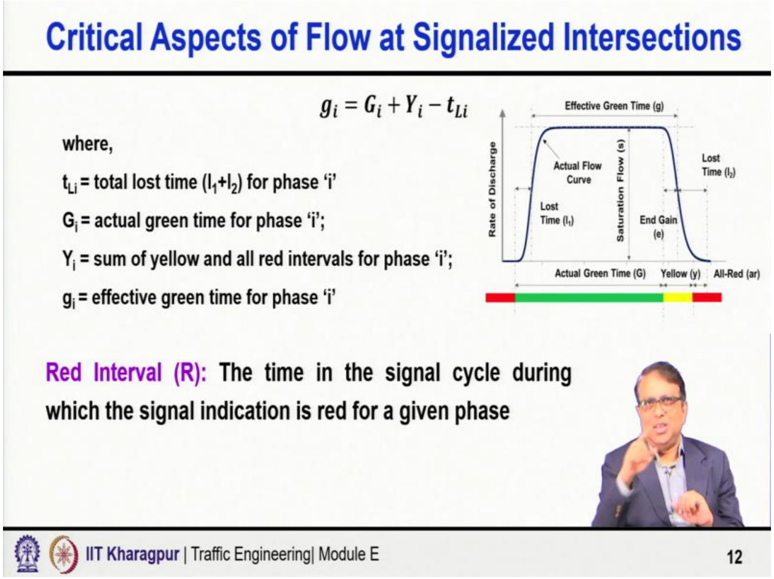

Now, then how we can calculate the effective green time? So, effective green time for at which are during which you are getting discharge at the rate of equivalent discharge at the rate of saturation flow rate. So, the actual green time plus yellow and all-red time notice that it is capital Yi, capital Y mean sum of yellow and all-red.

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

So, green time plus yellow plus all-red minus total lost time in the beginning and in the end. Startup lost time in lost time or clearance lost time, so, green plus yellow plus all-red minus total lost time that is the time when you got a discharge equivalent discharge at the rate of saturation flow rate.

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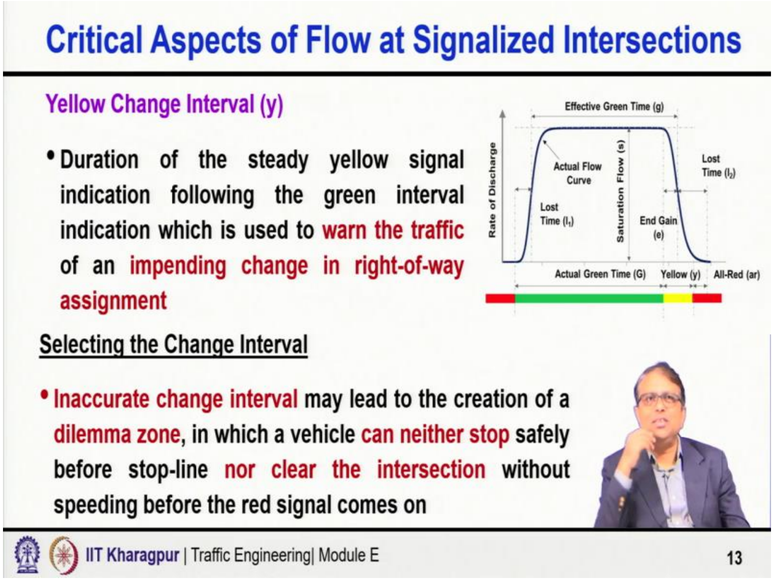

Now, let us go to the next slide, yellow change interval that it is the duration of the steady yellow signal indication following the green interval indication which is used to warn the traffic of an impending change in the right-of- way assignment. As I said, you have green interval you have green interval, then we have also discuss about the concept of effective green. Now, there is a yellow change interval. So, during which the signal remains yellow we know why we are giving it I have explained it.

But then now the question comes how to select this change interval, how many seconds, how long I should give green, amber or yellow. Understand that if inaccurate change interval is given then, that will lead to creation of dilemma zone. What is the dilemma zone? In which we will get a zone in the approach which will be dilemma zone I will explain it again further, what is dilemma zone? In that zone vehicle is there those vehicles cannot neither can stop safely before the stop line nor clear the intersection without speeding.

As I said the speeding is not that you accelerate and clear the intersection in green time. You should be able to clear in a normal manner. So, you will get a zone where the vehicles will neither be able to stop safely nor will be able to clear the intersection without speeding before the red signal comes on. Let me try to explain this.

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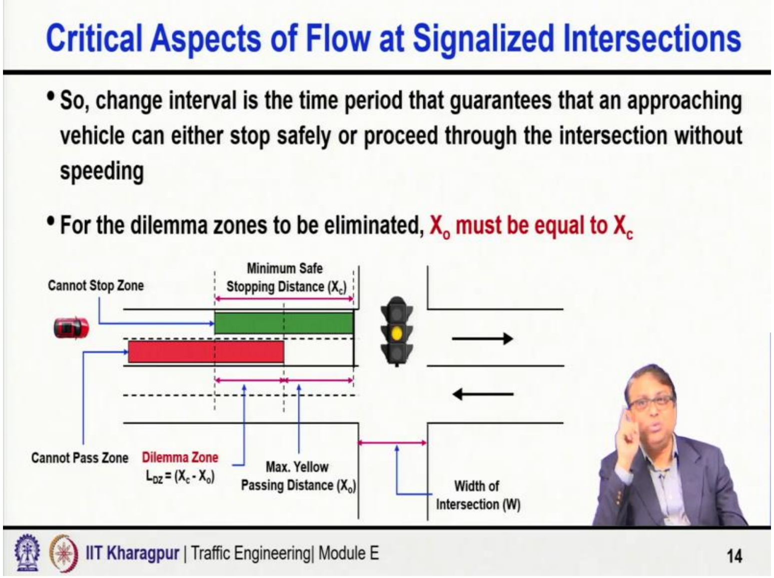

This is again very important concept why we give amber. So, the change interval time period that guarantees that an approaching vehicle can either stop safely or proceed through the intersection without speeding. So, the change interval is for that to assure that the vehicle can either stop safely or can proceed through the intersections safely without speeding. Let us consider that this is the stop line this line this is the stopline.

Now, let us consider this is location kindly follow my arrow; kindly follow the arrow if a vehicle is here based on the approach speed, this is the required stopping distance that means a vehicle which is here at this location if the vehicle applies brake in a normal manner without any aggressive braking in a normal way comfortable way, safe way then the vehicle will be able to stop at the stopline without any problem.

So, any vehicle which is either here at this location or behind in the queue all should be able to stop safely but any vehicle which is within this green area, not at the end, but somewhere in between or front or somewhere within this green shaded area will not be able to stop safely within the stop line because the required stopping distance will be higher than the available distance.

Now, for a given green for a given amber time, suppose whatever yellow time we have given it is maybe with a vehicle which is here up to that vehicle, the vehicles can cross the stop line in green time in amber time or yellow time and then any vehicle which is on the red area will not be able to cross the stop line in the available amber time. So, what will happen? Vehicle which are here in this white area, they can clear the intersection, they will cross the stop line within yellow, vehicle which are this point onwards on this side follow the cursor movement.

They will also be able to stop safely because available distance is equal to or higher than this required stopping distance. But then what will happen to the vehicle which will be in between this area this is called dilemma, what is happening in this area if a vehicle is placed in this area, and if you do not have adequate amber time then these vehicles neither will be able to stop safely at the stop line because the stopping distance required is higher than what is available at that point.

Nor they will be able to cross that intersections without speeding or without aggressive acceleration which is again not desire. They will neither be able to clear the intersection nor they will be able to stop safely that is what is the dilemma. So, for the dilemma zones to be eliminated if we do not want any dilemma zone, then my X0 must be equal to Xc what is the X0 is this distance what I have showing maximum yellow passing distance that means whatever your time you have given vehicle which are here up to that they should be able to clear the intersections within amber time.

And what is the Xc? Xc is the required stopping distance for a vehicle approaching the intersection with the given speed. So, the difference between Xc stopping distance minus maximum yellow passing distance is the dilemma zone. So, if you do not want the dilemma to remain then X0 the maximum you will have passing distance has to be equal to the stopping distance then there is no dilemma zone.

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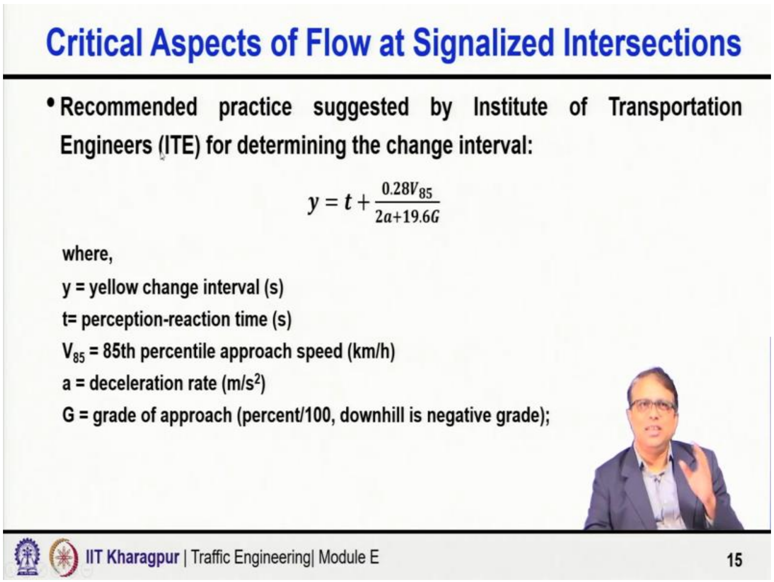

Now, ITE Institute of transport engineers, transportation engineers, they say how much should be the yellow change interval you can use this simple formula, this is a very simple formula y equals to t plus you can see is a function of V85 , the acceleration rate and the gradient, so, what is t? t is the unit perception reaction time always for any such calculation you have to consider perception reaction time and the other one basically is how much time it will take to stop if you are traveling at a speed V85, what is V85? V is the 85th percentile approach speed vehicles are traveling at different speed. So, it is taken as 85th percentile speed, the remaining calculation is easy.

$$y = t + \frac{0.28V_{85}}{2a + 19.6G}$$

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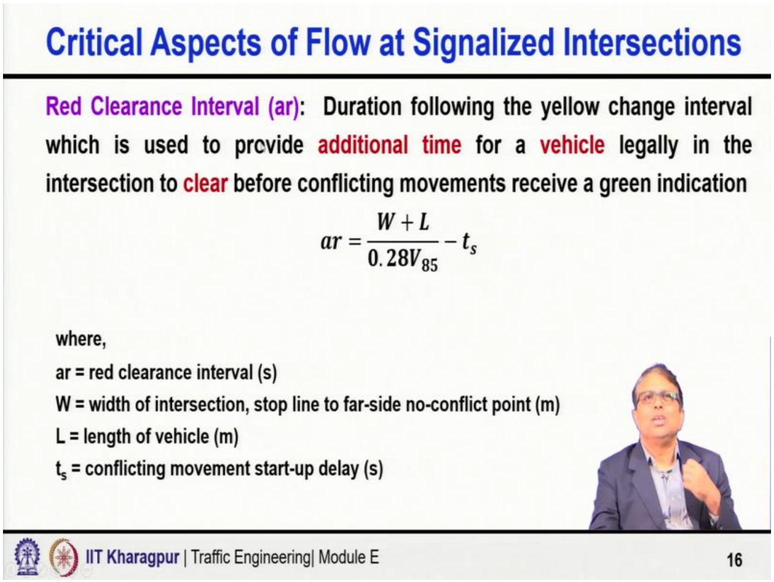

Now, red clearance interval I said that why we need red clearance interval the last vehicle which is entering legally in the intersection should be able to cross the intersection clear the intersection safely before colliding with a conflicting vehicle. So, how that interval can be calculated that is equal to W plus L what is the width of the intersection if it has to clear, clear the width of the intersection, plus L is the length of the vehicle divided by what is the speed? V85, 0.28 comes because of the conversion kilometer per hour to meter and all such conversions that is the thing minus it is saying ts, what is minus it is saying ts, what is ts? ts is that conflicting movements startup delay.

$$ar = \frac{W + L}{0.28V_{85}} - t_s$$

As I mentioned earlier do you give green does not mean the first vehicle immediately goes that is the startup delay. I said startup lost time end lost time. So, startup lost time I have explained very clearly. So, ts is the conflicting movements startup delay not that immediately. So, that minus of that startup delay because, if you require this W plus L by 0.28 V85 then even if after this you give green then also because of the startup lost time the movement will start after ts second. So, you can actually give the green if this is after this all-red time, so all-red time could be W plus L by 0.28 V85T minus ts, ts is the conflicting movement startup delay.

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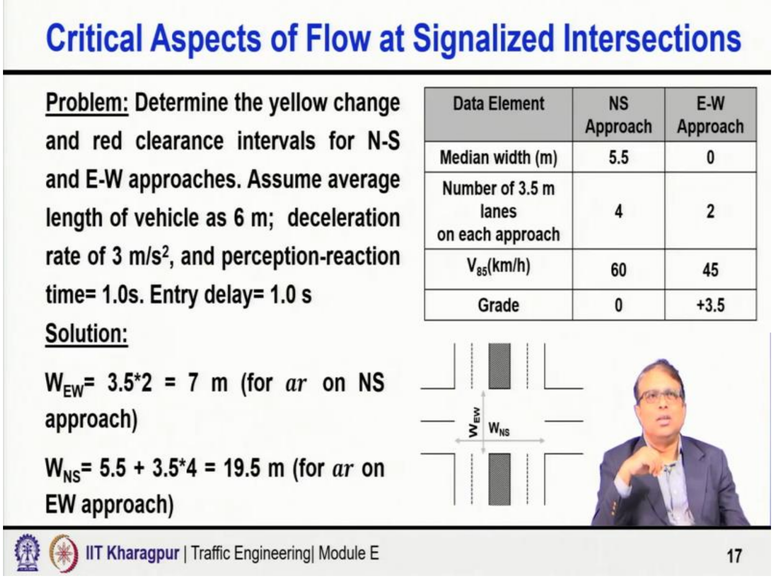

Now, let us take up a small problem. Suppose determine the yellow change and red clearance interval for north-south and east-west approaches assume average length of the vehicle is 6-meter, deceleration rate of 3 meters per second square and perception reaction time is 1 second entry delay is also 1 second and here the north-south approach, east-west approach. The median width, the number of lanes how many lanes are there of 3.5 meter width and what is the V85?

85th percentile approach speed is given and grade is also given if any. So, with this, how we can calculate the yellow change and red clearance interval for north-south and east-west approach. Now, let us consider what is the width of this east west approach? East west approach if you take the median width is zero, and there is 2 lane, 2 into 3.5 meter. Remember, these 7 meters who will cross who has to cross? A vehicle from north-south approach. So, any vehicle which is moving north-south, moving north-south has to cross this is west to east width.

Similarly, what is the width of the north-south? It is 5.5-meter median plus 4 traffic lane into 3.5, so 19.5 meter. So, these 19.5-meter North-South approach, who has to cross? Any vehicle trying to move from east to west or west to east that east-west movement vehicle has to cross this way.

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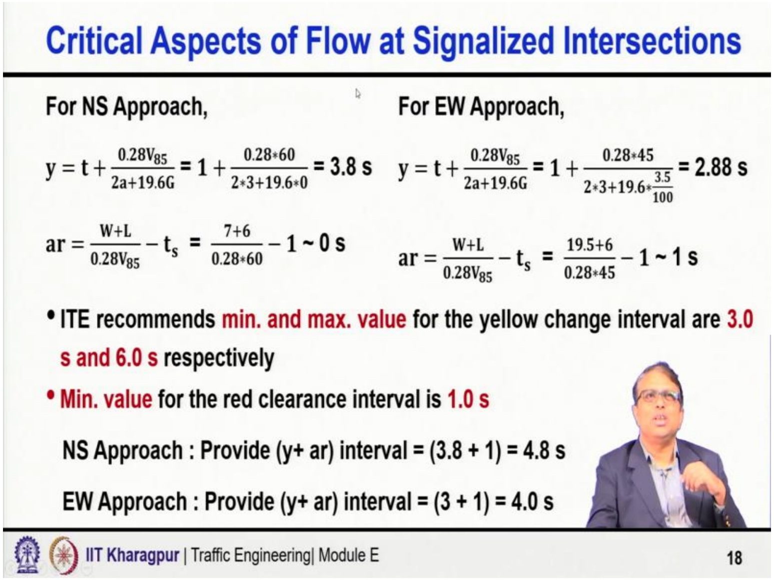

So, accordingly for north south approach what is the required time perception reaction time plus the remaining calculation is simple here you can get 3.8 seconds, all-red is almost 0. And here for this east west approach the y value is 2.88 seconds and all-red about 1 second, but then ITE recommends minimum and maximum value for the yellow change interval at 3 at 6 second respectively.

So, minimum value of the red clearance interval also is 1 second. So, accordingly for North-South approach for yellow interval what do you give? You got at 3.8 which is well within 3 to 6 seconds. So, you keep it 3.8 plus 1 second for north south approach why once again because although it is 0, but as ITE said that minimum red clearance as 1 second. So, you give that similarly, for east west approach 3 plus 1 equal to 4 seconds.

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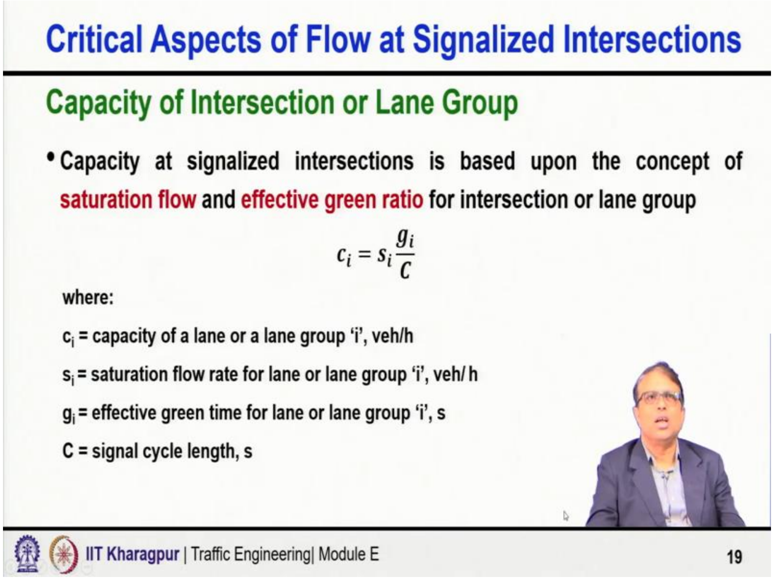

Now, how the capacity of intersection or lane group can be decided. Now, the capacity is saturation flow into g by C for that approach because saturation flow is always if the signal remains green all the time, but actually the effective green is gi and effective green is so, many seconds out of the signal cycle of so many seconds.

So, the capacity of a lane or lane group i is equal to saturation flow rate for the lane group or lane or lane group multiplied by gi by C, gi is the effective green time effective green time because we are talking saturation flow rate. It is the effective green time for lane or lane group i divided by the signal cycle.

$$c_i = s_i \frac{g_i}{C}$$

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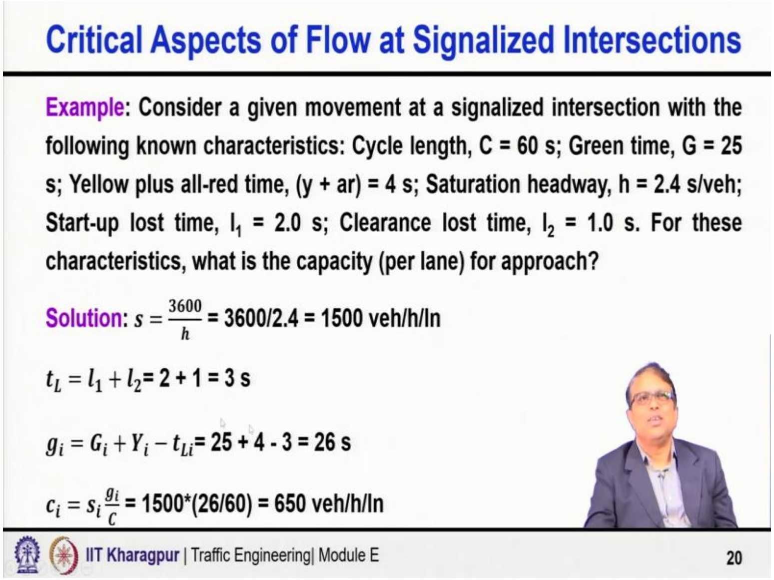

So, same way considered a movement at a cycle signalized intersection with the following known characteristic cycle length 60 second, green time 25 second, yellow plus all-red is 4 second, saturation headway 2.4 seconds per vehicle startup lost time 2 second, clearance lost time 1 second, now then what is the capacity per lane for approach. So, saturation flow is how much? 3600 by headway, headway is given here 2.4 seconds. So, you know that saturation flow is 1500 vehicle per hour per lane, what is the total lost times?

Startup lost time is 2 second, clearance lost time is 1 second so total lost time is 3 second then what is the effective green time? Actual green time is 25 second plus yellow plus all-red is 4 second minus the total lost time minus 3 so, 26 again. So, what will be then the capacity of that lane group? It is 1500 into effective green time 26 again divided by the cycle time 60 second. So, it is 650 vehicle per hour per lane.

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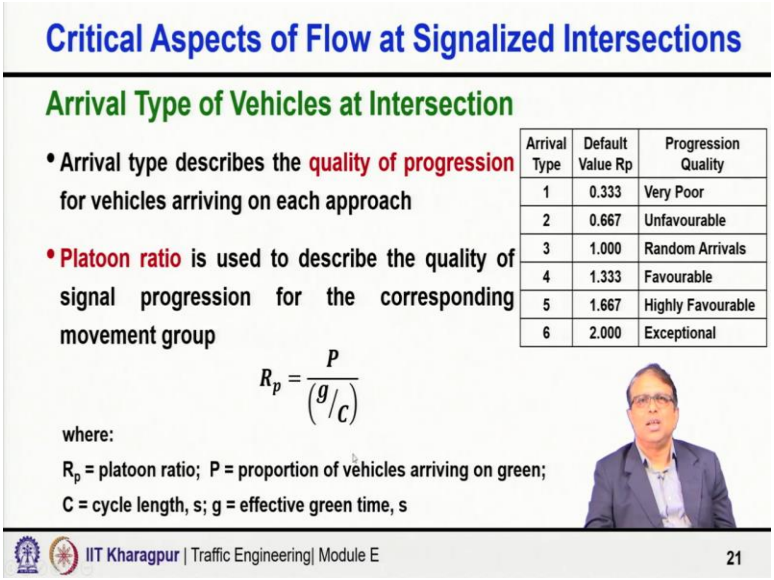

Now, before we close let us try to understand that different types of arrival of vehicle at intersection. This is very important because an intersection considered a given approach it is not always green, it is sometimes green, sometimes yellow, sometimes red or yellow is just a transition if we ignore that for this discussion, then only sometimes it is green and other time it is red any approach. So, if larger share of the vehicle can arrive the intersection during the green of that approach, then they will be able to cross the intersection without stopping.

The delay overall delay will be less for average vehicle delay will be less because the largest share of vehicle will be able to take advantage of the green time. So, how the vehicles are arriving, with a larger share of the vehicle is arriving in the green time, a larger vehicle arriving at the beginning of red time, beginning of green time, when they are arriving based on that the arrival time is decided and the progression quality, how the vehicles are progressing through a series of intersections on a major corridor that is decided.

So, we used the arrival type to describe the quality of progression of vehicle arriving on each approach and it is the platoon ratio that is used to quantify this. So, platoon ratio is used to describe the quality of signal progression for the corresponding movement group, how the platoon issue is quantified?

$$R_p = \frac{P}{(g/C)}$$

It is equal to P capital P, P is the proportion of vehicle arriving on green that mean in a signal cycle how many total vehicles are arriving typically, out of those vehicle how much percentage of vehicle is arriving on green; higher this value better will be the progression divided by g by C, g is the effective green time and C is the cycle length this interpretation you will know.

So, based on that different threshold values are given. So, for example, default values of Rp is 0.333 it is called arrival type one and indicates progression quality is very poor. Similarly, the best is arrival type 6 default, the threshold value of platoon ratio is highest here among all these values and that includes exceptionally good progression. So, in between as you are going higher and higher, worse to you are going towards better, further better and arrival type 6 is the best.

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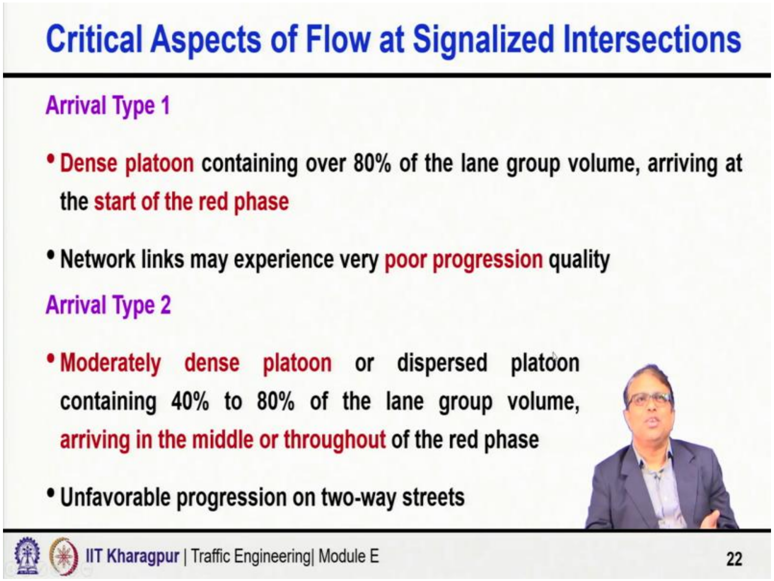

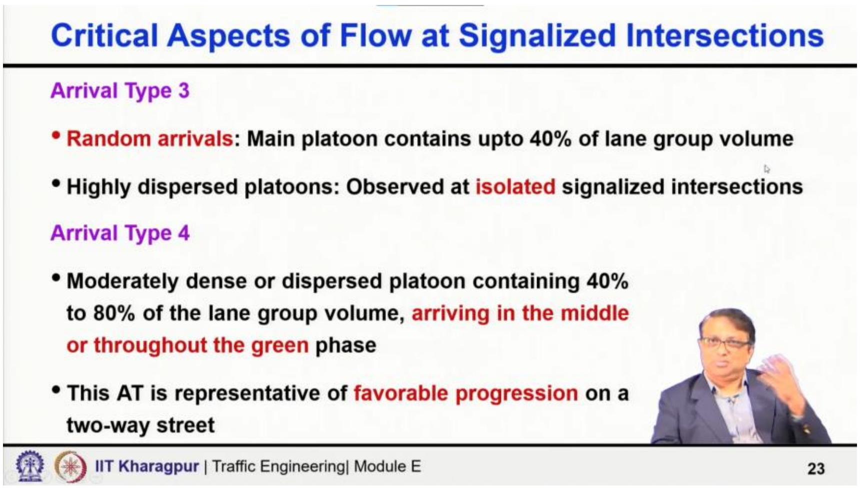

So, here it is said that arrival type one remember that arrival type one is Rp value is the lowest and very poor progression. So, obviously it contains over 80 percent of the lane group volume and arriving at the start of the red phase. So, majority of them arriving at the start of the red phase. So, network may experience very poor progression quality. Arrival 2 is little better because moderately dense platoon or dispersed platoon containing 40 to 80 percent of the lane group volume arrival in the middle or throughout the red phase.

Unfavorable progression again little better, but still bad. Similarly, three it is almost like random arrival, when platoon contents up to 40 percent of the land group volume not higher. Highly dispersed platoon observed at isolated intersection arrival type 4 further improvement, moderately dense or dispersed platoon containing 40 percent to 80 percent of the lane group volume arrival in the middle or throughout the green phase switching over and late through at the beginning of throughout the red. Now, in the beginning or throughout the green.

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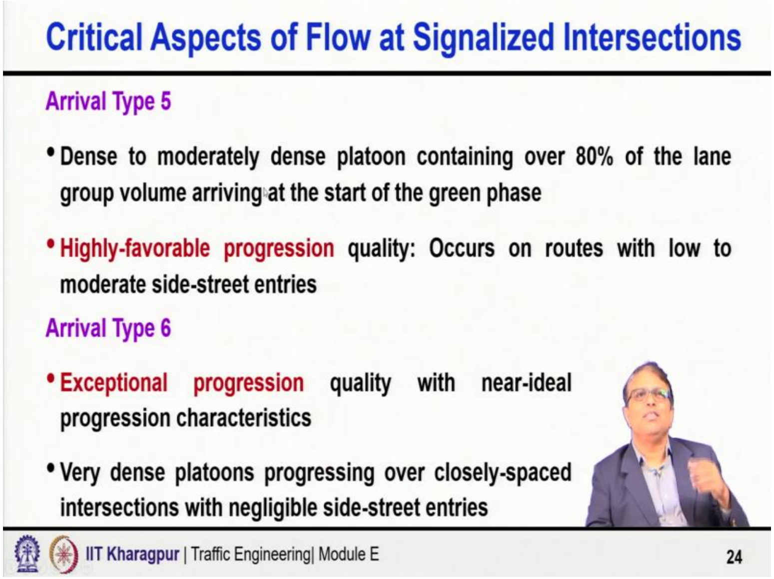

Similarly, as you say 5 and 6, 6 is the best as you are going you are actually better progression you can expect. So, once we know this platoon ratio and we can know the arrival type we can know what will be the quality of progression.

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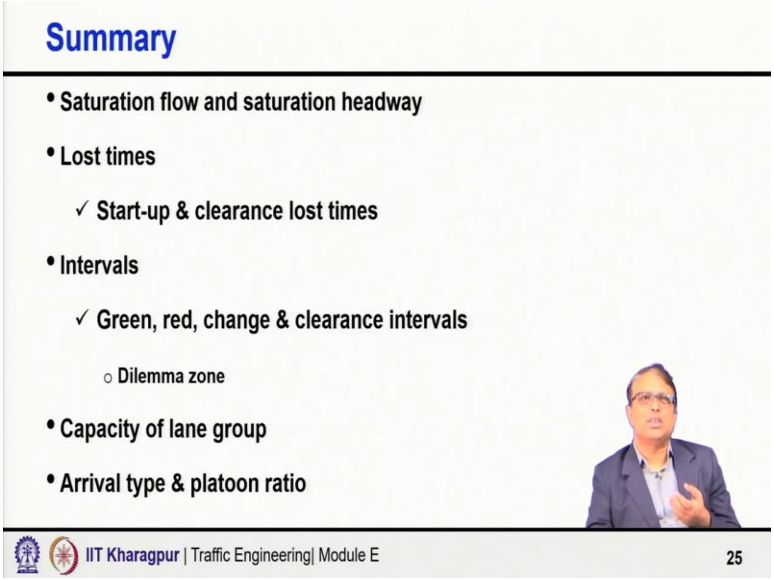

So, what we discussed here is the concept of saturation flow, saturation headway, startup lost time, clearance lost time, then the green red change and clearance interval and the very importantly the concept of dilemma zone. Then how to calculate the capacity of a lane group and how the arrival types can be captured using platoon ratio and then how the progression can be judged based on that. Thank you so much.