Traffic Engineering
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Lecture 42
Signal Coordination - III

Welcome to Module E, lecture 16. In this lecture also, we shall continue our discussion about Signal Coordination.

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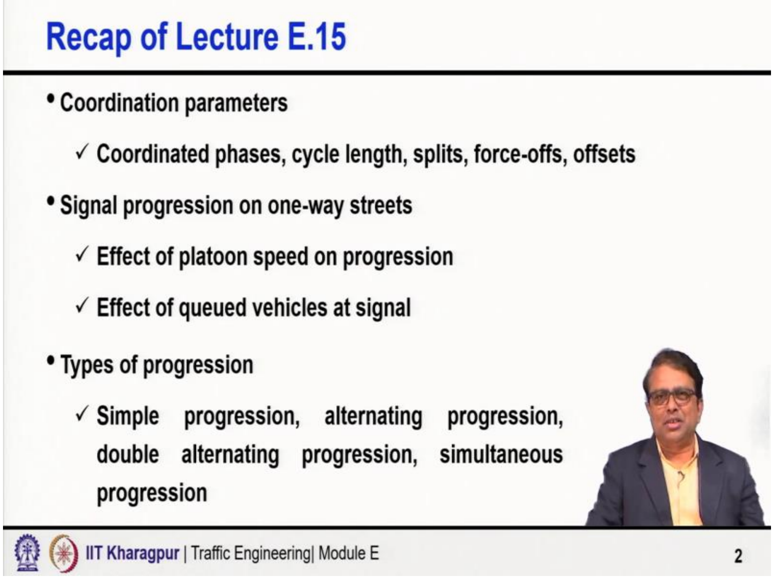

In lecture 15, I mentioned to you about various important coordination parameters. Namely, how to decide the coordinated phase, cycle length, splits, the concept of force off, and offsets, also discussed about signal progression on one-way street, effect of platoon speed on progression, and how to account for the effect of queued vehicles at downstream signals. Then, I close this lecture with a brief introduction to various types of progression. Mainly the simple progression, alternating progressions, double alternating progression, and simultaneous progression.

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So, in continuation to our discussion regarding signal coordination. Today, first we shall discuss about signal progression for two-way streets and networks.

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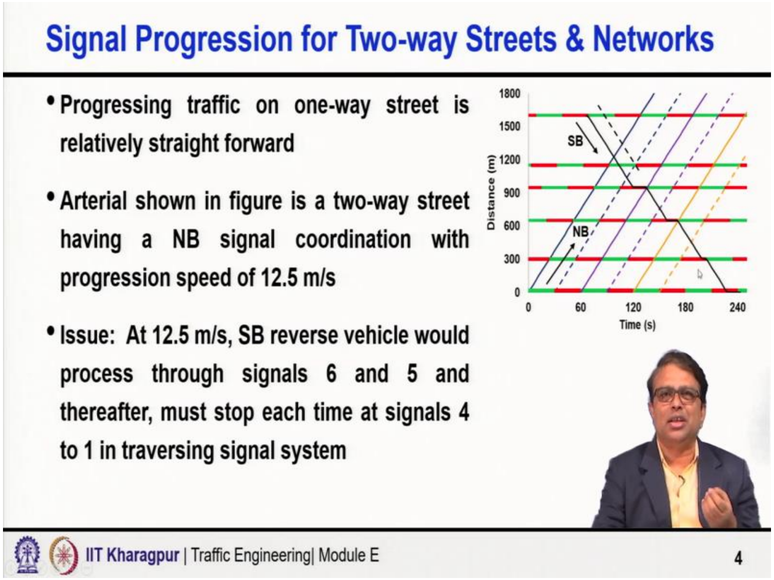

Now, progression of traffic on one-way street is relatively straight forward, but when we try to do the progression on two-ways, that means, if northbound, we are trying to do the coordination we are also trying to do the coordination simultaneously for the southbound traffic, or if we are doing it for eastbound traffic, then simultaneously we are also trying to do for the westbound traffic. So, here you can see in this time distance diagram, where we are showing the vehicle trajectories and trying to explain the coordination, how it works? You can see that the northbound coordination vehicles are moving towards north with a progression speed of 12.5 meter per seconds.

Now, if you do that, then it is very good in terms of northbound progression, we are getting maximum bandwidth, and bandwidth efficiency, capacity everything. But the issue is here, if we take a southbound reverse vehicle, when everything is so good, probably at its best in terms of the northbound direction, then if we take a vehicle for the southbound direction, then you can see here vehicle which is passing through signal 6, I think this is 1, 2, 3, 4, 5, 6. So, passing through signal 6 is able to pass through signal 5, somehow getting the green here, but getting stuck off in signal 4.

Again, once it gets cleared from signal 4, signal 3 again it has to stop, signal 2 also it has to stop, signal 1 it has to stop. So, you can see that only out of six signals, the southbound traffic under the same condition with the same coordination system and progression speed, when we are able to get best out of probably northbound direction, we are getting actually worst for the southbound direction, practically the no vehicle can pass through in an uninterrupted manner through all these signals, and the bandwidth is practically 0 for the southbound direction.

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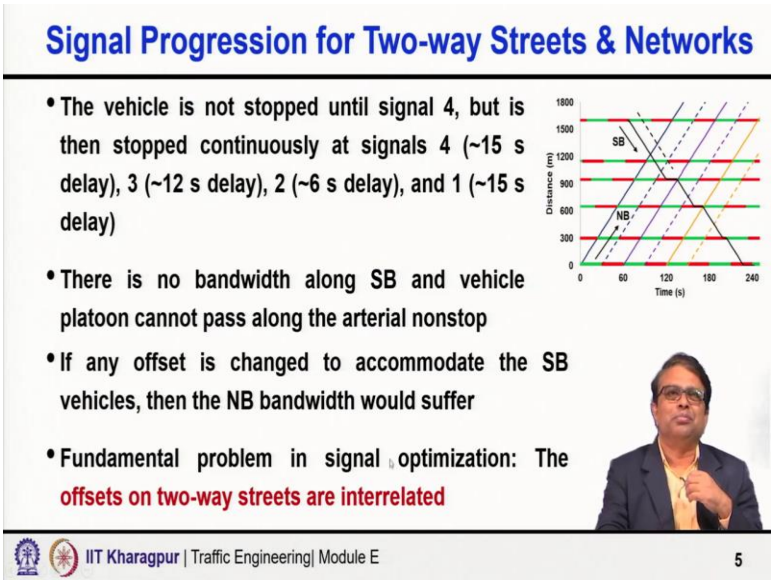

So, as I said the vehicle is not stopped until signal 4. But 1, 2, 3, 4. So, 6 and 5 it can cross, but then it stops at signal 4 for 15 seconds, signal 3 for 12 seconds. Signal 2 for 6 seconds, and then signal 1 for 15 seconds. So practically, as I said there is no bandwidth along southbound direction, and vehicle platoon cannot pass through that arterial nonstop. So, one way we are getting best, but the other way it is then the worst.

Now, interestingly you can try also, you can try slightly different offsets that what we can do to get some bandwidth in the southbound direction? You can definitely get. You can do some change in the offset, and do some adjustments to get a bandwidth in the southbound direction. But then, you will realise that your northbound direction bandwidth will not be so good as you are getting it now, that means if you want to do any interventions, you can always do it, and try to improve the performance coordination. We want to do it better for the southbound, then the northbound will become bad.

So, it will be done at the cost of compromising the northbound progression. Actually, the fundamental problem in signal coordination for a two-way street is, the offsets on two-way streets are interrelated, not independent. So, if I try to achieve maximum for one direction, I will be probably at its worst condition, I will probably be in the worst condition for the other direction, or I will end up probably in the worst condition for the other direction.

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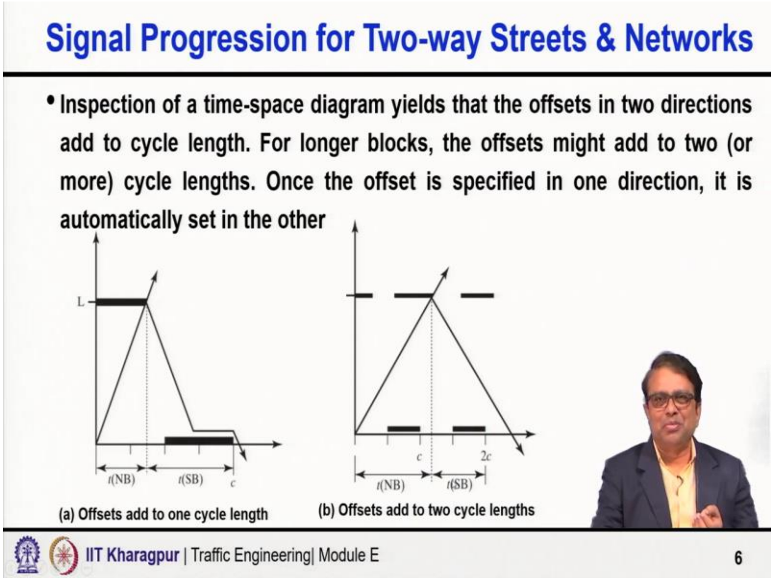

Now, if you do a close inspection of a time-space diagram, where we have offsets in two directions, you will realise that there are two possibilities where the offsets in the northbound and southbound direction will add up to one cycle length or in this case, in diagram b it is adding up to two cycle lengths, or even in general it could add up to a number of cycle lengths, where it could be 1, it could be 2, it could be even higher. So, you can see here, we have done the progression in such a manner here we are showing the offset in x axis, and y is the distance.

So, since the vehicle which is getting cleared in the green, and is just getting green here, so this is actually the northbound direction, we are getting the offset, and then your other direction offset is actually this one, as it is shown here, where the northbound and southbound offset together adding up to a cycle, and what is happening here vehicle is going uninterrupted, but in the southbound direction vehicle has to come and actually arriving at the intersection when the signal is red. So, it has to wait for this much long period of time before it get green, and clears the intersection.

In this case, the actually the signals which are getting coordinated are apart, and the distances generally significant or higher. So, by the time it is actually reaching to the downstream intersection you have actually completed one cycle. So, here in this case, the vehicle which is getting discharged in the green the first vehicle the platoon leader, it is reaching to the downstream intersection, it is getting a green, but the time is offset time is actually more than the cycle length. So, in this case, it will add up northbound and southbound offset together will add up to two cycle length.

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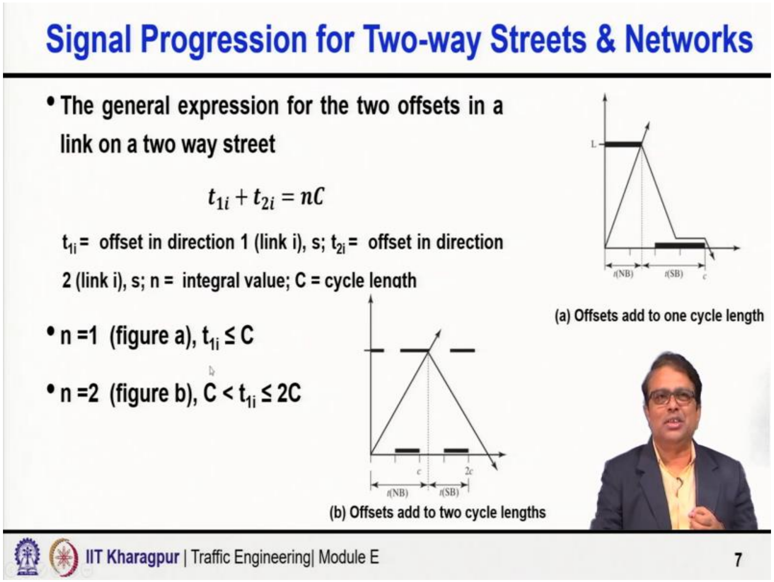

Now, the general expression for the two offsets in a link on a two-way streets is like this as I have shown t1i, plus t2i is equal to nC. t1i is the offset in direction one, which till this time, I was saying northbound and southbound. So, 1 you can consider northbound, 2 you can consider southbound. Or 1 you can consider eastbound, and 2 you can consider as westbound. So, generally the offset in two direction is equal to nC, where n is the integer value 0, 1 like this and C is the cycle length.

$$t_{1i} + t_{2i} = nC$$

Now, in this particular figure here, n is 1, and when the offset is less than a cycle length. So, in that case the offset in both directions may add up to a cycle length. And in figure b, in this figure, the you can clearly see that here it n is 2, and that means actually here the offset in direction 1 is greater than C, less than equal 2C. So, in between C and 2C, so, you are getting under this condition the n equal to 2.

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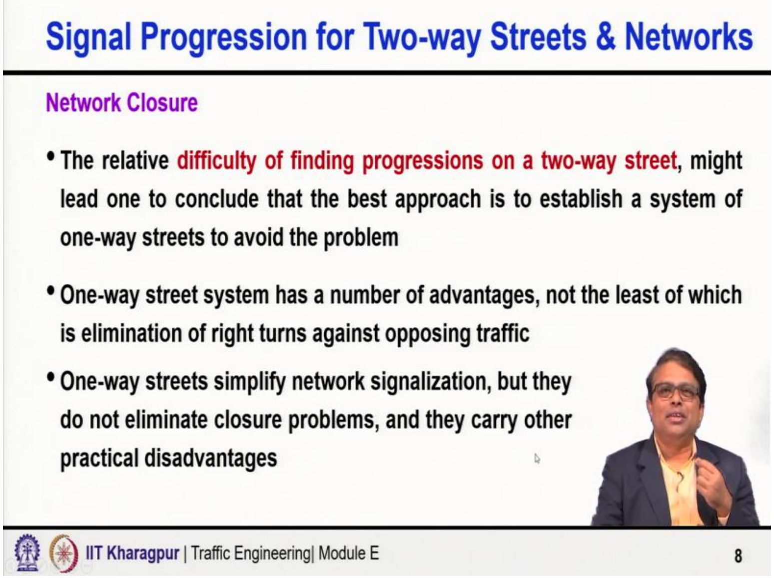

Now, coming to the concept of network closure, the relative difficulty of finding progression on a two-way link or two-way streets might lead one to conclude that the best approach is probably to establish a system of one-way street to avoid this problem. Because as I said the offset in both directions will be equal to nC, some of the offsets in both direction will be equal to nC.

So, maybe we can avoid that if we have a set of one-way streets. But one-way streets although has a number of advantages and disadvantages. But, one obviously, good thing is that, as I said here, one-way street system has a number of advantages, not the least of which is elimination of the right turns against the opposing traffic.

So, if there is no two-way traffic, there is no right turn against the opposition movement, that is one great benefit. But one-way streets although simplify network signalization, but this is most important, but they do not eliminate closure problems, that means end of the day somewhere again, directly or indirectly, these offsets and everything add together, the cycle length is coming back. So, do not eliminate closure problem. So, I will explain what is the closure problem, and they carry other also practical disadvantages.

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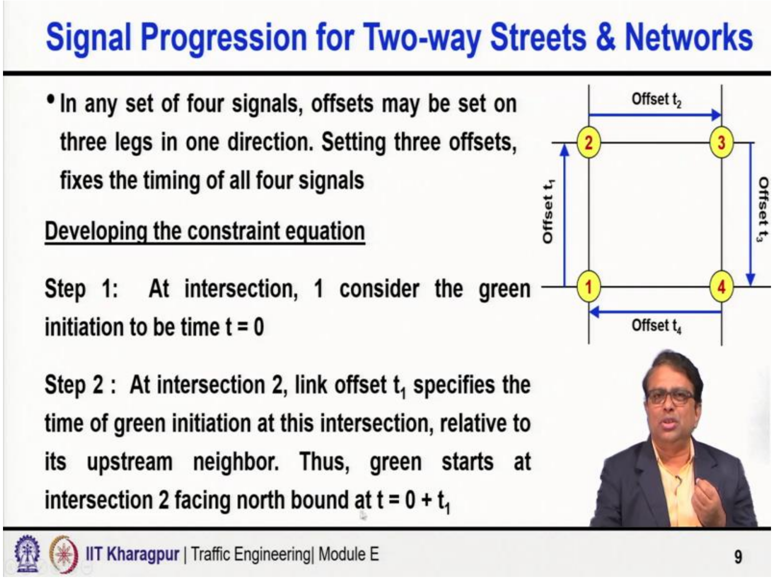

Let us stick out take this example, in any set of four lanes, offset maybe set on three legs in one direction, and because of this closure issue, setting three offsets, fixing actually the time of all four signals. So here you can see this is a one-way streets in a network of with one-way streets 1 to 2 one-way, 2 to 3 one-way, 3 to 4 one-way, 4 to 1 one-way.

So, we are operating with a set of one-way streets. But then, let us try to understand what is a closure problem. Since step 1, at intersection 1 considered the green is initiated at time t equal to 0. And here we are talking green is initiated in the northbound direction that means 1 to 2. So that is the time is t0. At intersection 2, here specifies time of green initiation at this intersection relative to the upstream neighbour.

So, does the green start at intersection 2 in this direction, at what time 0 plus t1, because here the offset is t1. But that t1 is in which direction? It is northbound also, because traffic is moving northbound, and 1 and 2 are these two signals are coordinated in the northbound direction. So, the offset, the green starts that intersection 2 facing northbound is at 0 plus t1.

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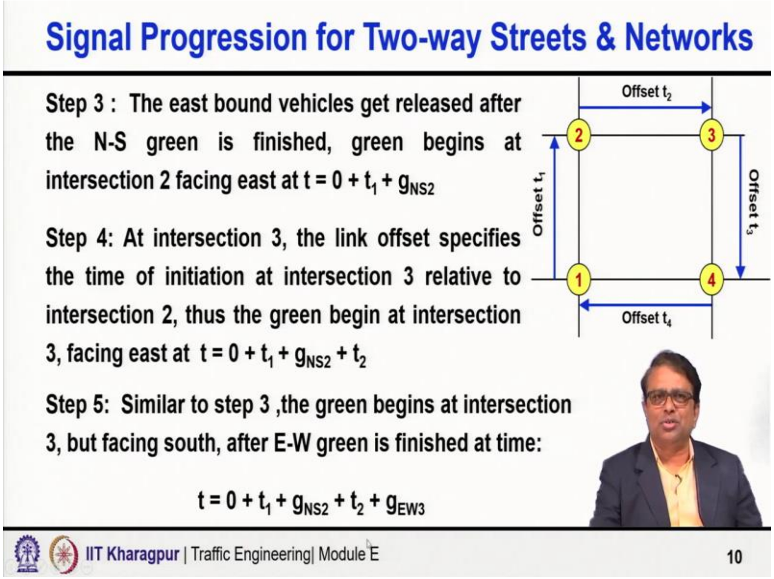

Now, step 3, when the eastbound green starts, eastbound green will start at 0 plus t1 plus whatever is the green time for north-south direction at signal 2, because we have initiated green first for the northbound direction, so it is over then only the eastbound will start operating, so when the eastbound would be green? It is at 0 plus t1 plus the green time for north-south directions at signal 2. Similarly, what will be then the initiation of green time at signal 3 towards east or eastbound direction? It will be 0 plus t1 plus gNS2 at signal 2, plus t2, t2 is this offset.

So, 2 and 3 are coordinated again in the towards east. So then, when the 3, 4 will start? 3, 4 will start plus after gEW3 how much green time, we are giving at signal 3 for the direction westbound. Once the eastbound is over, then only the southbound green will start. So, southbound green will start at this time.

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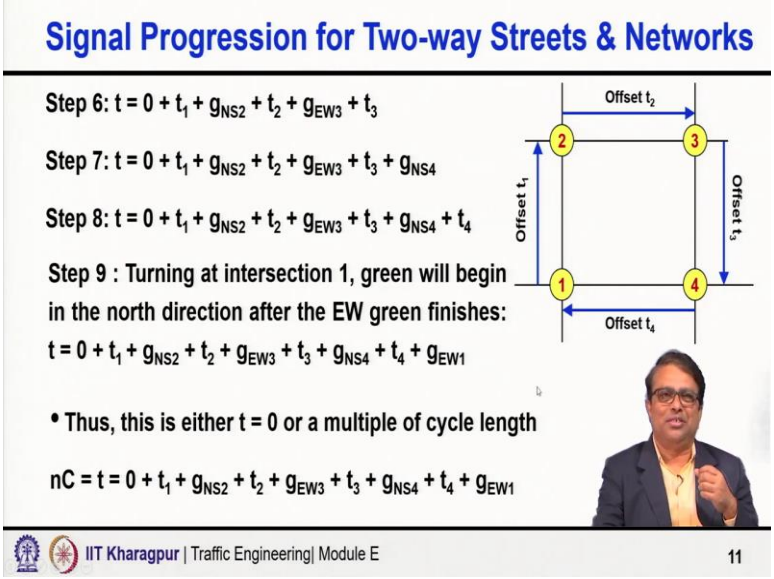

Like that. If you think, when the southbound green will start at signal 4, it will be plus t3, the offset. When the green for the westbound will start at signal 4, plus NS4, how much green time we are giving at signal 4, for this north-south movement, or southbound movement. Then, when the green time should start here again? In this direction plus t4, but differ will be towards west. So, when the north direction green should come back again, plus gEW1. That means, that signal 1 how much is the green time we are giving for the east-west movement, but actually westbound movement on east-west corridor.

So, this whole time what you have got this has to be equal to nC, because again the green should you should get the green as you start it, other is the whole system may not be able to work if your green time does not match, if this is not equal to a multiple of nC, it may be 2C, 3C, 4C we do not know, but it has to be something, other is the whole cycle after cycle this coordination and one-way progression through this network of one-way streets will not operate. So, this has to be equal to nC.

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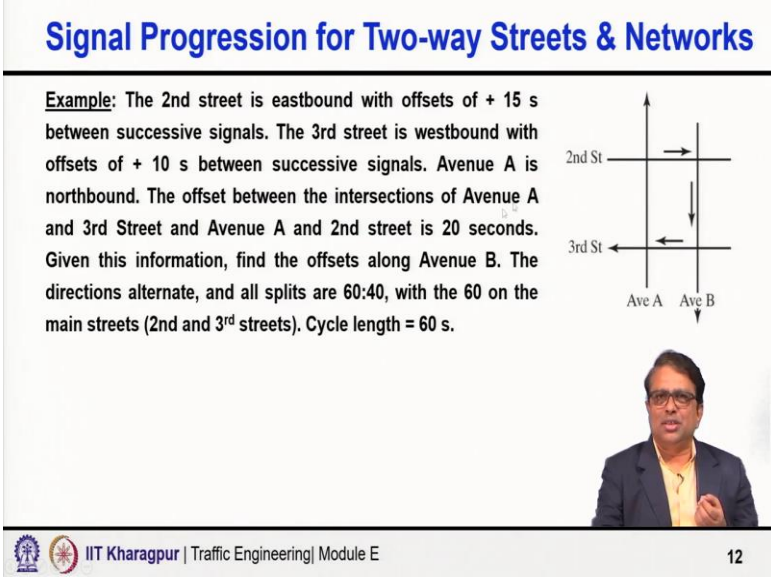

So, I have taken a problem here. The second street, here it is the second street, here it is the third street. Second street is eastbound is moving in this direction only traffic with an offset of 15 seconds between successive signals. So, this signal to this signal, it is 15 seconds. The third street is westbound with an offset of 10 seconds.

So, this to this signal 10 seconds. Avenue A is northbound, and the offset between intersection of avenue A and third street, and avenue A and second street. These two cases, the offsets each case is 20 seconds. Given this information find the offset along avenue B. The direction alternate and all splits are 60, 40. With 60 second on the main street, that is second and third street and cycle length of 60 second.

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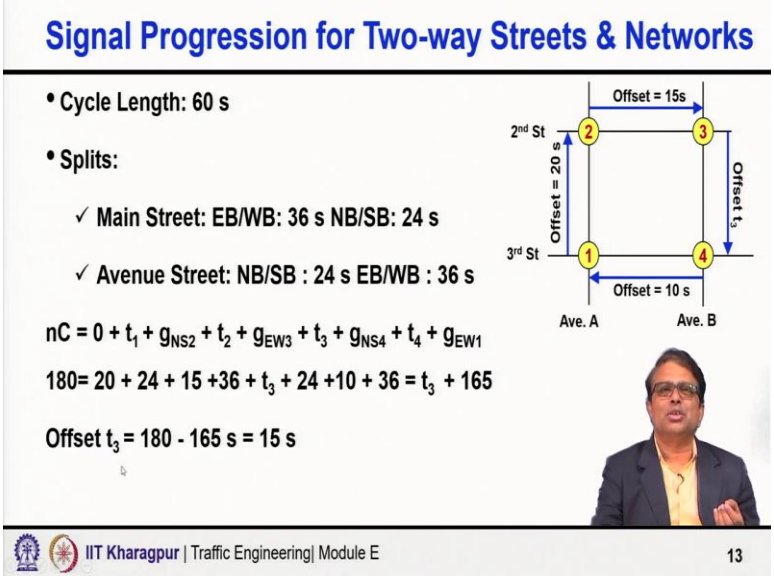

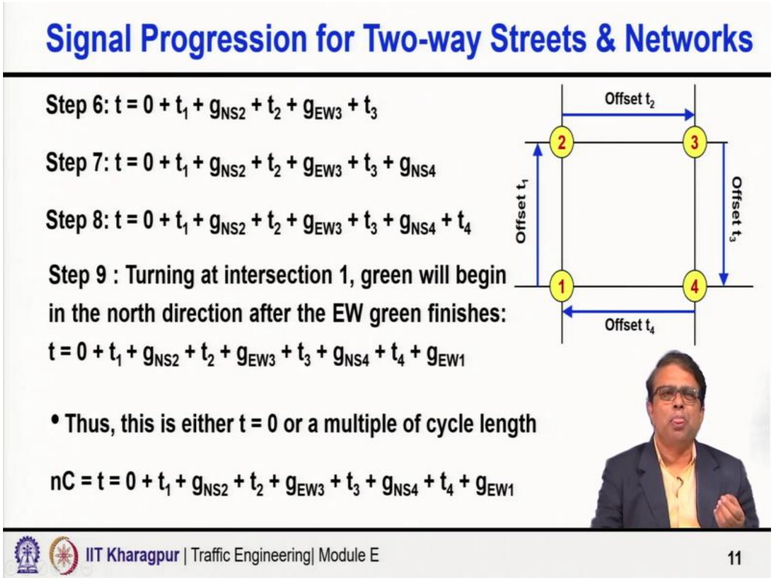

So, it is again taking the network closure fundamental. So, you know the main street is eastbound, taking the split the eastbound and westbound, 36 seconds and northbound and southbound 24 seconds, and avenue street north-south 24 second, and eastbound, westbound 36 seconds. So, nC in this case how much we can take? nC has to be because if you take the same formula what I used here finally, this is the formula I am using.

So, if you use that, then you get actually the nC equal to t3 plus 165. Obviously, then the nC has to be more than 165, because it is 165 plus t3. Obviously, all t1, t2, t3, t4 green time all are positive only. So, it has to be higher than 165 but nC. So, if the cycle length is 60 seconds, then 6 into 3, 60 into 2 is 120. So, 60 into 3 it is 180 seconds. So, nC you are taking 180 seconds, and accordingly we are calculating what is the offset then t3, which is 15 seconds.

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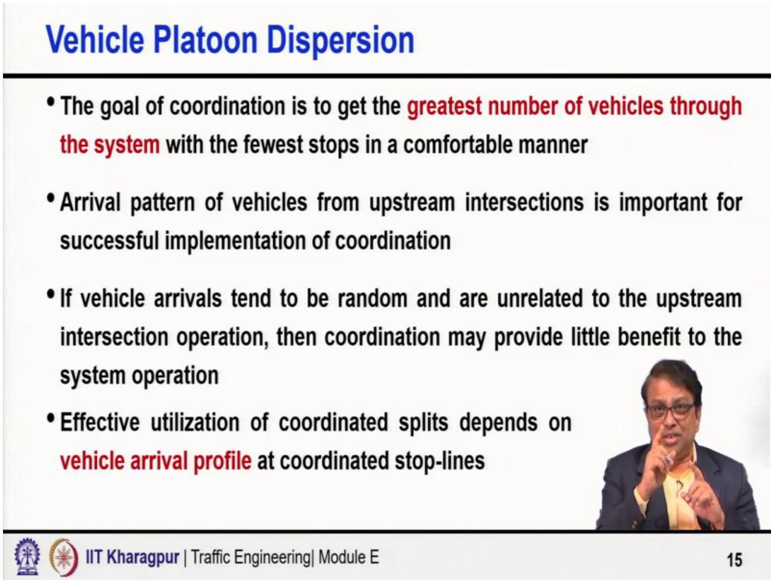

Now, coming to the vehicle platoon dispersion. The goal of coordination it is a new topic the goal of coordination is to set, or is to set the signal in such a manner so that we can get the greatest number of vehicles through the system with the fewer stops, or with no stops, and in a comfortable manner.

So, obviously the coordination we do along the direction of the major movements say that as I have said earlier also the in the morning if the travel all travel are towards that CBD area, so, in that direction we will coordinate the signals along major arterials because major traffic is actually CBD bound. So, what will be the success, or how effectively a coordinated signal, set of coordinated signals will work that largely depends on how vehicle are arriving at the downstream intersection?

You have coordinated a signal and particular phase. So, how vehicles are arriving? If majority of the vehicles are arriving in that phase for that direction, then the coordination will be very meaningful and successful. But if majority of the vehicles are not reaching during the green time, it is reaching otherwise or half of the vehicle are reaching in the green, and half are reaching in the red time, then the signal may not be that effective. So, what I am saying, the arrival pattern is extremely important, arrival pattern of vehicles from upstream intersection is important for successful implementation of the coordination.

And if vehicles arrivals tend to be random, and are unrelated to the upstream intersection operation, it is simply uniform arrival just for the sake of discussion I am telling, then coordination will provide little benefit to the system operations, the whole purpose of coordination is the bunch of vehicle should reach the downstream signal, and they should get green, then only it will be successful.

So, the effective utilization of coordinated split depends very much on the vehicle arrival profile at the coordinated stop-line. How vehicles are arriving at the downstream signal? And for that particular phase, which is coordinated. So, the arrival pattern is something which is very, very important, and it controls the success of the coordinated signal system.

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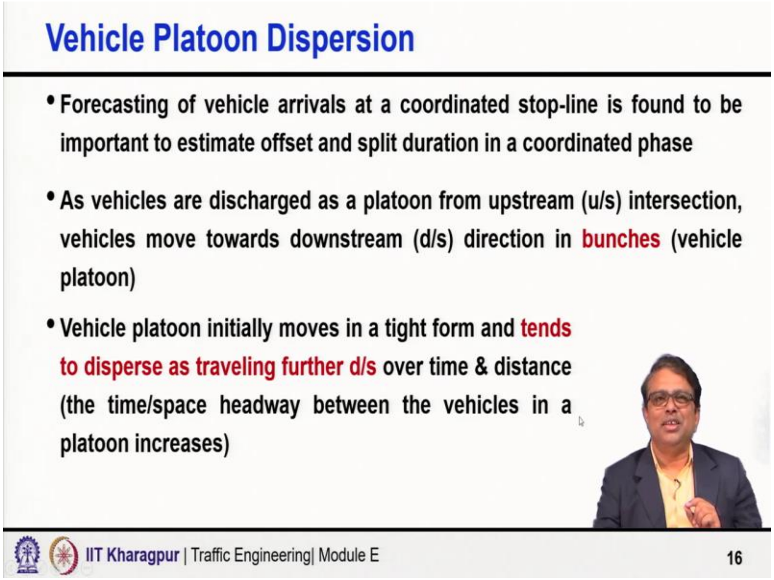

And therefore, forecasting of vehicle arrival at a coordinated stop-line is found to be important to estimate offset, how much offset I should set? It depends on how vehicle are arriving, what is the vehicle arrival pattern at the downstream intersection? And that will help us to decide what will be the offset and the split during duration in a coordinated phase.

As vehicles are discharged as a platoon from upstream intersection, vehicle move towards downstream direction in bunches, all of us we know the fundamental of signalized intersection is vehicle operates and move in platoons, vehicles are arriving at the upstream of the intersection when the signal is red, and waiting, it is the first intersection I am talking about.

Then, when the signal gets green, the vehicle starts moving in platoon, dense platoon, vehicles moving close to each other without significant gap in between, a bunch of vehicle getting released when the signal greens and if there are enough vehicles which are waiting in the queue during the red time, then you will find the discharge will happen at the saturation flow rate, at that level with saturation headway the vehicles are getting discharged.

That is the condition, that is the way the vehicle get discharged. And we want to take advantage of that. That bunch when reaching to the downstream if we can give the green at that time, then the whole bunch which is majority of the traffic along that movement, or with that through movement that can then get benefited.

Overall delay will get reduce, number of stops will get reduce, and so much benefit we can give to for all vehicle trip. But the reality is, also you have to consider another point. Vehicle platoons initially moves in a tight form, and then tends to disperse as traveling farther downstream over time and distance. It is getting released from the upstream signal in bunches I am talking about the first signal, then by the time it is reaching to the downstream signal. The second one, there is some distance in between.

And as the platoon travels through this distance, or over time the platoon gets dispersed. So, I have said, vehicle platoon initially moves in a tight form, and tend to disperse that traveling further downstream over time and distance, the time space headway between the vehicle in a platoon increases.

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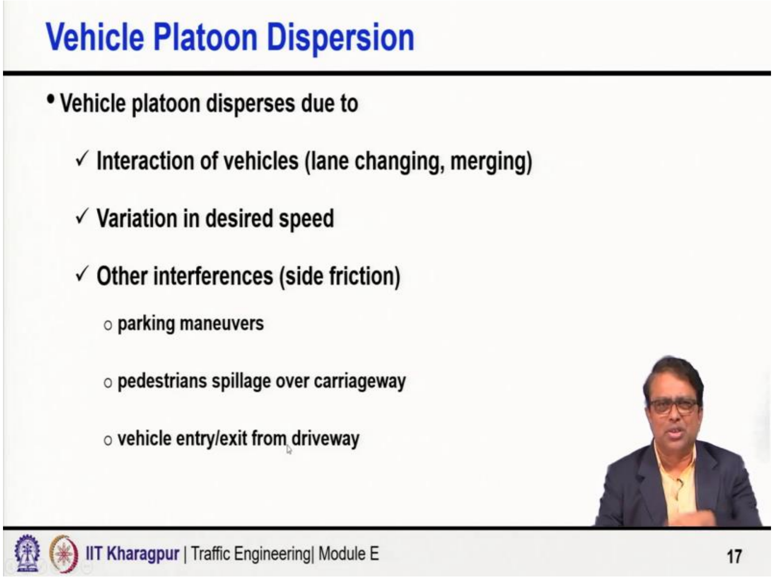

Why the platoon disperse? There are so many reasons. Platoon disperse because of interaction of vehicle, some vehicle lane changing, merging all these maneuvers may happen, variation in the desired speed which is very, very important and pertinent in Indian context because our traffic is heterogeneous, even the cars also within cars also so many different variety of cars you will find. Their speed capabilities, acceleration, deceleration capabilities, vehicle characteristics are different. And there is a wide variety of vehicles that are using Indian roads.

So, variation in desired speed is important. There could be other interference due to side friction, maybe parking maneuver, maybe pedestrian spillage over carriageway, maybe vehicle entry exit from the driveway going to minor road, some vehicles are entering from the side streets and all those.

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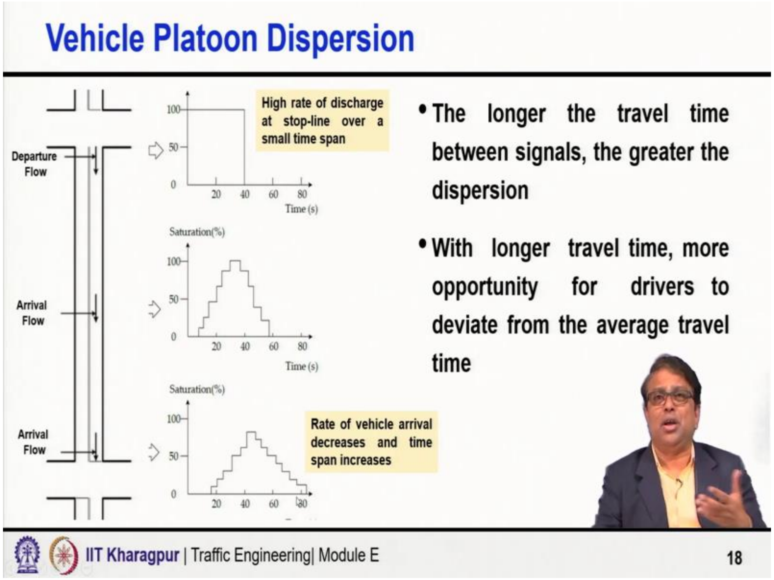

So, as a result what happened, the longer the travel time between signals, the greater the dispersion, that is what I have shown here. Say this is the upstream signal, or first signal and this is the downstream signal which is the second signal, and vehicles are getting discharged from this signal and traveling towards the stop line here. For signal to a downstream signal. When vehicles are getting discharged, it is getting discharged like this. Let us consider this lot of vehicles are waiting, and vehicles are all getting discharged at saturation flow rate, or with saturation headway.

Then, every interval suppose there are 40 seconds green, every 10 second same number of vehicles are getting discharged, or the headway between any two vehicle if you between successive vehicles not any two vehicle, the headway between any successive vehicle always is same, for all this bunches. And the rate of discharge you can say 100 percent. Every time duration 100 percent discharge, that means every time duration the vehicles are getting discharged with saturation headway. In between if I take a section just try to see how the vehicles are arriving, I will not find exactly this pattern by the time some dispersion has happened, some vehicles will travel very fast, some will travel little slower.

So, at the somewhere in between if I follow the arrival flow pattern, I will get like this, it is not like every interval same number of vehicle, not exactly the same figure is getting replicated here. No, already there is a disperse. So, maybe the first vehicle which it got discharged will reach at around somewhere around 10 seconds, after 10 seconds and the last vehicle which got discharged, or some in between also that vehicle may, the last vehicle which is reaching in the intersection may be as long as it is maybe as high as 60 seconds. So already it has dispersed. It is no more 40 seconds, the first vehicle arrival to last vehicle arrival.

Now, by the time you take the stop-line of the downstream intersection, it has dispersed further, that is what it is shown. Further dispersion has happened. And the first vehicle is reaching maybe somewhere around 17, 18 seconds. And the last vehicle which is reaching at the stop line is beyond 80 seconds, maybe 85, 86 seconds, that time it is reaching, so whatever was 40 seconds here became maybe 50 seconds here. And by the time it reached here it is more than 60, 65 seconds all together. The time gap between the arrival of the first vehicle, and the arrival of the last vehicle which vehicle is reaching that we still do not know.

Which vehicle and when that vehicle is reaching, but all what we can do here the first vehicle got discharged and last vehicle got discharged the time gap is only 40 seconds, but in between it was somewhere 50, 55. By the time you go to the downstream signal, it could 60, 65, 70 seconds, it could be even longer depending on other factors as I have listed in the previous slide and also depending on the length of the gap of the distance between the upstream and downstream signal. So, vehicle get dispersed, platoon is getting dispersed.

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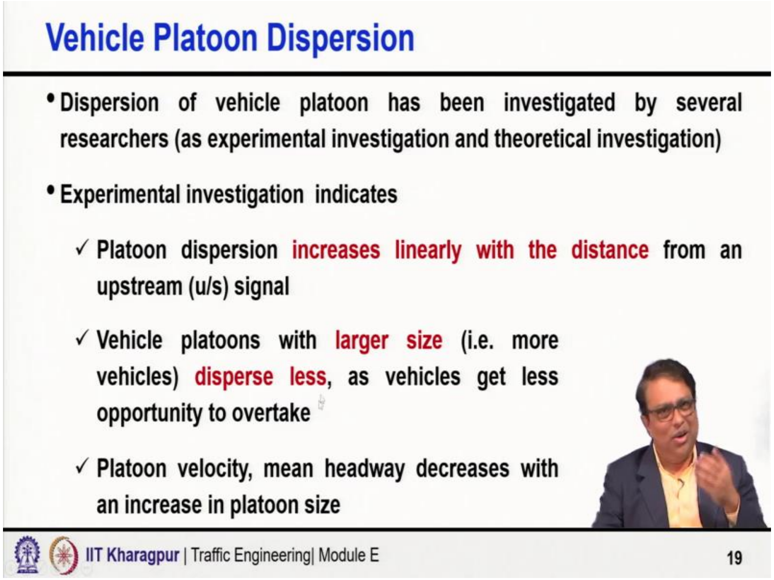

So, dispersion of vehicle platoon has been investigated by several researchers, they have carried out some are carried out theoretical investigation, somehow carried out experimental investigation, and what we find for an experimental investigation, that platoon dispersion increases linearly with the distance, as they travel away from the discharge point initial upstream signal stop line, the higher the distance the more will be the dispersion. Now, vehicle platoons with larger size, if there are more vehicle, platoon could be a large platoon, could be a small platoon, depending on so many factors even the green time.

So, if the vehicle platoon is a larger one, the dispersion will be less as vehicle gets less opportunity to overtake, so many vehicles. So, internal interaction among the vehicle will be very high, and opportunity for overtaking may reduce. Platoon velocity, mean headway decreases with an increase in the platoon size. Obviously, it is linked with the previous point.

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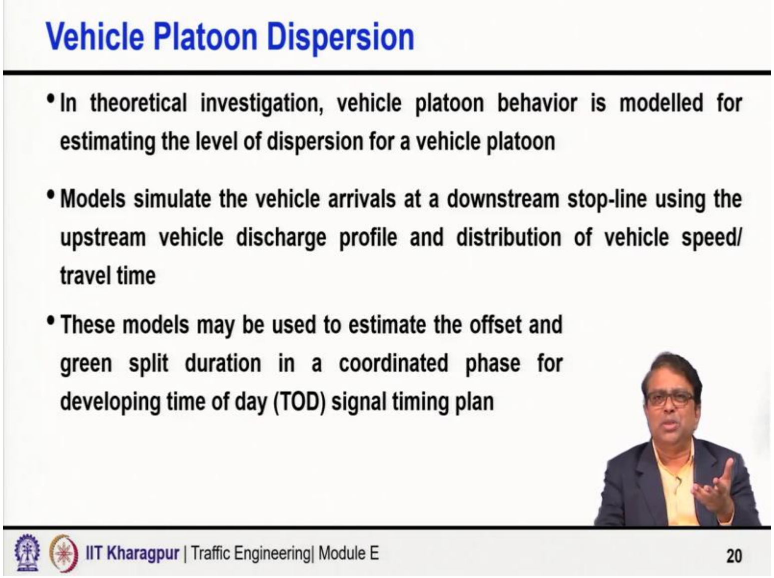

In theoretical investigation, vehicle platoon behaviour is modelled for estimating the level of dispersion for a vehicle platoon, and model simulate the vehicle arrival at a downstream stop-line using the upstream vehicle discharge profile and distribution of vehicle speed and travel time. So, what we try to model here, that if a bunch of vehicle has been released from the upstream intersection like this, then what will be the arrival pattern at the downstream intersection if I some distance apart if I have a downstream intersection, then how I expect vehicles to arrive there, what is the pattern? That we are trying to model.

Now, these models may be used to estimate the offset, because very purpose is that, and also the green split duration in a coordinated phase for developing a TOD signal timing plan, time of the day signal timing plan. Because the how the platoon will reach? How the platoon will travel will depend in the morning peak hour something, and off-peak hour something, lean hour something. So, it depends on the volume of traffic.

So, the TOD plan, TOD signal timings plan that you know I am doing it for the peak period. So, in the peak period, I want to observe or model that how the vehicle get discharge, what site, what duration, and what makes, and all those, and then how they are expected to reach to the downstream intersection. Another time of the day. Another signal setting may be decided.

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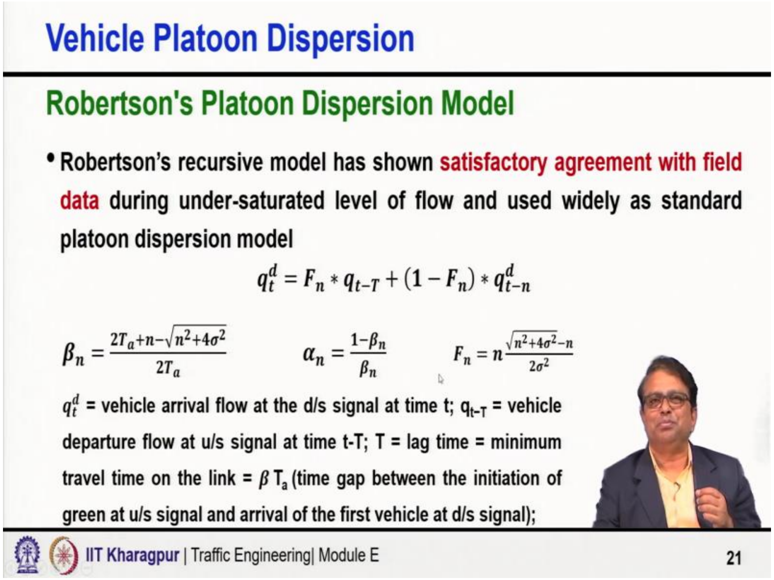

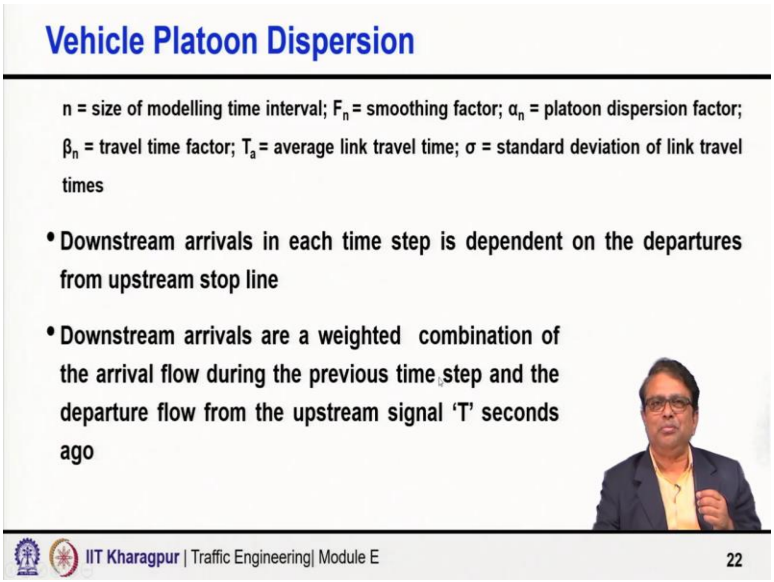

Now, there are many models, Robertson's model, percy's model, there are so many works that have been done theoretical models for doing the platoon dispersion. Now Robertson's recursive model has sown satisfactory agreement with field data under under-saturated level of flow, please observe that under-saturated level of flow and therefore widely used as standard to platoon dispersion model. So, Robertson's model is very, very well-known, widely used, because it shows satisfactory agreement with field data as compared to other models, but under-unsaturated level of flow.

What is this model? How it say? qt d, let us talk about qd, what is d? d is the arrival flow rate at the downstream signal. Here t indicates at time t. It is a function of q t minus capital T. What is q minus capital T? q minus capital T is the vehicle departure for at the upstream signal at time what this we are talking t time. So, it is t minus capital T time. What is the capital T, capital is the lag time that is minimum travel time on link, and how you can calculate it that I have shown it alpha into Ta. So, it is basically the time gap between the initiation of green at upstream signal, and arrival of the first vehicles at the downstream signal.

$$q_t^d = F_n * q_{t-T} + (1 - F_n) * q_{t-n}^d$$

$$\beta_n = \frac{2T_a + n - \sqrt{n^2 + 4\sigma^2}}{2T_a} \qquad \alpha_n = \frac{1-\beta_n}{\beta_n} \qquad F_n = n\frac{\sqrt{n^2+4\sigma^2} - n}{2\sigma^2}$$

So, once the vehicle get discharged, when the vehicle got discharged, and then after capital T seconds, I am trying to see that downstream intersection what is happening? So, this plus 1 minus Fn into qdt minus n. Again, it is qd that means, we are talking of the downstream signal, what is what happened at time t minus n, what is then n? n is the size of modelling time interval. Suppose you say 60 seconds, and every 10 seconds I am trying to understand. How many got discharged, and how it arrived at the downstream signal. The overall time maybe 60 seconds but every 10 seconds I am analysing so that timesteps is the n.

And here, there is one factor called beta, and other factor is called alpha, another is called Fn. Fn is what? Fn is actually called the smoothing factor, I have shown it using this expression eventually you can if you see more you will realise that Fn is actually a function of alpha and beta also. So, alpha, beta and this smoothing factors here it is Fn, here it is one minus Fn.

So, I am not going into very detail, but what we are trying to say here, see there are two terms there, one is Fn into qt minus T. qt minus T is what? Something which is happening upstream before capital T time, and another component is what happened here only in the downstream signal not in the present interval but just t minus n time.

So, what we are saying here, downstream arrivals in each step is dependent on the departures from upstream stop-line, and downstream arrivals are a weighted combination of the arrival flow during the previous time step, this is one component, what is the previous time step? And the departure flow from the upstream signal T seconds ago. So, the second part is here, the first part, and the first part, what I mentioned here is the weighted combination of the arrival flow during the previous time step that is the second part here.

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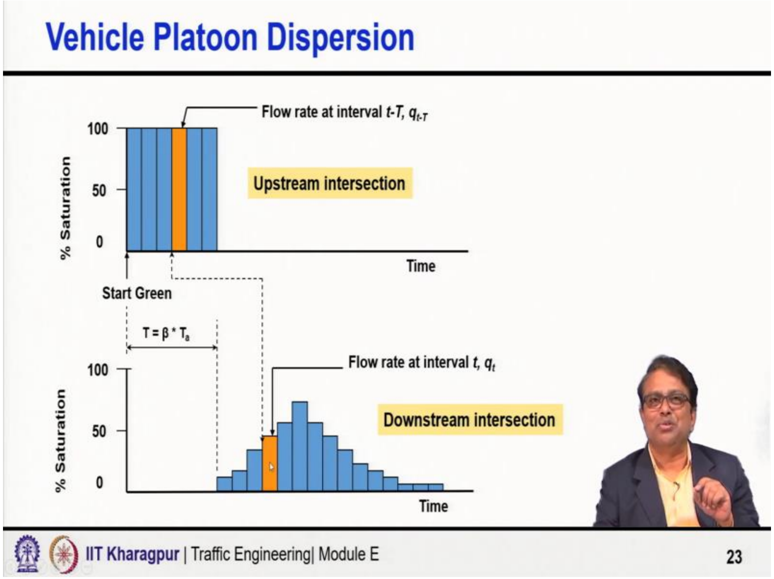

Now, I am just showing here. Suppose, it is the 60 seconds 1, 2, 3, 4, 5, 6, 60 seconds green. So, every 10 seconds interval, if you are taking that n equal to 10 in that case 10 seconds, so, every interval is not n equal to 10, but n is based on 10 seconds interval. So, I am talking about 1, 2, 3, fourth, if I do a fourth interval, then at the downstream also I am trying to see 1, 2, 3, 4.

Now, obviously, because of the platoon dispersion, 100 percent saturation which was discharged here in the fourth interval itself 100 percent saturation has not arrived, and whatever will arrive here, it will some part of this fourth one, and smaller, smaller part maybe from first one second one and third one and slowly, that together will bring this flow rate here, that is what we are trying to do.

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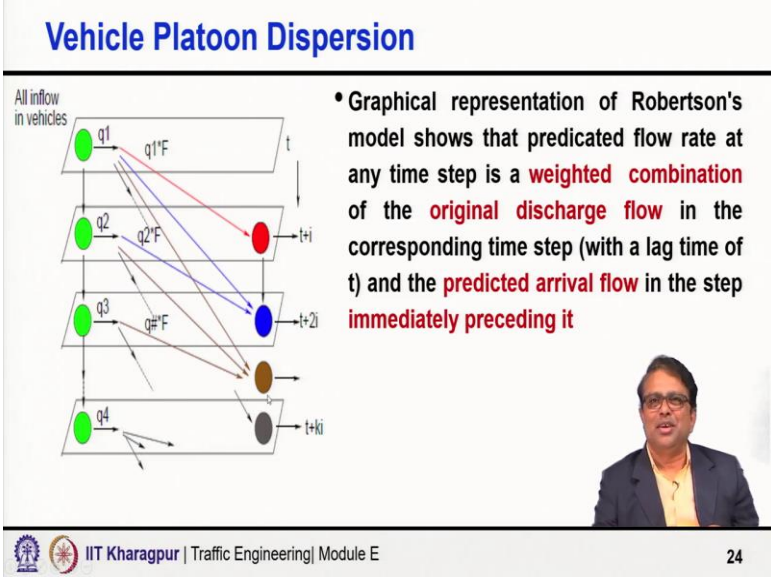

So, essentially what we are trying to say, if this is the upstream discharge at any time interval, then it takes time t to first reach to the next one, next intersection. So, if it is the first interval, downstream first interval will happen after some time, but how much will not all of them will reach in first interval itself in the downstream one, some will go to the second, some will go to the third. Similarly, for the second nothing can come to the first. But second one for the second one a part of that will go to second, a part of will go to third, also a part of will first, go to fourth one.

So, at any interval in the downstream whatever vehicles are reaching, suppose, it is the second one then obviously, it is reaching from the second one, but it is also reaching from the time interval before that, here in this case the first one. So, if you take the third one, maybe it is reaching from part of q3, definitely, but also part of q2 and q1.

So, graphical representations Robertson's model show that predicted flow rate at any time step is a weighted combination of the original discharge flow in the corresponding time steps 3 here, so, it is 3. See 2 here it is 2, 1 here it is 1 of course, some time interval after some time interval, is a step with the weighted combination original discharge flow in the corresponding timestamp, and the predicted arrival flow in the step immediately preceding it, say part of this whatever is the left out is coming here, part of that. Again, whatever is the left out something is going there. So, that is the way.

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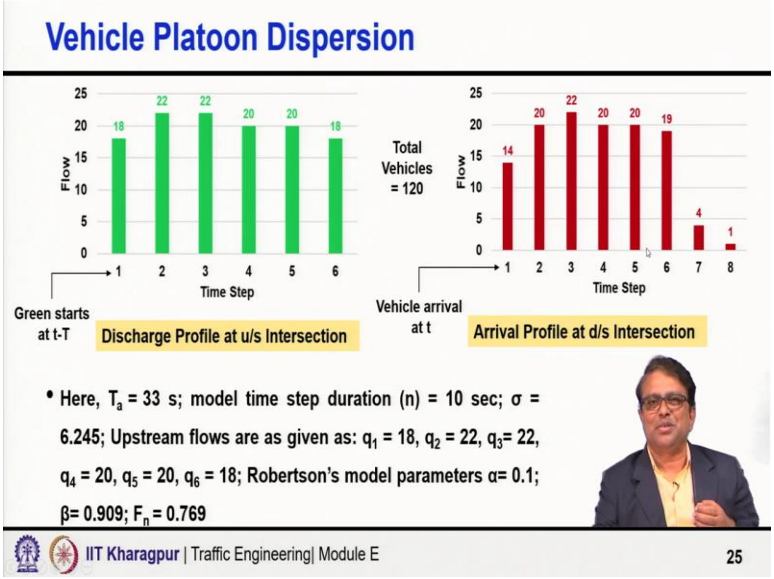

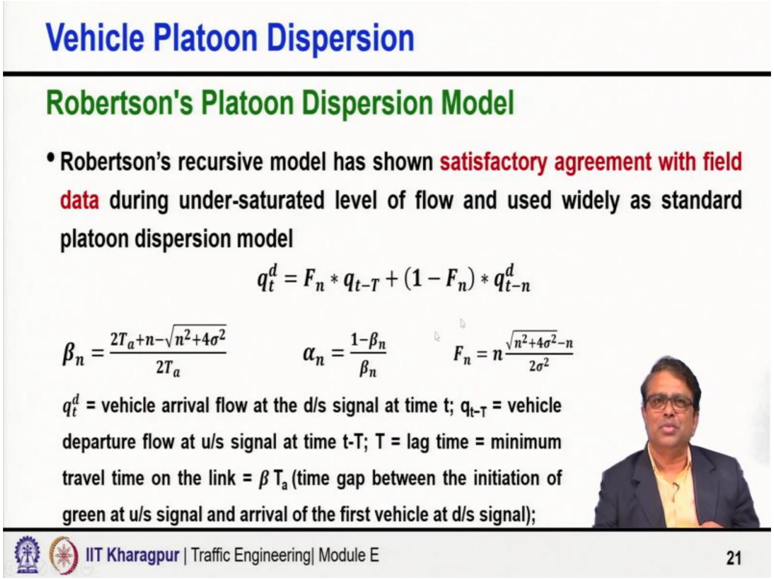

So, here I have given you one example problem, I have shown the flow rate in this 6, 10 seconds interval, how the vehicles number of vehicles are getting discharged at the upstream and given all these parameters that Ta equal to 33 second, model time step duration 10 seconds, and all the inputs as I have described earlier in the earlier slide and given here, you will find eventually the arrival at the downstream intersection will be like this, once you follow this Robertson's model.

And with all this input parameter, you can do the calculation and we can discuss later if you find any difficulty. So, please try that, with this input and as per the model of what I have given here in this shown in slide 21. And with all the inputs which are given here, if these are the input for the model at upstream the discharge, the arrival flow rate will happen like this. So, with this I close it.

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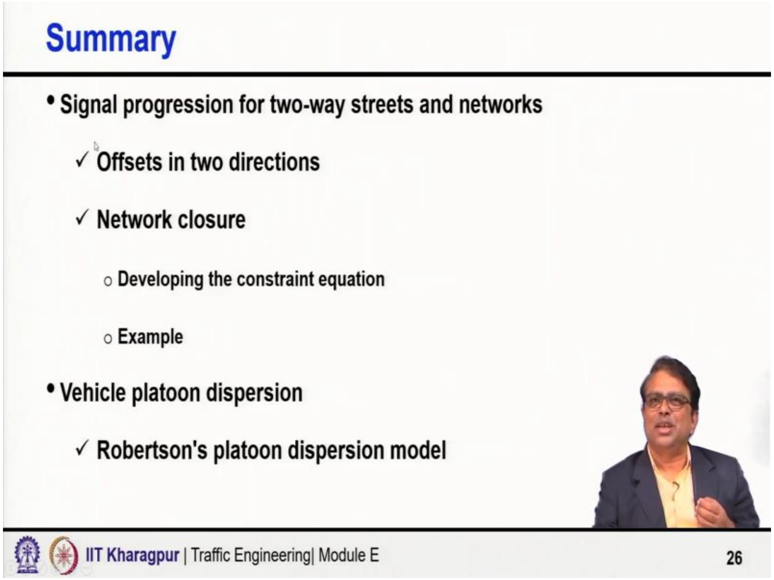

So, we discussed here mainly the two-way streets and networks, the offsets in two directions how they are interdependent, how both directions equal to nC, then the concept of network closure and the challenges, and also mention to you about what is vehicle platoon, how they disperse and very basic understanding about the Robertson's platoon dispersion model. So, with this I close this lecture, thank you so much.