Traffic Engineering
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Lecture 08
Traffic Density and Relationships Among Macroscopic Parameters

Welcome to Module B, Lecture 3. In this lecture, we shall discuss about Traffic Density and the Relationships Among 3 Macroscopic Parameters that is traffic volume or flow, speed and density. In the previous lectures I mentioned to you about traffic volumes and the speed, and in today's lecture, first we shall discuss about traffic density and then explain you the relationships among these fundamental traffic stream parameters.

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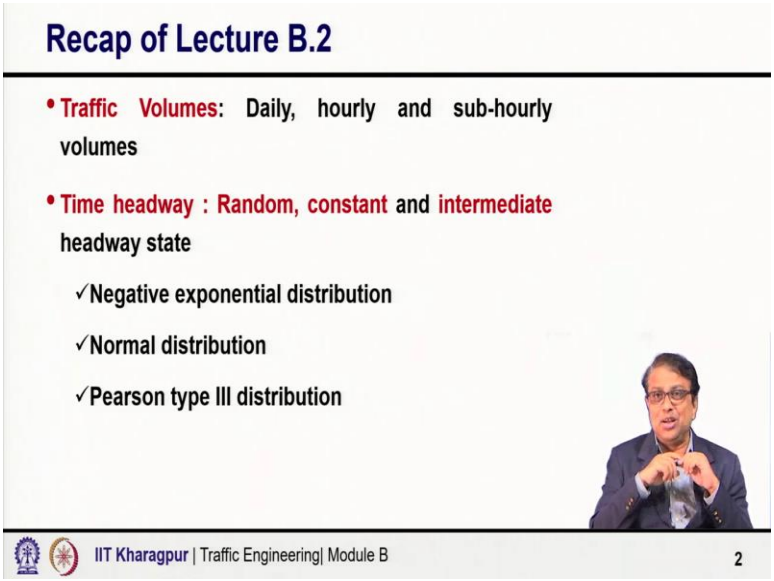

To start with first let us talk about the traffic density. But before that a quick recap on the Lecture 2. In Lecture 2, I mentioned to you about traffic volumes, different measurements, daily volume, hourly volume, sub-hourly volume, why we need such measurements and what are the real applications or uses, then mentioned to you about the time headway, what is time headway, why it is important and also how the distribution of time headways changes with the flow level. At low flow level, it is something random. As the volume increases or the flow increases and the flow is almost near capacity, then the platooning will happen and majority of the vehicle will follow a constant headway and the intermediate flow level it will be something in between.

I also explained to you with an example in each case that how the negative exponential distribution, normal distribution and Pearson type 3 distribution can be fitted to the observed highway data and how they really represent. Primary to conclude that, the distribution of headway will depend on the flow level or the volume level. At low volume level, maybe the negative exponential distribution will reasonably indicate good fit to the data.

But as the volume increases at high flow level, negative exponential may not work. In that case Pearson type 3 distribution may fit better. So, we must keep in mind that when we are fitting a distribution to observe dataset that what is the volume level that we are considering and to keep that in mind that the distribution which is likely to fit to a given data will be a function of the flow level.

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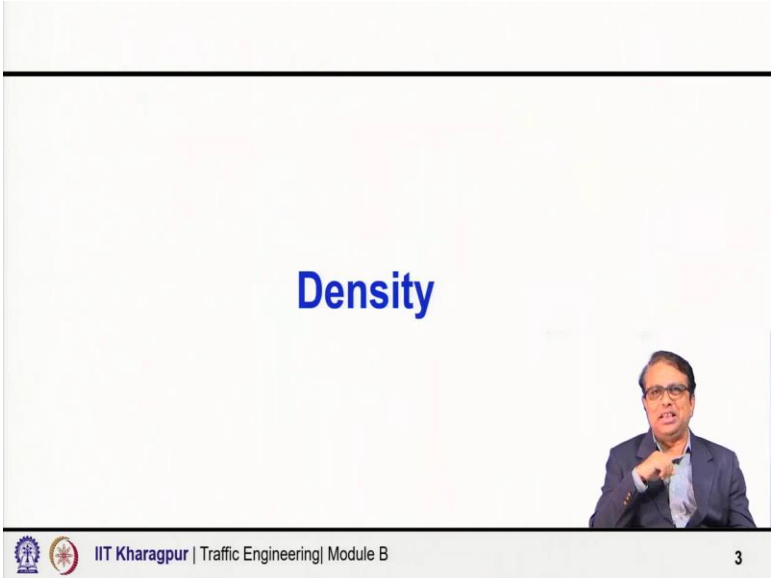

Now, with this background, first today let us discuss about the traffic density. And then we shall talk about the relationships.

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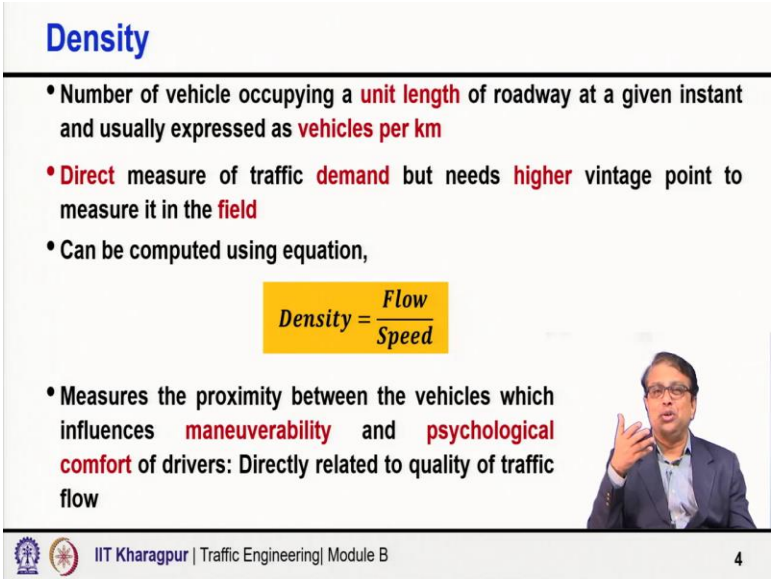

Density may be defined as the number of vehicles occupying unit length, let us consider 1 kilometer of length, at a given instant of time. So, how many vehicles are there occupying that 1-kilometer length. So, we can express density in terms of number of vehicles per kilometer. A direct measurement of density is possible, but sometimes difficult in practical sense, because you need a higher vantage point from where you should be able to clearly view a reasonable length of the road. You want to do photography, you want to do videography, you need a higher vantage point and then focus the camera to take a snapshot or video.

Now, such kind of higher vantage point may not be available at all contexts at all places. So, therefore, the direct measurement may be difficult. But the density can be computed using this equation, as I have shown, flow by speed. Flow unit is vehicle per hour, speed is kilometer per hour. So, you get dimension wise vehicle per kilometer, which is the unit of the density. I will explain you further how these relationships are valid and how they can be, I can explain you even in more details the formulation of this relationship to convince you in a better way.

Density measures the proximity between the vehicles which influences the maneuverability and also the psychological comfort of drivers. If you are driving a vehicle and all around to you if there are too many vehicles that means density is high, there will be psychological effect of that on your driving behavior, on your maneuverability of vehicles, so that's why the density is very important and a very important rather stream parameter which directly relate to the quality of traffic flow.

Higher the density, there will be lesser freedom in the moment and that way the traffic stream or the driver behavior is going to get impacted.

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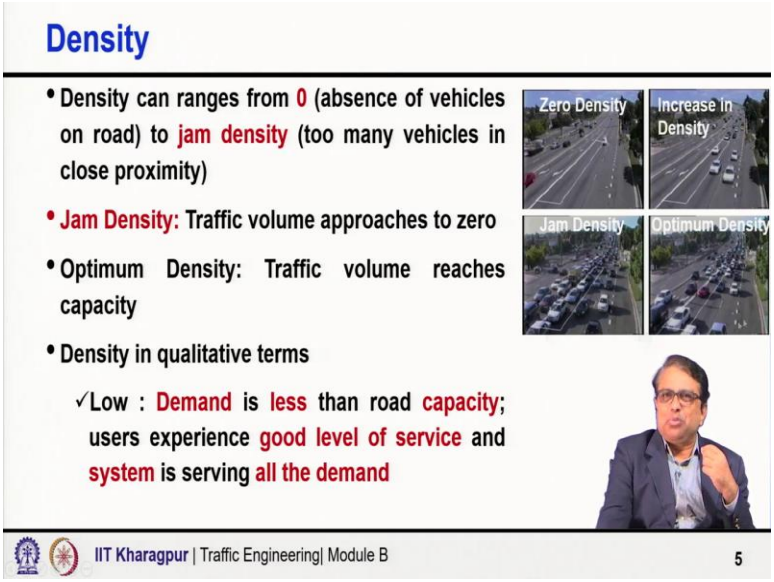

Density can be expressed in the range of 0, the lowest value could be 0, because as usual, you take a kilometer length of the road, early morning hours, extreme lean hours, there may not be any vehicle. So, you take a snapshot, and you do not get any vehicle on the road. So, that is what is shown here, 0 density. If I take a snapshot here, I do not see any vehicle and the road is marked. This is 1 kilometer maybe. And you know that over this length, there is no vehicle so the density is 0.

On the other hand, at the maximum level, the density can attain a practical maximum value. When vehicles are almost jam packed, one after another with minimum gap in between, minimum practical gap in between, so that's the maximum density what you can get under that condition. So, that is called the jam density.

The jam density is basically the maximum limit, higher value, what highest value rather, what highest value of density you can get. And at that time traffic volume approaches to nearly 0, because vehicles are practically not able to move. So, if you are counting the vehicle, saying that how many vehicles are passing at a given time or during a given time, you will find nearly it is 0. So, the volume is 0, the speed is also 0, because vehicles are not able to move, but the density is at its maximum that is called the jam density.

Optimum density you will get when the vehicles are operating at capacity level or the traffic stream is able to discharge flow at the rate of capacity, because that is where we say optimum because you get maximum throughput in a sense from the overall road system. Density can also be expressed in qualitative terms, low density, medium level density and high density.

Here I have shown some of the state. Here I have shown some of the states using these photographs. Here it is 0 density, here it is the jam density, vehicles are one after another with minimum gap, no vehicle can be accommodated practically on the road, and here it is optimum density where there are some gaps, but quite reasonable value o f density not very low and you get the maximum throughput or the volume is near capacity.

As I said, the density can be expressed in qualitative terms. So, the low density you will get when the demand is less, actually less number of vehicle on road than what the road can accommodate. Flow also is lower than what is the capacity. Users experience good level of service because not many vehicles are around. So, the freedom of movement will be very high and system is serving all the demands, because demand is obviously less than the capacity. So, the whole demand is actually served by the road system.

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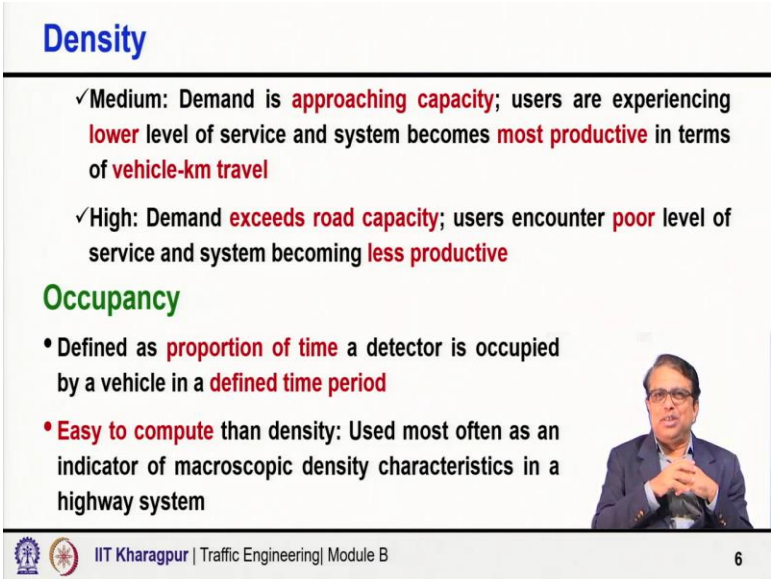

At medium level, the demand is actually approaching towards capacity. So, the density is higher than the previous one. Freedom of movement will be lesser than the previous state. And users are experiencing overall lower level of service, but the system becomes most productive in terms of

vehicle kilometer travel. And as I said, since you are approaching capacity, your throughput is actually maximum to get a traffic volume which is almost equivalent to capacity of the road. So, that is probably one sense, in one sense, the optimal use of the facility. You are able to discharge maximum number of vehicles through the road system.

Density could be even higher. And when it will be higher? When the demand exceeds the road capacity. Whatever road can accommodate, you are trying to pass through more than that number of vehicles. Demand is higher than the capacity. And then upstream of that section, not really the bottleneck where the road is narrow, but upstream to that.

Suppose a three lane is there and then get reduced to two lane whatsoever maybe the reason, maybe the road could not be widened or maybe the, some maintenance work is going on, and if the demand is more than the two lane, obviously, only two lane demand can be served through that bottleneck and upstream of that bottleneck, where actually there are three lanes, there the density will be very high, because that will operate also the flow will be unstable in that section. So, demand exceeds capacity when the density is high.

Users encounter poor level of service. It is the forced flow, stop and go situation. You often find that suddenly the road is narrow and you are trying to pass through that road and during the peak hour the demand is much higher than the capacity of the bottleneck. So, you, before you enter into that section, the vehicle does not move steadily, but it moves some time and then you stop, again a few steps, again you stop, so that stop and go situation or it is called a forced flow situation or unstable flow situation because you cannot move continuously.

Density as it is difficult sometimes to measure directly there is another measurement which can help us to get the fill of the density that is called occupancy. And occupancy is important because these days often we use detector on roads. So, it is defined, occupancy is defined as the proportion of time a detector is occupied by a vehicle in a defined period of time. What is the proportion of time that the detector is actually occupied.

It is easy to compute density from that and use most often as an indicator of macroscopic density characteristics in a highway system simply because it, you can easily probably put a detector on the road and measure the occupancy rather than finding in every place a vantage point where from you can do the photography of the whole road stretch.

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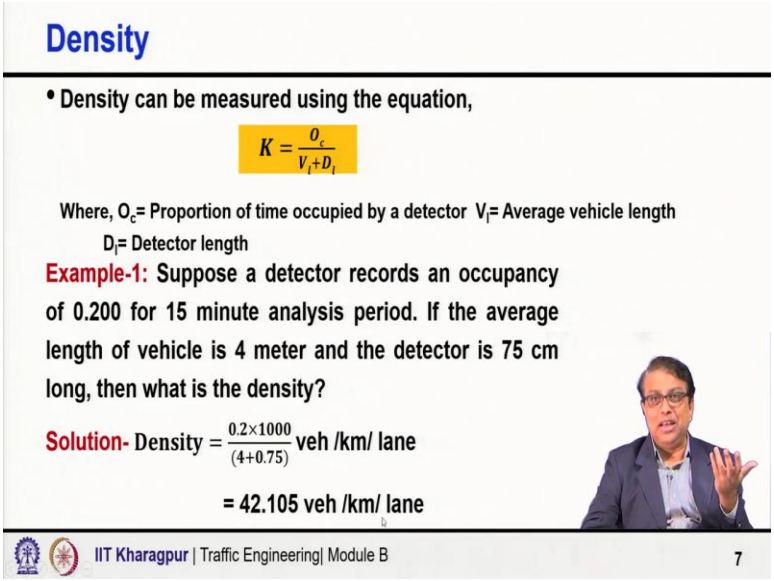

So, once the occupancy is known, you can also calculate the density using this simple equation. $K = \frac{O_c}{V_l + D_l}$; What is the Vl? Vl is the average length of the vehicle and Dl is the average length, sorry, the length of the detector. Different vehicle types are passing through the detector.

So, you take an average vehicle length to the present the stream and Dl is the detector length. Why it is Vl plus Dl, because you see the detector is like this, if a vehicle is entering the moment a part of the vehicle is entered the detector will show that the detector is occupied and it will remain occupied till the, even a small part of the vehicle at the rear end is still on the detector. So, it is, it should be not only the detector length, it is detector length plus the vehicle length that will be there in the denominator.

So, take an example. Let us take an example. Suppose the detector records an occupancy of 0.2 for a 15-minute analysis period. If the average length of the vehicle is 4 meter and the detector is 75 centimeter or 0.75 meter, then what is the density? You can directly use this formula. Oc in this case is 0.2, Vl 4-meter, Dl 0.75 meter, and since we want to express density in vehicle per kilometer, so it will be multiplied by 1000, so you get somewhere 42.105 vehicle per kilometer per lane. Lane is the density.

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Now, going to another measurements, microscopic measure. We discussed about time headway and here we are talking about distance headway.

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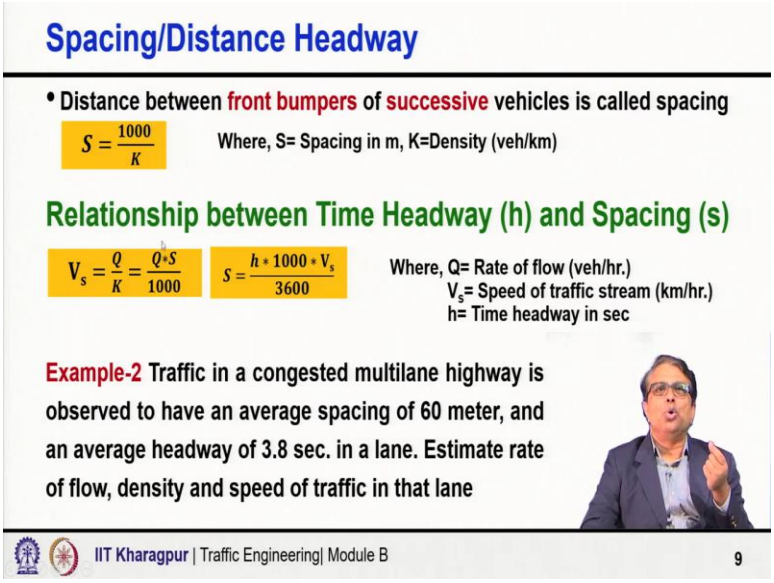

So, time headway was what. It is the time gap between passage of two vehicles, the same point of two vehicles. What we say, front bumper to front bumper. So, I am observing here the front bumper of the vehicle cross this point I record the time, then the next immediate vehicle front bumper again touches this point I record the time, the time difference is the time headway for this pair of vehicle.

Similarly, what is the actual distance between front bumper to front bumper that is actually the spacing or you can call it as space headway.

So, I can take a snap. I can simply measure what is the distance between the front bumper of the vehicle in front to the front bumper of the immediate following vehicle. So, that distance in meter can give me the spacing. So, spacing is what. Unit is in meter, meter per vehicle in a way. So, if the density is known, I know if there are K number of vehicles are there on 1 kilometer then what is the average spacing 1000 by K that is what can give you the density.

$$S = \frac{1000}{K}$$

Now, interestingly this time headway is one microscopic parameter, microscopic because it is for the pair of vehicles not for the whole traffic stream as a whole. Spacing is again microscopic, because again it is for the pair of vehicles not for the traffic stream as a whole. So, these two microscopic parameters are again related. How they are related. Let me explain you that.

You know this equation speed equal to flow by density. I said earlier density is flow by speed. So, speed is flow by density. Now, this K density I can replace by S. So, K will be 1000 by S. Now, what is Q? Q is again 3600 by h, h is the time headway. If the time headway is h, then how many vehicles are passing in one hour if h is in second, 3600 by h. So, I can replace Q by h. And therefore, you get this relation S equal to h into 1000 into Vs by 3600. So, that gives you the relationship between the time headway and the spacing.

$$\boldsymbol{V_S = \frac{Q}{K} = \frac{Q*S}{1000}}$$

$$\boldsymbol{S = \frac{h*1000*V_s}{3600}}$$

Let us take a small example. Traffic in a congested multilane highway is observed to have an average spacing of 60 meter, so S is 60 meter, and an average headway of 3.8 seconds. So, I know h is 3.8 second in a lane. Estimate rate of flow density and speed of traffic in that lane. Fine.

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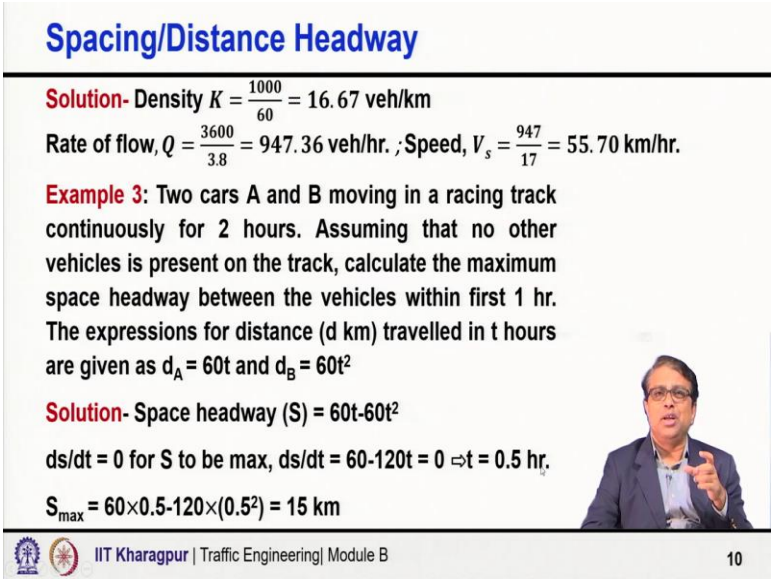

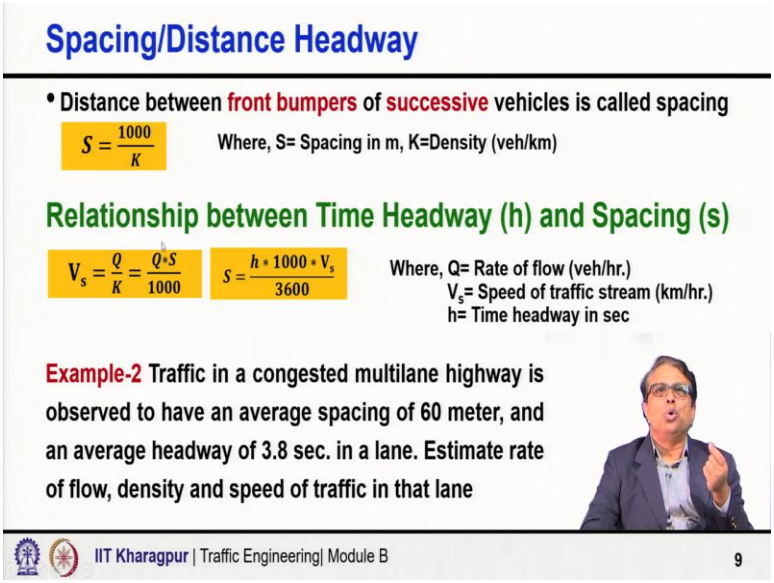

I know there are 60 vehicles, spacing is 60 meter sorry. So, what is the density? Density will be 1000 by 60, so 16.67 vehicle per hour. I know that 3.8 seconds is the headway. So, what is the flow? 3600 by 3.8 so you get the flow. And once you know the flow and you know the density you can get the speed. Simply speed will be flow by density.

Now, let us take another example. Two cars A and B are moving in a racing track continuously for 2 hours. Assuming that no other vehicle is present on the track calculate the maximum space headway between the vehicles within first 1 hour. The expressions for distance that is d distance

traveled in t hours are given separately for two vehicles A and B. For vehicle A dA equal to 60t, for vehicle B the distance dB is equal to 60t square.

So, what is then the spacing at any instant of time? It is 60t minus 60t square. That is the distance between the two vehicles. And we are talking about when the distance will be maximum. So, we can, with respect to time, so we take the derivative of this, ds dt equal to 0 and you get here t equal to 0.5 hour. 0.5 incidentally is within 1 hour. And S max then will be how much. Simply put this time t, so 60 into 0.5 minus 120 into 0.5 square, so you get 15 kilometer. So, at 0.5 hour the distance or the spacing between two vehicles will be maximum and that is equal to 15 kilometer.

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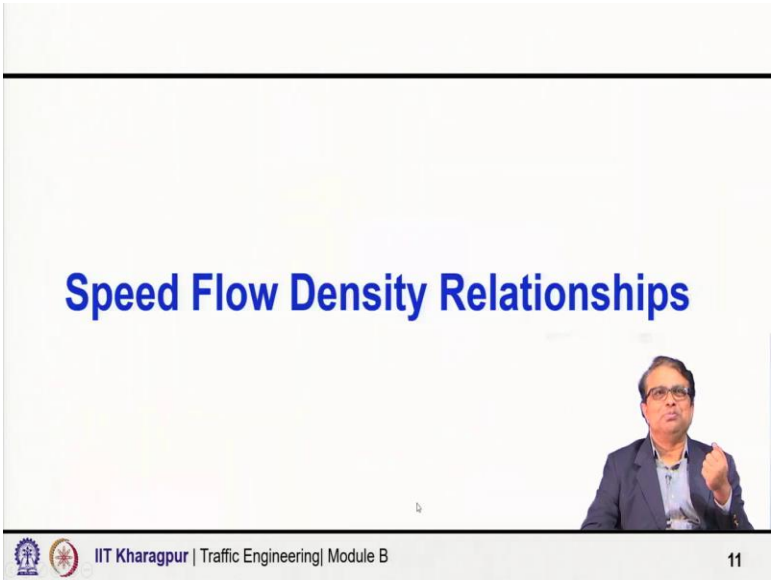

Now, let us go to the next part. That means so far I have talked to you about the traffic volume speed and also into this lecture first part I have talked to you about the density. Now, the speed, flow and density all are related. So, let us try to understand their relationships.

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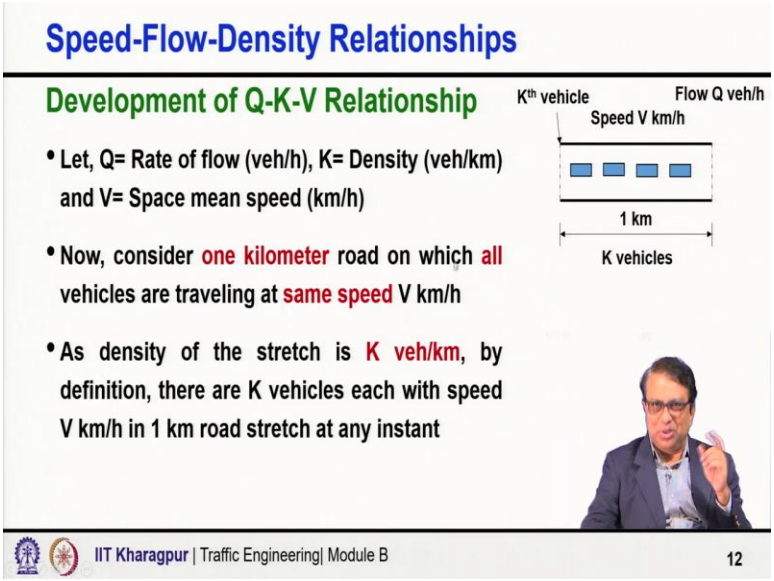

First, let us see how we can convince you about there is, that there is a relationship. Let us consider Q equal to rate of flow vehicle per kilometer, D is the, K is the density vehicle par, sorry, let us consider flow Q equal to vehicle per hour that is the rate of flow, K is the density vehicle per kilometer and V is the space mean speed. Remember that it is not TMS, it is SMS, because we are taking a stretch of the road and for that traffic stream as a whole we are saying what is the speed over that 1-kilometer distance in this case. We will consider a 1 kilometer stretch now. So, that is the space mean speed.

Now, if we consider 1 kilometer of road, then all the vehicles each of them is traveling at the same speed that is V kilometer per hour. And as density of the stretch is K vehicle per kilometer, so, by definition, how many vehicles are there within this 1 kilometer stretch, K number of vehicles. So, K number of vehicles on 1 kilometer stretch and each vehicle is traveling at a speed of V kilometer per hour. So, if this is my first vehicle from the front, after 1 kilometer the last vehicle I will get, if I count the vehicle that will be the Kth vehicle, because the density is K vehicle per hour.

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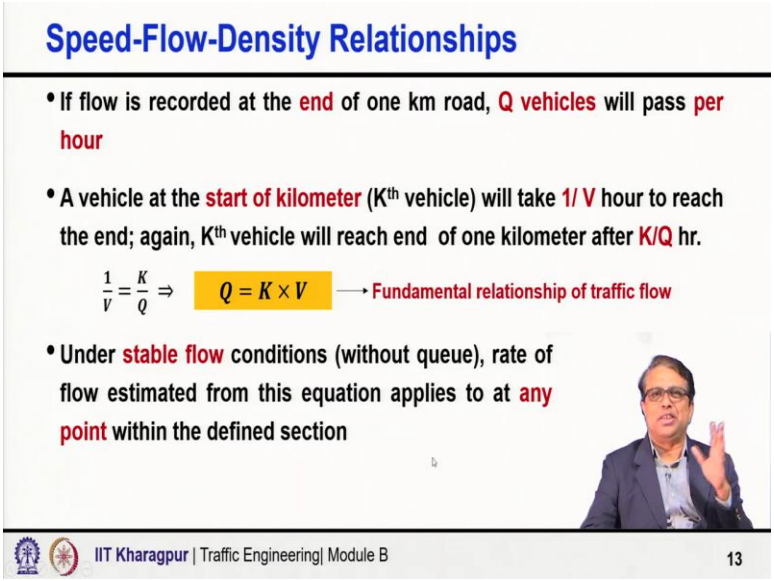

Now, if the flow is recorded at the end of 1 kilometer, if an observer is actually counting the vehicle, how many vehicles are passing through an hour, the observer will get Q vehicles per hour because the flow rate is Q vehicles. So, now you consider at the vehicle at the start of kilometer that means the Kth vehicle how much time it will take to reach at the end he has to, that vehicle has to travel 1 kilometer how much time it will take. It will take 1 by V hour. Why 1 by V hour, because the speed is V kilometer per hour. So, in 1 hour I can cover V kilometer. So, in 1 kilometer, to cover 1 kilometer how much time I will take. I will take 1 by V hour. So, that is simple.

But again, the Kth vehicle will reach at the end of 1 kilometer after K by Q hour. How I am saying that. Actually 1 by Q is what, headway, time headway. So, the Kth vehicle to reach how much time it will take? K into 1 by Q that much hour. So, 1 by V equal to K by Q ($\frac{1}{V} = \frac{K}{Q}$) and that keeps you this extremely interesting fundamental relationship of traffic flow that is Q equal to K into V ($Q = KV$) , flow equal to speed into density. Now, these three are related. Unit wise also you can relate them easily.

Does it mean that I can keep one parameter constant and keep playing around the other two? No, you cannot do that. That is something you should understand clearly. That means this Q, K and V they all will change simultaneously. Always this relationship will hold good, but three parameters will change simultaneously. I cannot keep K constant and then see if I am increasing V how my Q is changing or I cannot say I will keep one constant and then play around the other two, not

possible. All three will change simultaneously, but the relationships will hold good. Now, under stable flow condition without Q, all vehicles are moving steadily, not stop and go situation, rate of flow estimated from this equation applies to at any point within the defined section.

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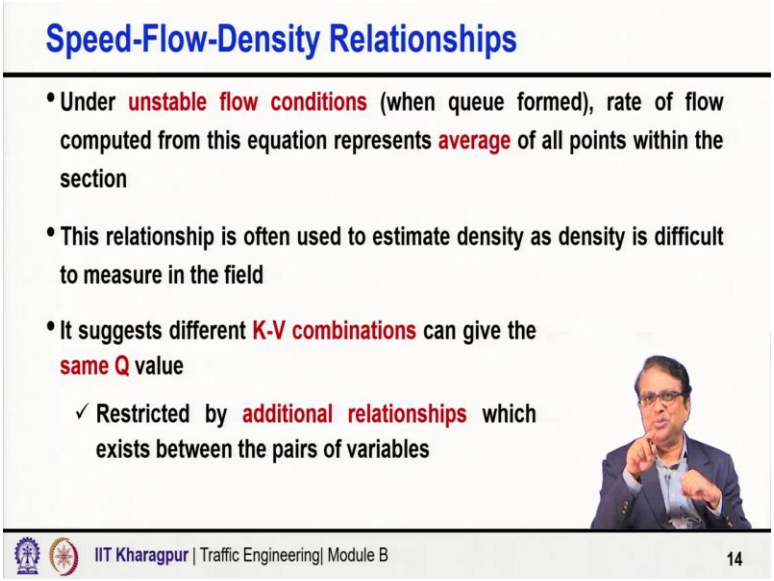

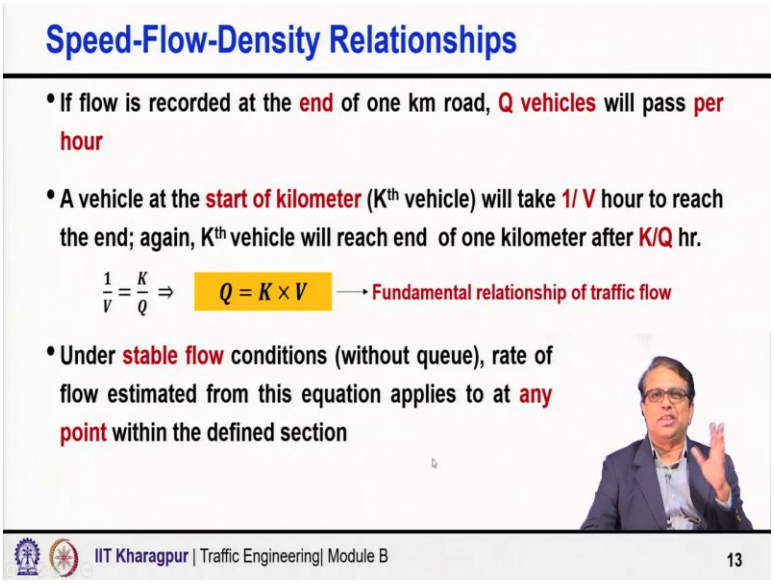

But if it is a force flow, unstable flow, then it may change from point to point, always not be exactly the same, but then the rate of flow computed from this equation will represent average of all points within the section. This relationship is often useful to estimate the density, as I said, it is much easy to measure speed and measure flow rather than measuring density. So, once the relationship

is known and you have measurements of flow and measurement of speed, then you can actually calculate the density.

And this equation, as I said, it suggests that different K-V combinations can give the same Q value, because Q equal to K into V. So, different K and V combinations can give you the same Q value. Yes, that is true. But remember that all these values will change simultaneously, all these parameters will change simultaneously. So, while different K-V combination can give you same Q value, but there are additional relationships that also has to be kept in mind.

Why I, what I want to mean by additional relationships. K and V there is a relation, V and Q also there is a relation and K and Q also there is a relation. So, these three variables are connected together through this equation, but K-V, K-Q, V-Q, there are different relationships. So, those relationships will also hold good, while making it possible to have the same Q with different K-V combinations.

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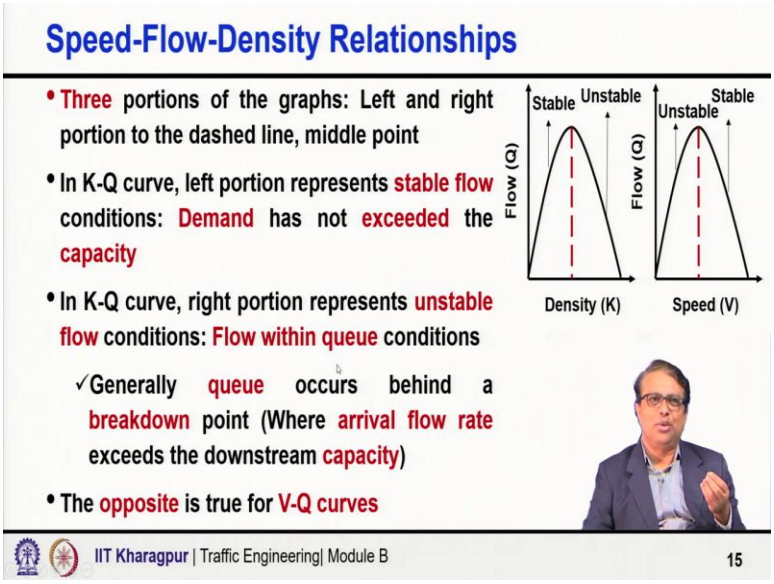

I have shown here. First let me show you the flow density and flow speed relationships and then I will explain you the speed density relationship. Let us consider that at an early morning you are on a highway and trying to measure the flow. Early morning normally the vehicle will be very less on roads. So, if you are actually counting vehicle how many vehicles are passing through a given point over a period of time, you will get the flow value very low, maybe almost 0, almost 0. Why 0? Because there are actually no vehicles on roads. So, the flow is almost 0, density is very low,

but the speed will be very high, because there are only few vehicles road. So, the freedom of movement will be very high. So, you get a point here.

So, whatever operations we are representing through this point on the speed flow car, the same operation I am representing through this point on the flow density car. Flow is less because less number of vehicle, density is less because less number of vehicle, speed is high because less number of vehicle and high freedom of movement.

Now, starting from the morning now the more and more vehicles are on road, so your flow value will increase. And as flow will increase there will be interaction among vehicles. So, there will be loss in the freedom of movement. So, the speed will come down. So, you will find it we are going like this. Speed lesser and lesser, but you are getting higher flow.

At the same time, you are actually moving from this point along this curve, the density is becoming now more and more, because there are more and more vehicles on road and the flow is also becoming higher. And at some point, you will reach to a maximum value of flow which will be the capacity. So, as compared to the free flow condition which is shown here, the density will be much higher at the capacity. As compared to the free flow condition, the speed will be at this point will be much lesser. So, compared to the free flow condition at capacity condition, speed will be lower, density will be higher.

Now, think of another extreme situation. Vehicles are actually, maximum number of vehicles are there on road, bumper to bumper with bear minimum gap the vehicles are one after another. That way the whole thing is packed. So, the density is at its maximum, jam density. That is the point. Density is now maximum. But when the density is maximum, the flow is also 0 or near 0, almost 0. Why? Vehicles are so much packed that actually vehicles are not able to move almost. So, if you still count how many vehicles are passing through a given section over a period of time, you will find very less number of vehicle, almost 0. But now the speed is also very low, because vehicles are not able to move.

So, as you are getting a point here extreme situation at jam density, the same point is represented here on speed flow curve by this point. Speed is almost 0, flow is almost 0. And here on flow density curve flow is almost 0, density is maximum. So, this is another state where you follow my cursor movement. For every flow there is an alternate state of travel where the density is higher,

speed is lower. And the other side of this dotted line, here the density is lower and the speed is higher. So, any flow other than the capacity flow, I can get two operating state one with higher speed, lower density, and another with lower speed higher density.

So, the operation which is with higher speed lower density is called the stable flow operation. It is the stable flow part. The other one with higher density lower speed is unstable or force flow operation. Why this operation then switch over from this point to that point or this point to this point, we will see that. I will explain you further. So, that is what I have explained here what is the Q-K curve, the left portion, right portion and the midpoint is the really the capacity point.

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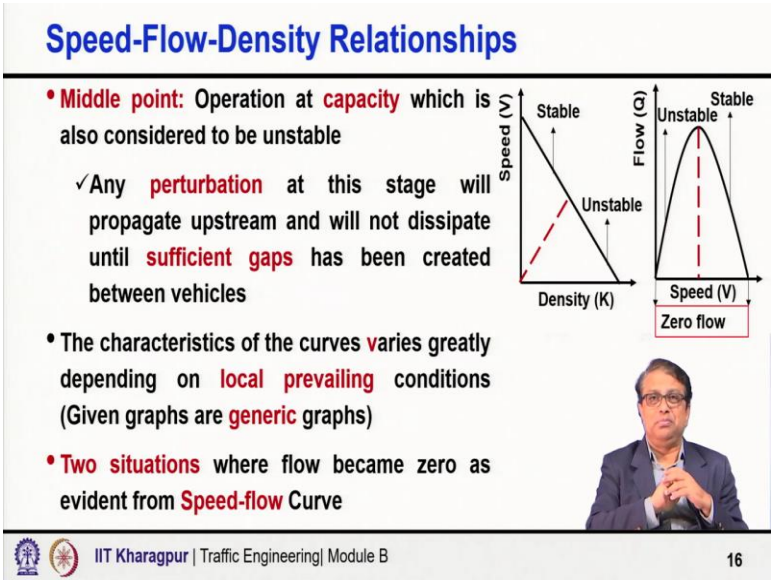

If you look at the speed density curve, it may follow a linear line like this or something similar or close to this. As the density is increasing speed is coming down. So, when at free flow condition density is very small, practically 0, speed is very high. At jam packed condition, jam density, the speed is almost 0, density is maximum. In between somewhere is this capacity point and this portion free flow speed to a speed up to capacity this range is stable flow, because this is this speed flow curve this section and this portion is unstable or the forced flow which is represented by this portion of the speed flow curve.

The characteristics of the curves varies greatly depending on the local prevailing conditions. So, exactly what will be the equation that I have not said so far. The equations may vary, the model

may vary. It will depend on the local condition and so many other things. But basic nature will remain valid, that will be valid.

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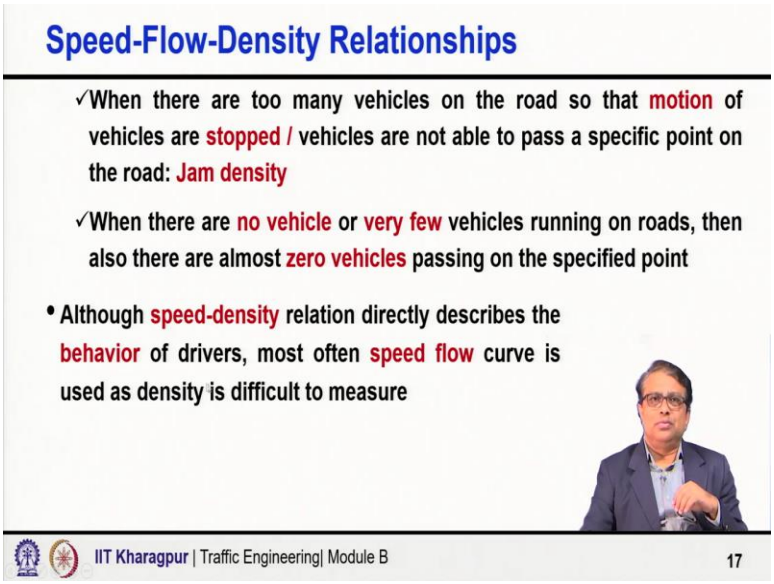

Now, although speed density relation directly describes the behavior of drivers, most often speed flow curve is used as density is difficult to measure. The same point I have mentioned to you earlier. Now, let us consider some practical issues.

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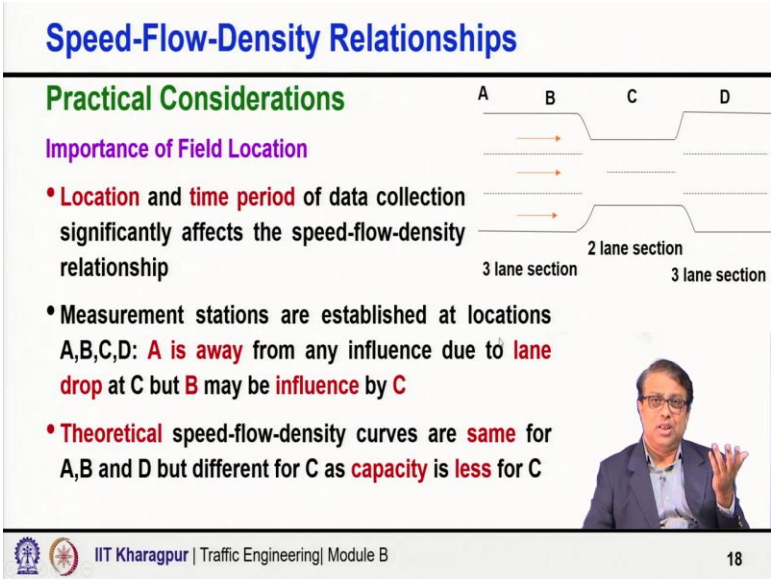

Now, let us consider some practical issues. Let us take a thing, take a section of the road, it is a three lane road, but in between a portion of the road is having capacity of two lane. Maybe due to land acquisition issue you could not widen the road completely. You got only two-lane width here. Or maybe there are three lanes but one lane is under maintenance or some construction is going on so it is not in use. This kind of situation is called typically the bottleneck. Bottleneck means capacity of this portion is lower than the capacity of the road upstream or downstream of it. That is what is the capacity and constraint or the bottleneck situation.

Here we are considering one-point C which is at the bottleneck, another point D which is downstream of the bottleneck because traffic is moving in this direction, one stream immediately one section B immediately upstream of this bottleneck and another section A which is far away from this bottleneck and where the operation of traffic is no way influenced by the presence of this bottleneck. Now, what will happen?

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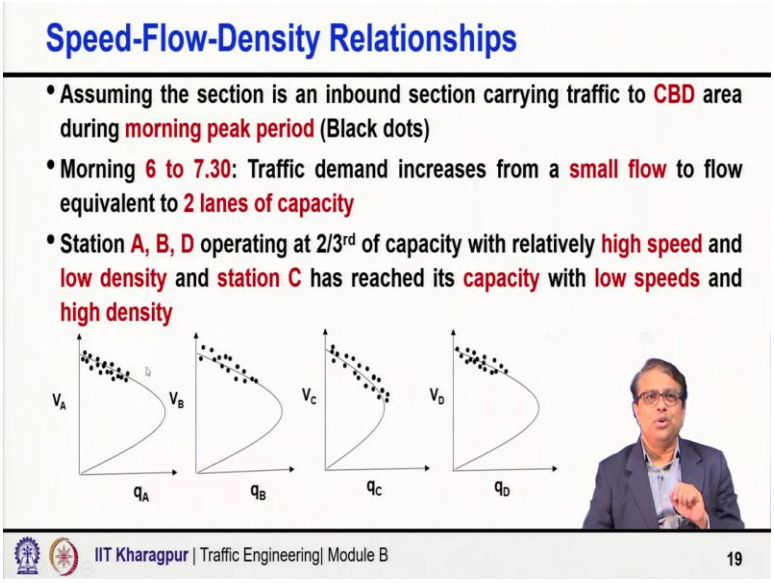

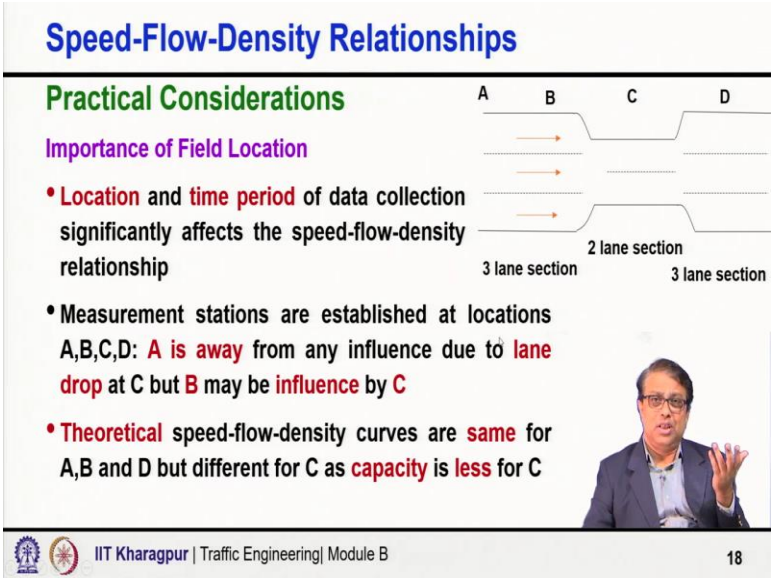

Suppose you consider morning 6 to 7:30 the traffic gradually is increasing and it goes up to a demand which is equivalent to capacity of a two lane. So, that means my demand has gone from 0 to a level which is equal to the capacity of this section C. So, section A will operate with two-third, the demand, current demand two-third of its capacity, for B it is two-third of its capacity, C also is capacity so demand to capacity ratio is 1. The demand is exactly equal to capacity, so all the demand will pass through. And D also will have a demand two-third of its capacity. You have three lane, you have demand equivalent to two lane capacity.

So, A, B and D will operate at the same state. On the speed flow curve, you will get points up to two-third of the capacity. And point C you will get points actually spreading up to the capacity point, but all the demand is passing through section A, section B, section C and section D. The speed of vehicles will be higher in section A, B and D because capacity is higher. In the speed flow diagram the point will be differently located than the point C, section C, corresponding speed flow curve.

So, I am showing it here. Nearly two-third of, if I consider this as the capacity flow, then I got points up to two-third of the capacity. Here also same, here also same. But here in section C it has gone up to capacity. But all the flow is able to pass through. Speed here will be higher because on a speed flow curve this point is at two-third of the capacity where it has come down up to capacity. So, obviously the flow has gone up to capacity. The speed has come down further. So, the speed of vehicles on sections will be lower, but anyhow all the vehicles will be able to pass through.

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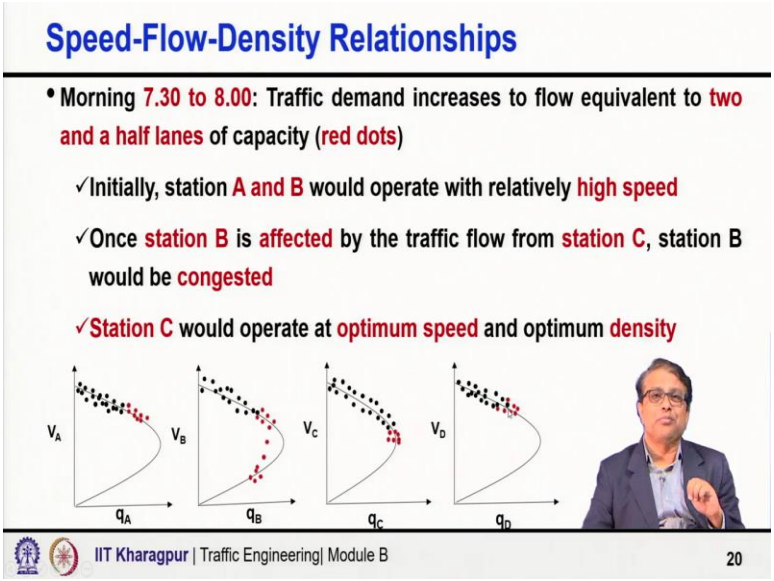

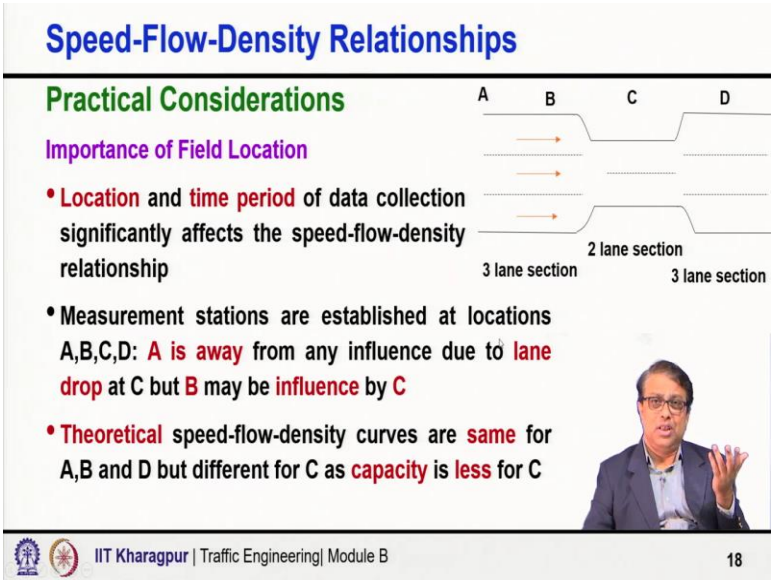

Now, let us consider 7:30 to 8 o'clock now you consider that now the demand is equivalent to capacity of two and half lanes, not two lane anymore, but two and half lanes, further increase. So, what will happen? This section capacity is only two lane. So, only demand equivalent to the capacity of two lane will be able to pass through this section, nothing more. And because only demand equivalent to two lane capacity will pass through this section, section D will only receive demand equivalent to two lane capacity, nothing more than that.

And there will be immediately accumulation of vehicles, immediate upstream to section C that is on section B and the section D will now go from stable operation to forced flow operation because

of this bottleneck and access demand. A which is further upstream away from this influence will still have three lane capacity and it will operate with two and half lane demand without having much problem, because the demand is still less than the capacity.

Here in section B although there are three lanes, so this section capacity is not an issue, but still the operation will switch over from high speed low density to low speed high density force flow operation. So, you can learn here if there is a bottleneck and there is really capacity constraint demand is higher, then the worst condition is going to be not for the bottleneck section but it is the section immediately upstream of the bottleneck. And if this continues for a longer time, the length of the section B will be longer and longer over time.

So, what you will get here? The additional points, which have come between 7:30 to 8, that is shown here using the red dots. So, at section A you will have some more red dots. You have higher flow. Earlier it was two lane capacity, demand equivalent to two lane capacity, now demand equivalent to two and half lane capacity so some more points towards the capacity you are getting but otherwise no problem.

Here it will go to forced flow condition. C will operate at or near capacity only. And D will be some red and blacks are overlapped here, because D is still getting only two-lane input. So, it will be still on the two lane. Earlier also it was getting two lane volume. Now, also it will get two lane volume. So, it will operate around this point shown as red dots. But some of the red and black dots are actually overlapped. That will be the operation.

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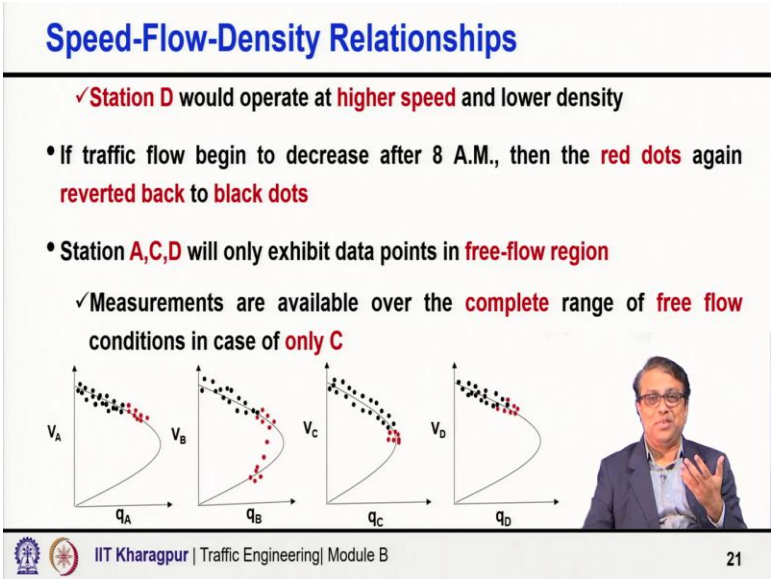

Now, what happens after 8 A.M. if the traffic volume or the demand reduced, is reduced, becomes lower and eventually become very low. The red points will again go back to black points. Black will again move as the volume becomes lower. So, if traffic flow begin to decrease after 8 A.M. then the red dots again reverted back to black dots. Now, here section A, C, D will exhibit only data points in the free flow region. You will get here in the free flow means stable flow, rather not free flow only, but stable flow region.

And C will, A, B and D, C will have up to capacity. B and, A and B will, A and D will not show the data point up to capacity, C will only show and B will also show some points on the forced flow operation. So, a lesson learned from this, where you were taking measurements and under what condition that matters a lot, what points you will get. You collect the data and you say I am getting like this. So, how you will get the points it depends on where you were collecting the data and under what conditions.

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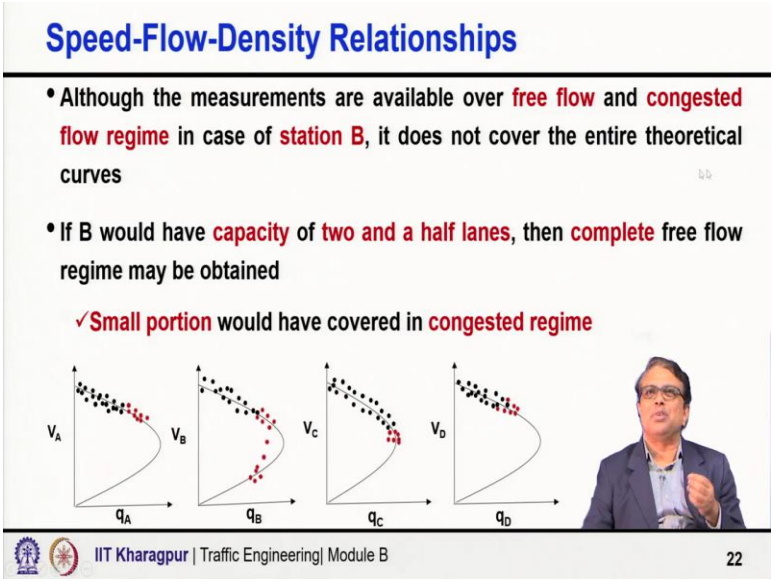

So, although the measurements are available over free flow and congested flow regimes in section B does not cover the entire theoretical curve. If B would have capacity of two and half lanes instead of three, then some of the red points would have come here and also go to, anyhow go to forced flow condition because of the bottleneck of the constraint capacity in C section. But you would have got some more points probably almost up to capacity.

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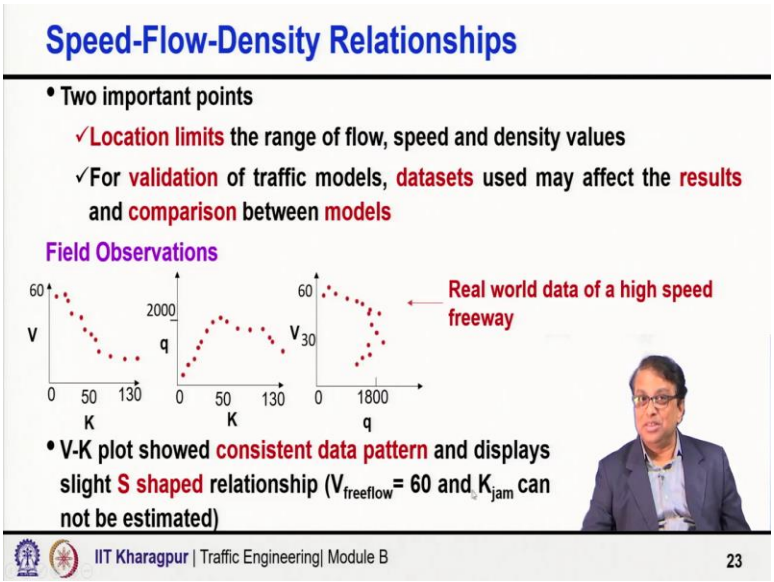

So, two important points to take away from this discussion. One is location limits the range of flow speed and density values where you are measuring. And therefore, for validation of the models

dataset used may affect the results and comparison between models. I may not observe everything in every context. It depends on where I am taking the measurements and under what traffic conditions only that will constrained what kind of data I will get.

Quickly I will show you two examples. This is a real-world data for a high-speed freeway. High speed freeway normally we are able to cover quite a good range, low to near almost near capacity to some points even in the forced flow range. But you can see you may not still get 100 percent.

So, this example for this V-K plot showed consistent data point and displace somewhat like a set or reverse a set, whatever you say. And it gives an indication to you that the free flow is somewhere around 60 kilometer per hour and K jam is somewhere around this, but no I cannot conclude, because I did not get points which are touching the K axis. I still do not know. I know it came down. Came down almost up to 130, but it did not touch. So, I cannot say that jam density is 130. I know it is even beyond that and I cannot tell the value.

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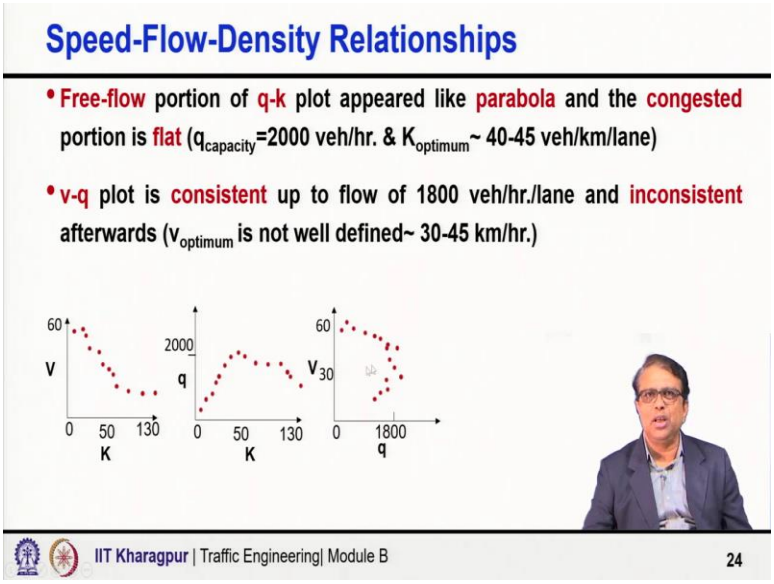

Similarly, free flow pattern portion of the Q-K plot if you see, it tell that it looks like a taking a shape of a parabola, but then the congested portion here it became somewhat flat. I did not probably get the full parabola also. It gave an indication that it is likely to be in the shape of a parabola, but congested portion I did not get points like that I got somewhat flat point, indicating that somewhat the capacity is around 2000 vehicle that is what is going and the K optimum at the capacity is somewhere in the range of 40, 45. And if you look at the V-Q plot, it is consistent up to 1800 point,

but then inconsistent afterwards, not really telling the peak here. And V optimum is not very well defined, but we know it is somewhere going to be in the range of 30 to 45 probably that much.

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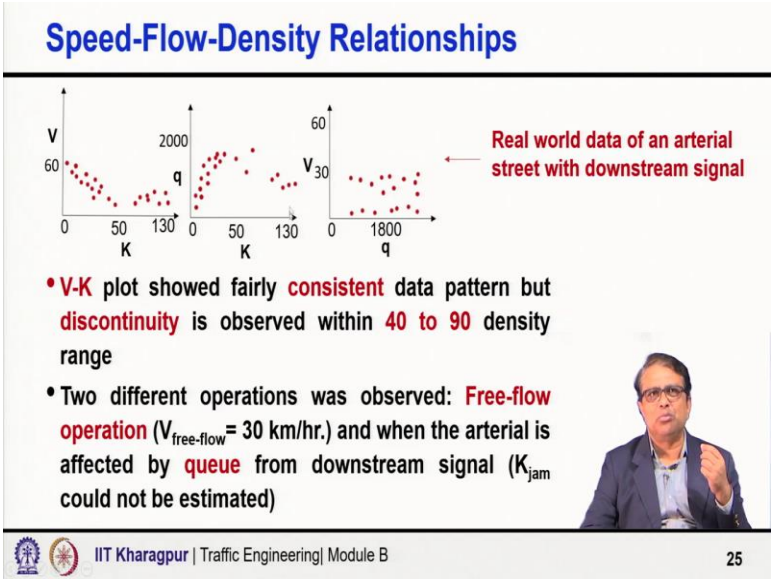

Whereas on an arterial road if you collect the data you may get entirely different types of points, because arterial with an effect of a signal in the downstream, so downstream signal will affect the operations, especially in the congested hours. So, you may get scatter like this. And it may again tell you that V-K plot shows fairly consistent data pattern but discontinuity observed between 40 to 90 somewhere, we are not getting data point continuous, we exactly do not know the pattern. Here also free flow operation V free flow speed is around 30 kilometer per hour. K jam, jam density I cannot estimate because it did not really come to that point. Here also not touching. So not very confidently I can estimate.

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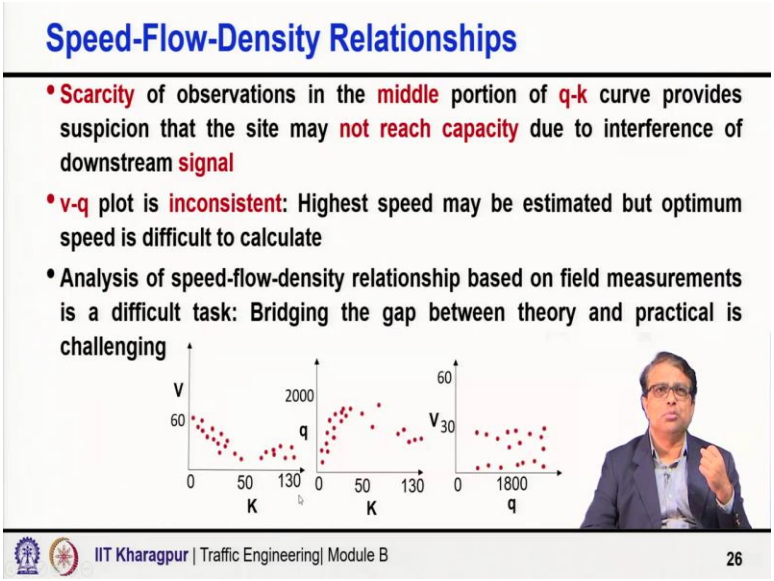

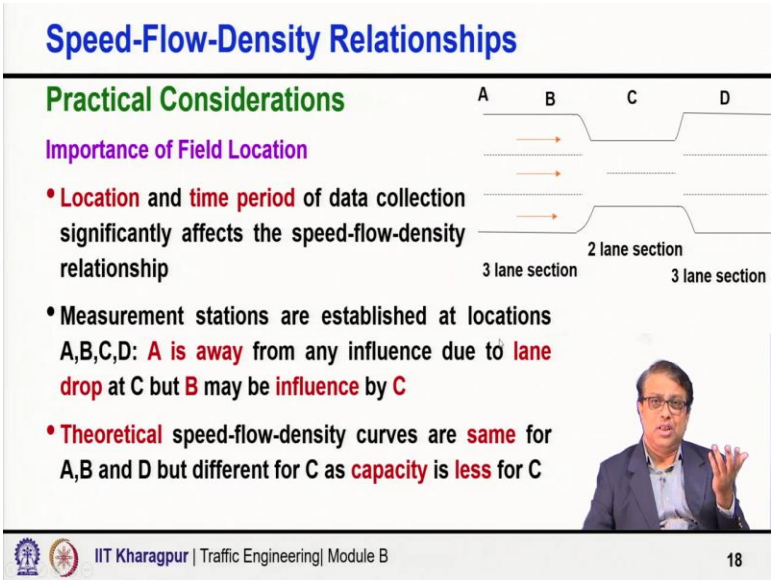

And like that you will get some more observations as I have said here. But the essence is what, essence I am trying to say. That whatever theoretical shape I have showed speed flow, speed density and flow density, the relationships, the actual variation is true theoretically but not that always you just go to the field and collect some data and you will be able to construct that. You will be able to get that. The entire region starting from free flow to capacity to forced flow the entire portion, entire range of operation you may not be able to observe.

And it matters where you were collecting the data. The same data, as I said, we are collecting here at point D, point C, point B, point A they will tell us four different things depending on what is the

demand as compared to the capacity of this bottleneck section. So, where you were measuring the data, what you were measuring, which period you were measuring that is very, very important. So, you what you will actually get or observe it depends on that.

So, analysis of speed flow density relationship based on field measurement is a difficult task. Bridging the gap between the theory and the practical is really challenging, because the kind of data what you will get it depends on where you were collecting the data and what time you were collecting the data, what is the capacity, how much is the demand and so many other factors.

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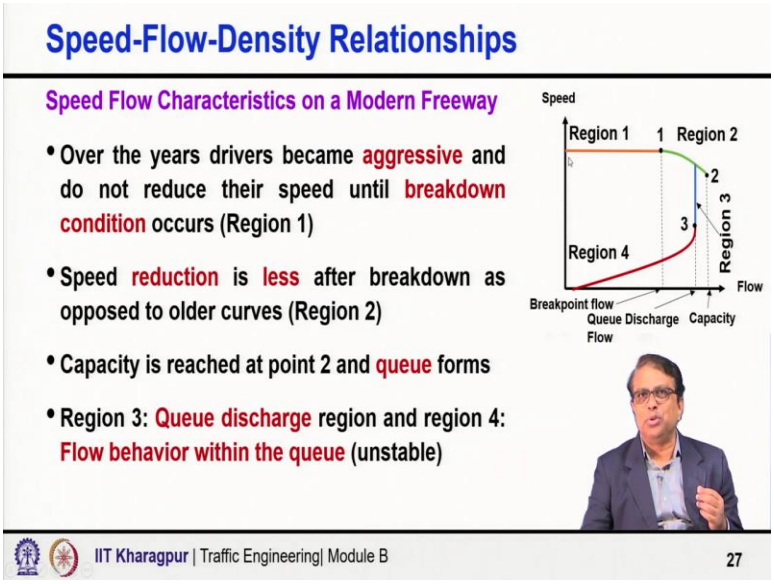

Now, before I close, a very quick look a the speed flow characteristics on a modern freeway. Look at this freeway. So, access control, high speed facility. Drivers over here also now became aggressive. And therefore, they really do not reduce the speed until a breakdown condition occurs. Theoretically what we showed? We showed a curve like a parabola, like this. But you can say the initial portion is actually flat. It does not. 1 vehicle, 2 vehicle, 3 vehicle, 4 vehicle, 10 vehicle on road it does not really matter.

So, the up to certain flow level there is no impact actually on freedom of movement and drivers are quite aggressive to maintain the speed. After that in region 2 speed reduces, but reduces not so sharply as we have observed in earlier cases. If you take a major arterials, you will probably get a different picture. Or if you take simple a national highway or a state highway you will get a

different picture, but here it is access control, so the reduction in speed. Even up to the capacity point the speed reduction is not so significant.

In another road other than modern freeway probably, we would have got the curve to follow like this and get capacity point somewhere here, somewhere here and with a curve of like this. But that much speed drop has not happened, yes. Beyond point 1 up to point 2 there is a speed drop but not as sharp as we have observed in older curves. Then the C is the queue discharge part, queue discharge region you can all and region 4 is the forced flow condition.

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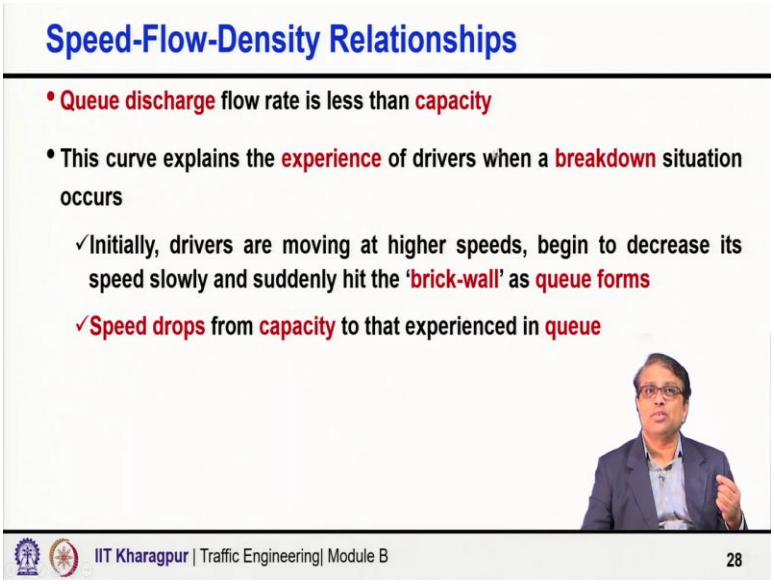

So, queue discharge flow is less than the capacity and the curve explains the experience of driver when a breakdown situation occurs. Initially drivers are moving at a higher speed, begin to decrease the speed slowly beyond the threshold point, but not drastic reduction in speed. But then eventually they hit the brick wall and as the queue forms. So, speed drops and the capacity, from capacity to that experienced in queue.

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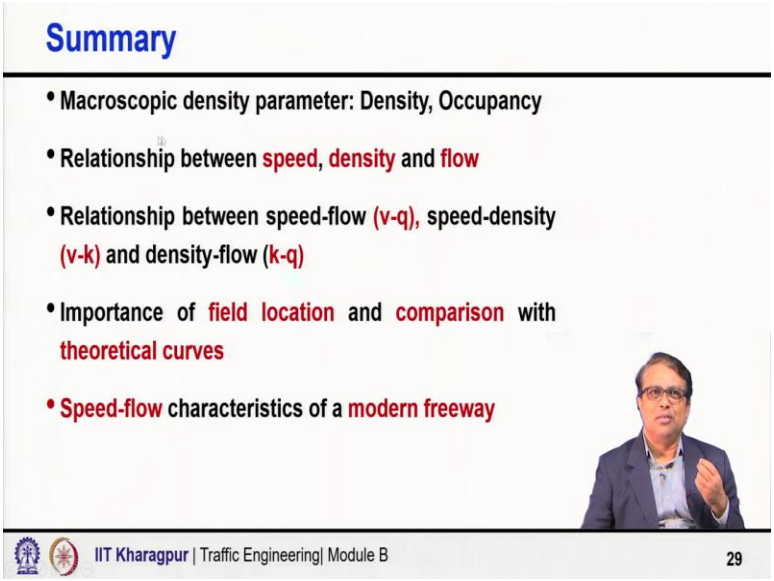

So, overall, here we talked about the macroscopic characteristic's density and the microscopic characteristic occupancy, macroscopic characteristics density and also how the occupancy can be used to measure density. Then the relationship among speed flow density curve and individual speed flow, speed density and flow density and highlighted the importance of field location when you are trying to collect data and comparison with the theoretical curve. Also mentioned to you about how the speed flow curve may look like for modern freeway. With this, I close this lecture. Thank you so much.