Traffic Engineering
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Lecture 10
Multi-Regime Models and Characteristics of Interrupted Flow

Welcome to Module B, Lecture 5. This is the last lecture of this module. And in this lecture we shall discuss two things; first about Multi-Regime Models; and then about the Characteristics of Interrupted Flow.

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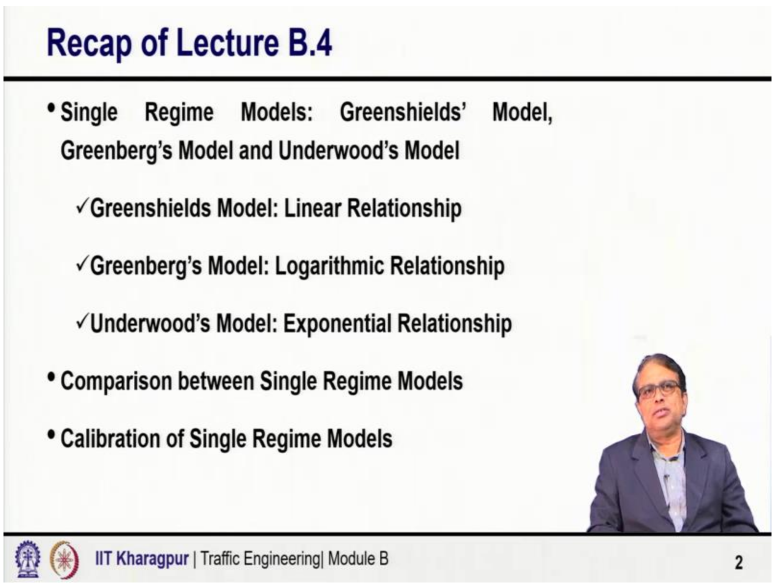

In Lecture 4, I discussed about single regime models, particularly three models, Greenshields' linear model and then Greenberg's model and Underwood's model. Of course, Greenshields' model when I said linear it is flow density, speed density model, sorry, when I said Greenshields' model, linear model, I mean that speed density model is linear.

Then the non-linear model Greenberg's model and Underwood's model. Greenshields' model follow linear relationship of speed and density, Greenberg's model follow logarithmic relationship and Underwood's model follow exponential relationship. I also mentioned to you about the comparison of all three models, which are all single regime models. Then highlighted a few important points related to the calibration of single regime models, how we calibrate.

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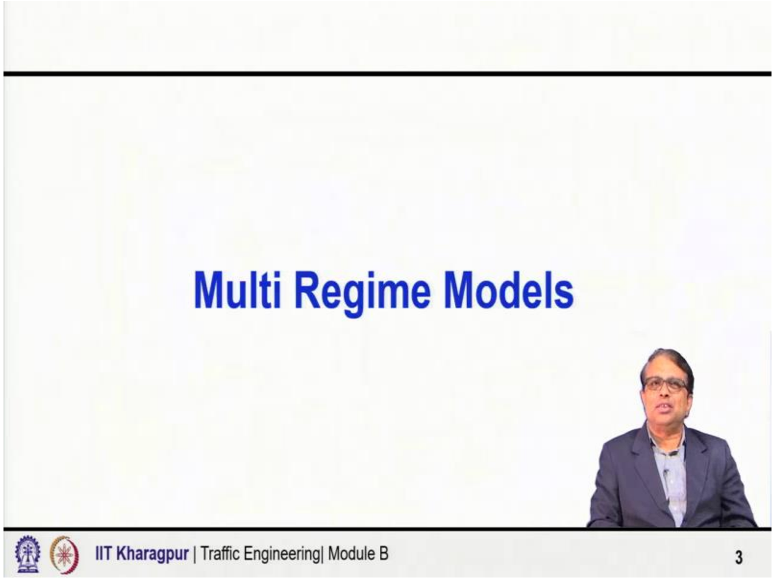

With this background today, first we shall discuss about multi-regime models.

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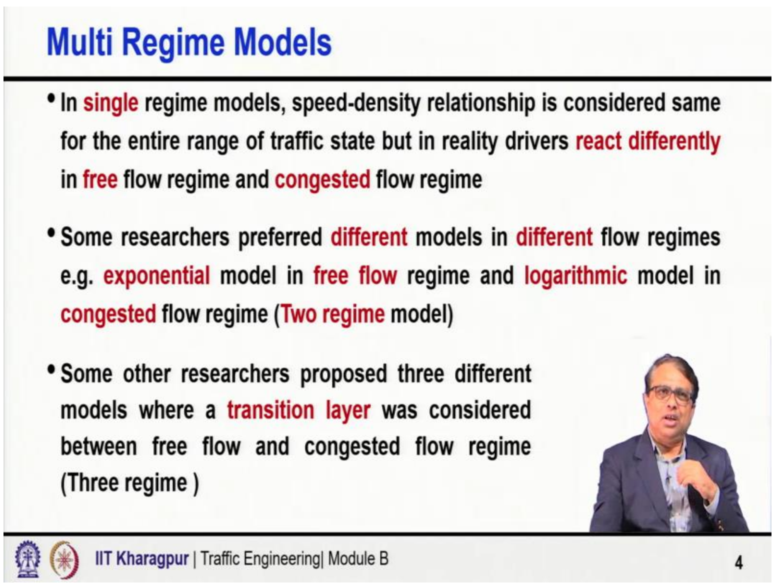

In single regime model, speed-density relationship is considered the same for the entire range of traffic state, how the speed varies with the density that is expressed for the entire range of speed or density, I am saying, in general, for the entire range of traffic state using a single equation. That means, the same equation is applicable for free flow regime or we can say the stable regime and also for the unstable or congested flow regime.

But some researchers found that single regime model do not work properly in many cases. So, they preferred different models in different flow regimes. For example, exponential model in steady state regime or free flow regime and logarithmic model in the congested flow regime. Now, when you are using two different equations of or two different models of speed density relationship for different regimes then it is no more a single equation. So, it is called multi-regime models. Obviously, if we are using only two relationships to describe the entire range, then we can call such models as two regime models.

Similarly, some other researchers proposed three different models where in between a transition layer was considered that is another state between the free flow or stable and congested flow regimes. So, because we are now using three different equations for three different segments of the entire speed density relationship or entire range of speed density relationships, that is why we may call such models as three rigid models.

So, single regime means only one relation for speed and density for the entire range of traffic state, two regime predominantly when one relation for the steady state or free flow regime, and another for forced flow or congested flow regime, and three regime models when we are using three different relationships, one for free flow, another for congested flow, another for the transition one.

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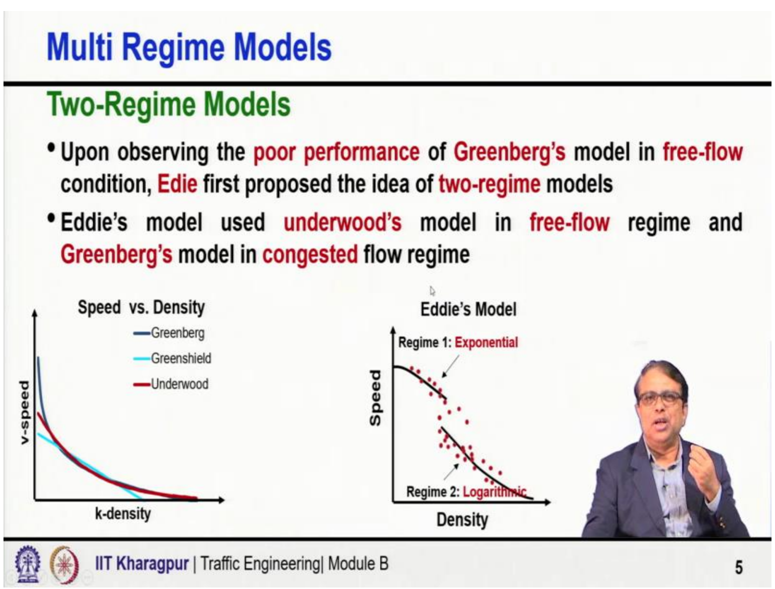

Now, first about two regime models, upon observing the poor performance of Greenberg's model in free flow condition, poor performance in the sense that we said that the Greenberg model, I am showing this slide once again, which I have already shown you in the previous lecture, that if you take Greenberg's model, it does not give a definite speed for low density. The reasons also I explained. But in practice or in practical sense, if you see, there will be a limit for the speed for various other reasons, vehicle technology limitation, road engineering limitations, so, but it does not give, it does not cut or touch the speed axis or the y-axis.

On the other hand, Underwood’s model does not give 0 speed. Any density maybe very small, but it does not touch the x-axis or the K or the density axis. So, what was proposed by Edie that two different models should be used free flow condition, Greenberg's model, for the poor performance we avoid the Greenberg’s model, and therefore, Edie proposed this two-regime model to use Greenberg’s model for the congested portion. You can see here. For the congested portion, he suggested the use of Greenberg’s model and the Underwood’s model, which does not touch the x-axis that is the density axis that was used for the free flow regime.

See the difficulties what we found that one does not touch x-axis. So, while it does not get touch x axis do not use that for the high density or congested flow regime. And the one which does not touch the speed axis do not use that for the low flow or the free flow regime. So, that way, Edie proposed that use Underwood’s model in free flow regime and use Greenberg's model in congested flow regime to describe the speed density relationship.

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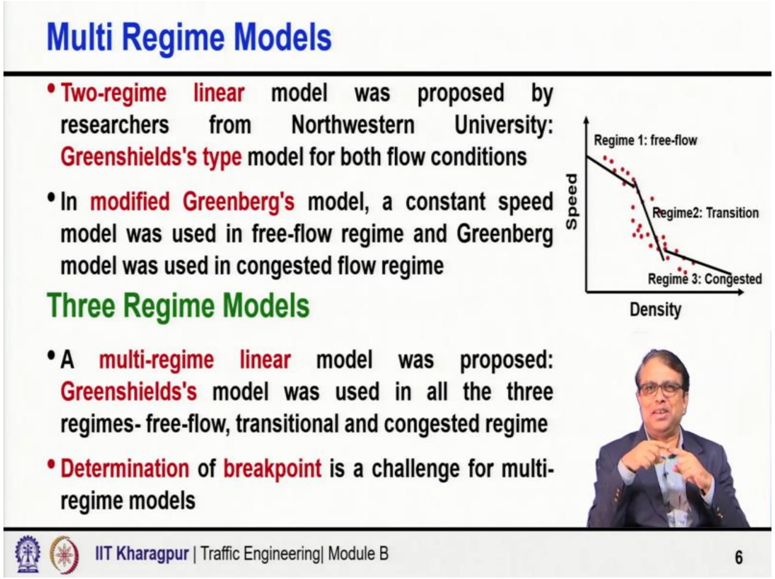

Two regime model was also proposed by researchers from Northwestern University and they used Greenshields' type model, but two different equations, not the same equation for the entire range, two different equation, but both are Greenshield types model, so linear model. So, two linear model for two ranges, one is the steady state flow, the other is the forced flow or congested flow regime. In modified Greenberg's model, a constant speed model was used in free flow regime. And Greenberg's model was used in congested flow regime that was another way of or another attempt to explain the speed density relationships considering two regimes.

Similarly, further development also happened. Researchers came out with three regime model as well. So, a multi-regime linear model was proposed. And in that case, Greenshield model was used in all the three regime. You can see here there are three linear equations, but for three regime, one is for the free flow regime, another is for the congested regime, and in between the transition regime another equation. So, not by one equation or one straight line or linear model, but all are linear only but three different linear models to represent free flow state, transition state and congested state.

Of course, in all such cases, three regime model determination of breakpoint is a challenge. It is for three regime, also for two regime, because you are fitting the model separately in two regime. So, it may not give wherever transition is happening, the breakpoint will be there in all possible practical situations.

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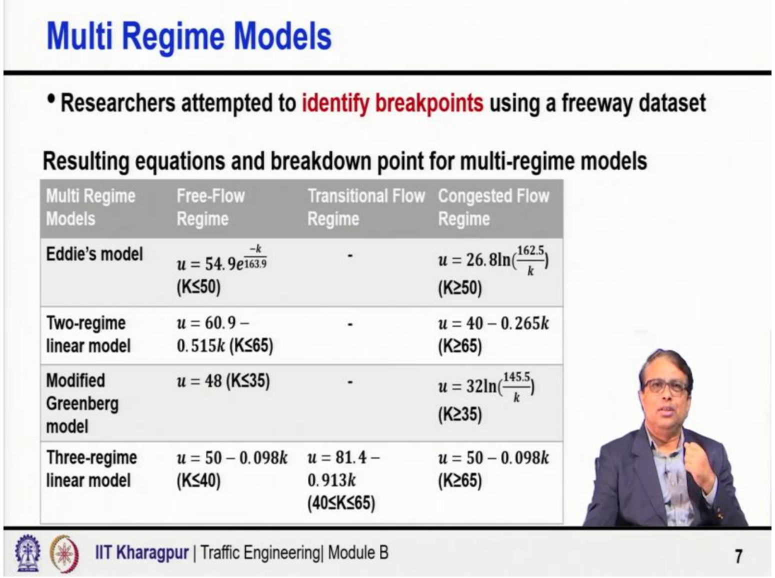

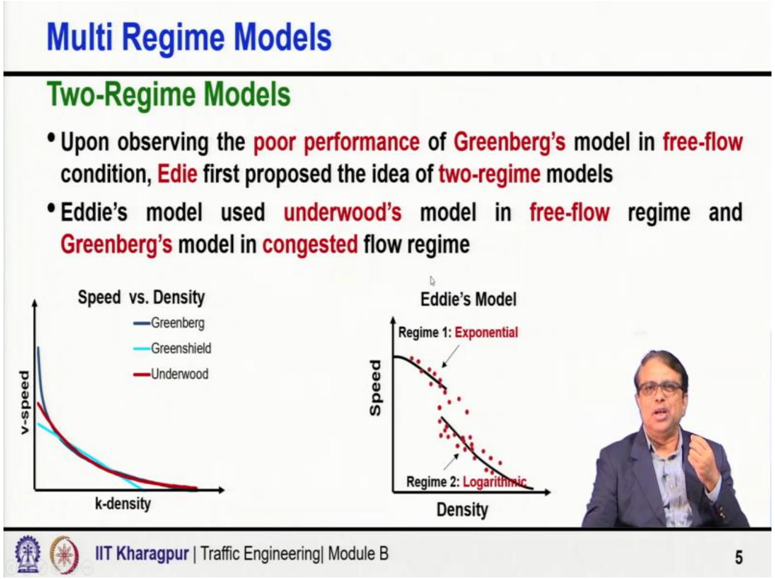

So, researchers attempted to identify these breakpoints using a freeway dataset. And I am showing some example model here. Eddie's model, as I said, what Eddie's model did? It used Underwood's model in free flow regime and Greenberg's model in congested flow regime. So, it was calibrated like this, one model for the free flow regime and other model for the congested flow regime. This was developed for K greater than equal to 50 and free flow regime or steady state stable flow that was represented using this fit density model, which was applicable up to K value of 50.

Now, two regime linear models that were also tried, I have, as I have shown here in the slide. And here the K value one case was taken up to 65 inclusive of course, so K less than equal to 65 density and in the congested flow regime K greater than equal to 65. Now, what I said, you can see here. If you put the value of K equal to 65 in the congested flow regime whatever value of U you will get, if you also put K equal to 65 in this free flow regime model, you will not get the same value of the speed. So, two different values will get. And that will happen for all the models there.

In three regime model, one case here also a similar model, modified Greenberg's model and three regime linear model. Here also three, the whole range was divided into three portion or three segments, one for free flow regime, one linear equation like the Greenshields' equation, one for the congested flow regime and one for the transitional flow regime.

So, three different equation. And if you calculate here congested flow regime equation put a value of 65 and also use the transitional flow regime equation and put the value of K equal to 65 you may not get the same value. Similarly, whatever you will get as U by putting 40 here and whatever you will get if you use the free flow regime model and put the value of K equal to 40 again those two values may not match exactly. So, the breakdown points are always an issue.

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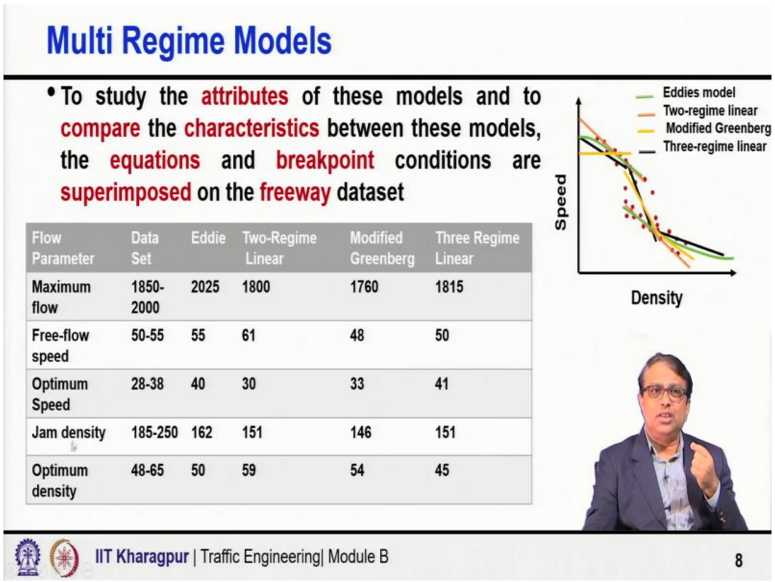

Flow Parameter	Data Set	Eddie	Two-Regime Linear	Modified Greenberg	Three Regime Linear
Maximum flow	1850-2000	2025	1800	1760	1815
Free-flow speed	50-55	55	61	48	50
Optimum Speed	28-38	40	30	33	41
Jam density	185-250	162	151	146	151
Optimum density	48-65	50	59	54	45

To study the attributes of these models and to compare the characteristics between these models, the equations and breakpoint considerations are superimposed on the freeway dataset, as I have shown here. Of course, it looks a bit clumsy because so many models are shown on the same dataset in one figure, but still some of the very interesting observations we can make. Also, this table includes some of the silent values, important values.

For example, what is the maximum flow we are observing from the dataset and as we are getting from different models, similarly, what is the free flow speed, in which range as per the data and as per different models, optimum speed that is the speed and density, what the data set indicate and what we are getting from different models, multi-regime models. Same is done for jam density and optimum density.

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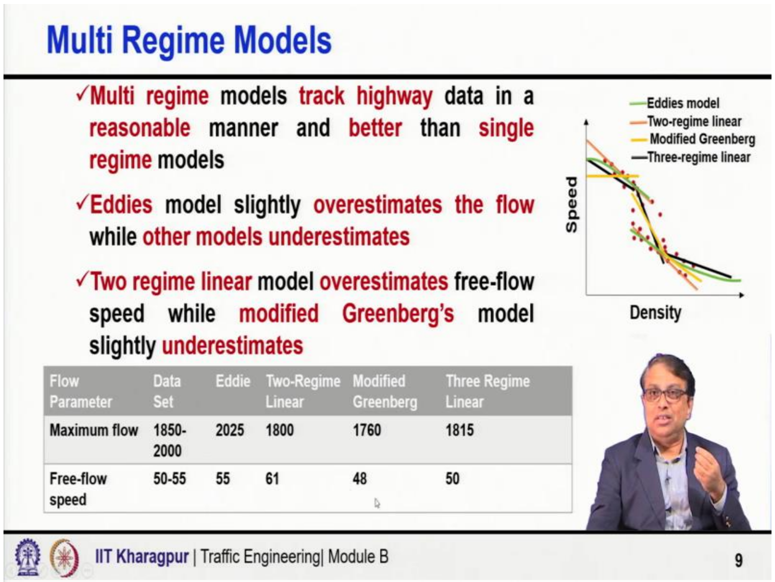

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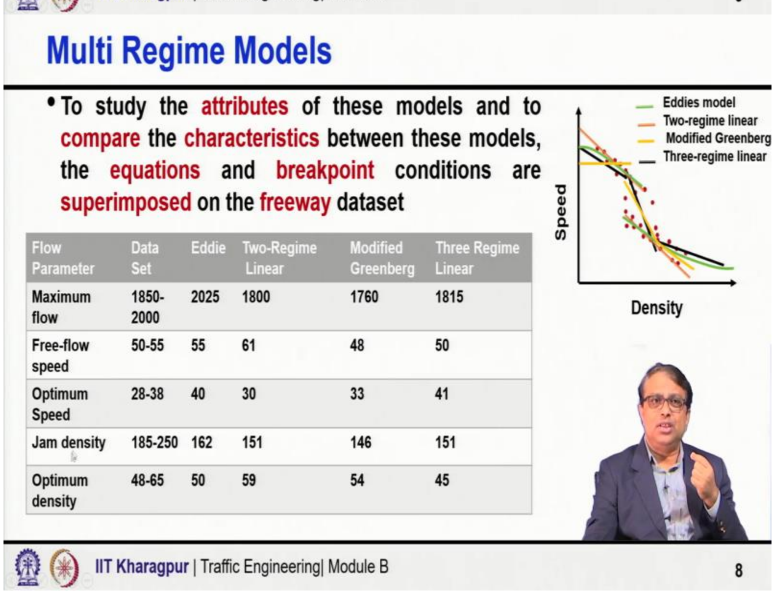

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Now, let us see what are the silent observations. First thing, multi-regime models track highway data in a reasonable manner and much better than the single regime model. So, that is one conclusion. That entire range if you try to describe with one model or one equation, whatever fit you will get or representation you will get, you are expected to get a better representation when you are fitting different models or different curves on different ranges, for different ranges. So, multi-regime models generally fit the data better than the single regime model.

When we compare what we observed from the data and what we got from different models, it may be observed that Eddie's model slightly overestimates the flow, while other models under estimates. I have shown it here. This is not a new table. It is a part of this previous table only, but brought it here, I have brought the values here again so that you can readily see and compare.

Look at this maximum flow in the range of 1850 to 2000 as per the data set and Eddie is giving slightly higher value, whereas all other three models are actually giving somewhat on a lower side. Also, two regime linear model, when you are using two regime linear model, overestimates the free flow speed, while modified Greenberg's model slightly underestimates. Look at the free flow speed, the observed data indicates in the range of 50 to 55. And two regime model gives it more than 60, so slightly overestimating. On the other hand, the modified Greenberg model says that as per the model the free flow speed is the lowest among all these models and it is 48.

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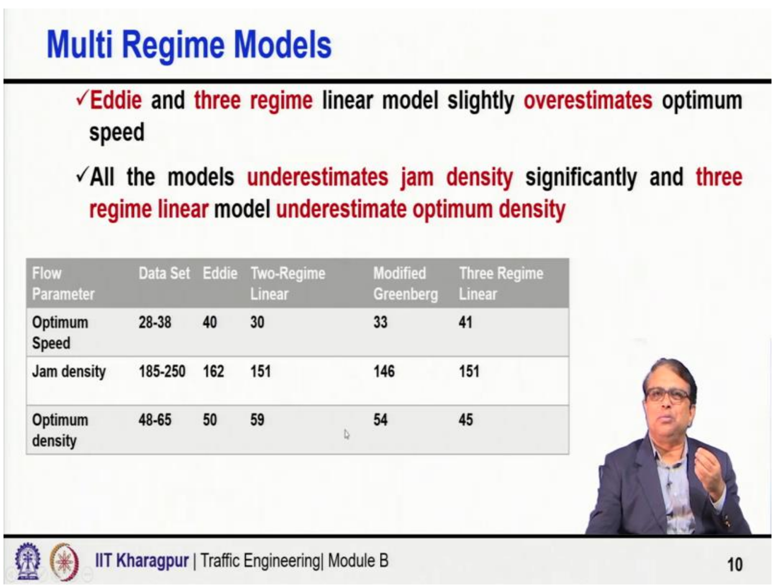

Similarly, Eddie and three regime linear model slightly overestimates optimum speed. Optimum speed means speed at capacity. If we look at the data, then it appears that it is somewhere in the range of 28 to 38. We cannot give a single value because it is all scattered. So, it appears that it is in the range of 20 to 38. But then Eddie is telling it as 40 slightly higher and also three regime linear model is also telling it a bit higher.

All the models underestimate jam density significantly and three regime linear model underestimates optimum density. If we look at the jam density, then jam density as per the observed data it is, it appears that it is in the range of 185 to 250. But if you see what Eddie's model predicted, what two regime linear model predicted, what three regime predicted and what modified Greenberg predicted, all are on the lower side. And if we look at the optimum density, then the three regime model is actually predicting it on the lower side as compared to the other model which are predicting within this range only.

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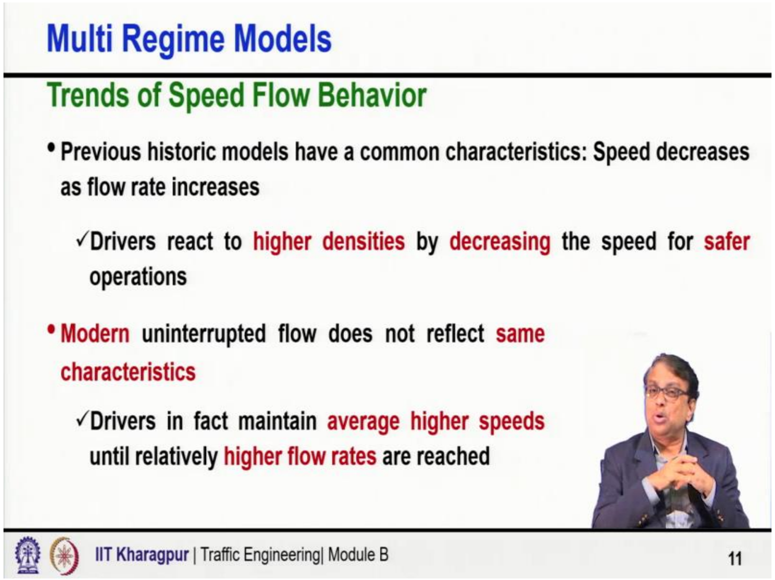

With this background, I would like to make a conclusion that please understand that how the behavior happened, how the density and speed will be related that depends on several factors, roadway traffic, control conditions, whether it is freeway, whether it is a major national or state highway or a major arterial. So, it will depend on that. So, many factors, traffic. So, you are unlikely to get a single model fitting uniformly in all the datasets that is unlikely to happen.

So, everybody is true. Everybody tried to apply it for some dataset got good results. And some other datasets when same models are applied maybe it could not produce very satisfactory results. So, this tells you what is single regime model, what is multi-regime model. Within multi-regime model again two regime model, three regime model and tells you all the possibilities and what all different researchers attempted.

Now, coming to the trends of speed flow behavior. As I said that speed flow behavior we do not directly measure the density, most cases we try to observe the speed and flow, because these are easily measurable quantities and practically it is easy to measure these quantities in the field as compared to the measurement of density. So, most cases we try to fit speed flow curve and then from that speed flow behavior we try to derive what is then the density.

Majority of the historic models which were developed at early stage have a common characteristic. All of them they say generally speed decreases as the flow rate increases. If you remember the speed flow relationship as we got from the Greenshields' model, it is showing almost the speed is decreasing or depending on how you are plotting which axis you are using as x-axis and which one you are using as y-axis the orientation may change. But always as if from free flow as soon as the speed volume or the traffic flow starts increasing, the speed is decreasing. Of course, the rate of decrease will be higher as the flow is approaching the capacity value, but speed decreases steadily as the flow increases.

And what is actually revealed or understood or assumed from that behavior that drivers react to higher densities by decreasing the speed for safer operations, as density is increasing, as more and more vehicles around, drivers reduce the speed to make the operation safer. But modern uninterrupted flow does not reflect the same characteristics, particularly if you say access controlled facilities or the facilities which are operating not theoretically as access controlled facilities, but somewhere, somewhat nearer to that, maybe long sections of highway without much interventions or interference in between.

There what is observed these days that drivers in fact maintain average higher speeds until relatively higher flow rates are reached. Immediately speed does not come down. Whether it is 1 vehicle, 2 vehicle or 10 vehicle as the flow starts increasing in the initial part for quite some time up to some threshold value of flow, the speed is more or less same. So, it is almost like flat. Then it starts decreasing. But it also may not decrease as it used to be assumed or predicted in earlier model. Earlier model predicts that speed drop is very sharp.

But I can also add here that not that always you will get the same behavior as I am saying as modern uninterrupted flow, the roadway, traffic and control conditions, they will influence and they are bound to influence. So, some of the roads you may find even the speed is decreasing drastically even following the earlier trend, but you are more likely to get a different behavior. And similar to what I am saying here under more than uninterrupted flow that you will get on expressway, access control facilities and which are actually high-quality roads, not on all roads.

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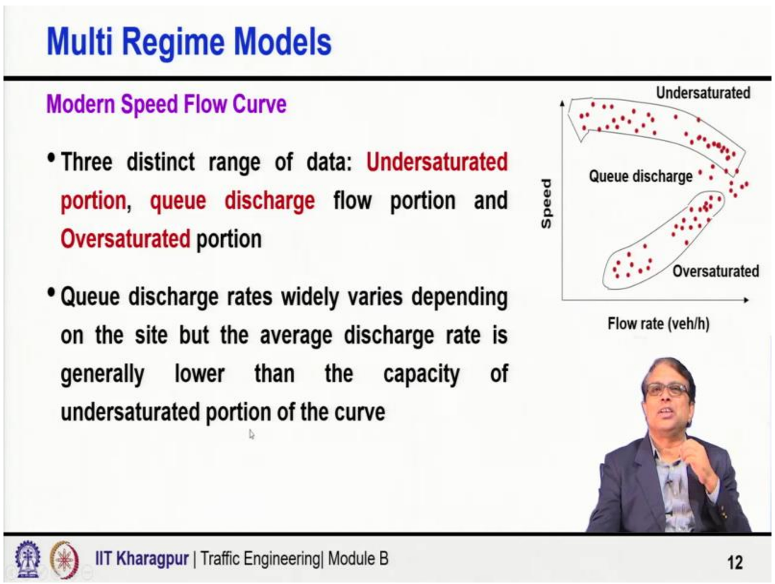

So, how the modern speed flow curve look like? There are actually then three distinct range of data, one is undersaturated portion. You can see it here. That is the undersaturated portion, almost flat and then some decrease, but not sharply coming down like this. Second, a queue discharge portion when the queue is formed just upstream of the bottleneck and the queue is getting discharged through the bottleneck.

Third, the oversaturated portion, unstable flow or unforced flow condition. And queue discharge rates vary widely depending on the site, but what is observed is an interesting phenomena, average discharge rate is generally lower than the capacity of the undersaturated portion of the curve.

As long as, suppose you have a bottleneck and suppose its capacity is two lane, so if the demand is exactly up to two lane, you will, you are getting actually capacity discharge exactly say two lane. So, there is no queue. All the vehicles are able to pass through, but then the moment the demand is more, then the queue is formed immediately upstream of this bottleneck, even though there the capacity is higher, but immediately queue formation will happen.

And when the queue formation happened, whatever queue discharge you will get, you may not get exactly the capacity value. It is slightly lower than the capacity discharge. So, the queue discharge is generally found to be slightly on the lower side as compared to the capacity in an undersaturated portion of the curve.

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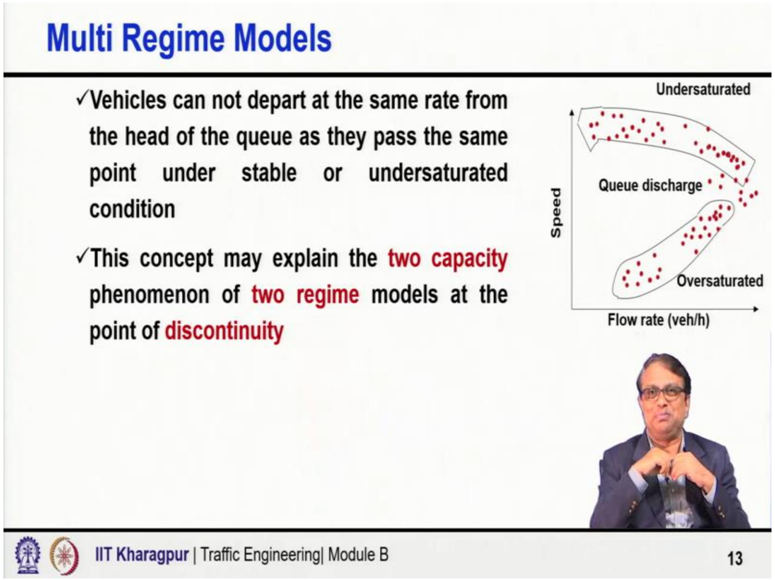

Why, there is a reason. The reason is vehicles cannot depart at the same rate from the head of the queue. As I said a two lane is the bottleneck and then upstream it is three and the demand is more than two lane. So, the head of the queue is at the interface, where two lane is the bottleneck and upstream is three lane and the demand is higher than the two lane capacity. So, there vehicles cannot depart at the same rate from the head of the queue as they pass the same point under stable or under saturated condition.

That means if the demand is two lane then, of equivalent to capacity of two lane road, then the discharge will be actually two lane capacity that value you will get. But the moment the demand is higher and the queue has formed, vehicle cannot really depart at the same rate from the head of the queue as they pass the same point under stable or undersaturated condition. And this concept may explain the two capacity phenomena of two regime model at the point of discontinuity or the break point what I said earlier why you are getting two different values.

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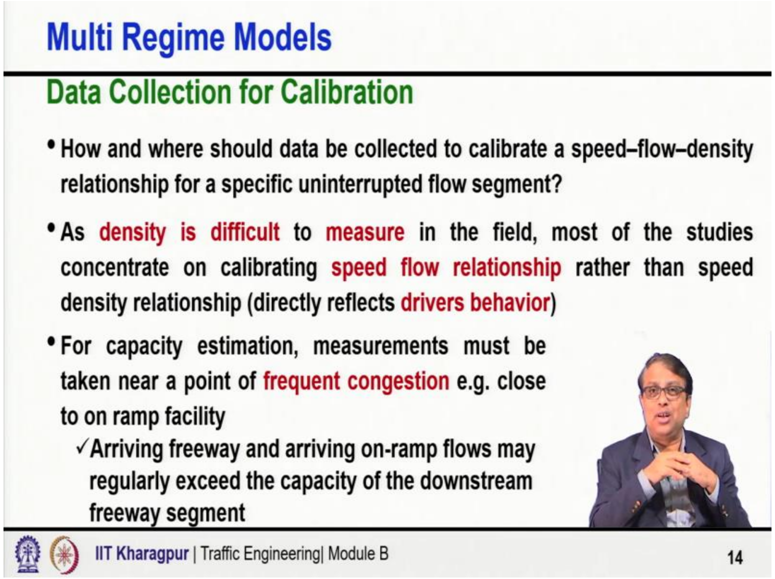

Now, going to the data collection part for calibration, this is again important. How and where should data be collected, these two are very crucial, to calibrate a speed flow density relationship for a specific uninterrupted flow segment. Generally, as I said earlier a number of times, density is difficult to measure directly in the field.

So, most cases or most studies attempt to calibrate speed flow relationship rather than speed density relationship. Although there is a much deeper sense in speed density relationship, because speed density relationship directly reflects driver behavior, as the density around, drivers cannot sense the flow so easily.

You as an observer can always stand by the side of the road and measured the flow easily, but drivers, how the density is getting developed, how more and more vehicles are around and then how they are changing their speed that is very important. So, that is the reflection of driver behavior. So, speed density relationship actually directly reflects driver behavior. So, it is very meaningful. But because of the difficulties in direct measurement of density, often most of the studies actually try to calibrate speedy flow relation.

Now, for capacity estimation, measurements, if we are aiming to capture the capacity flow, then we must do the measurements or carry out the measurements near a point of frequent congestion. Why? If we are getting near a point of frequent congestion that means we are more likely to get actually more possibility of being able to capture the capacity flow. For example, where such locations can be there, close to on ramp facility. Why close to on ramp facility?

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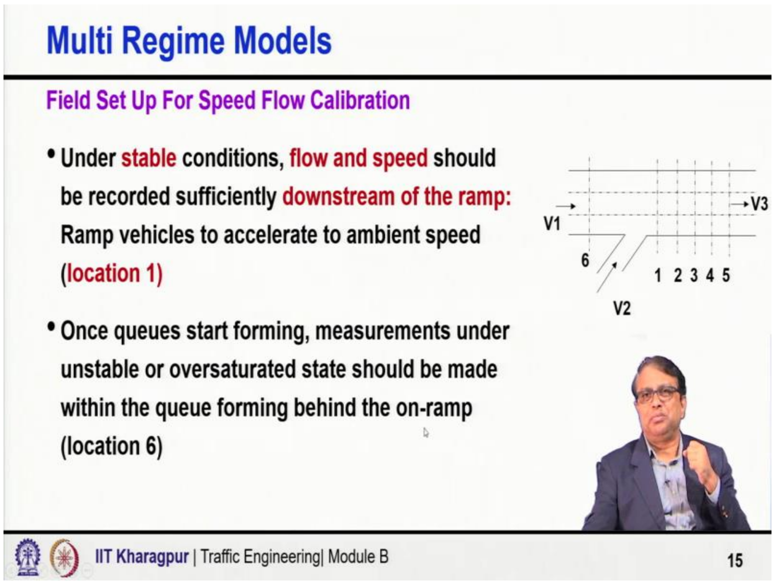

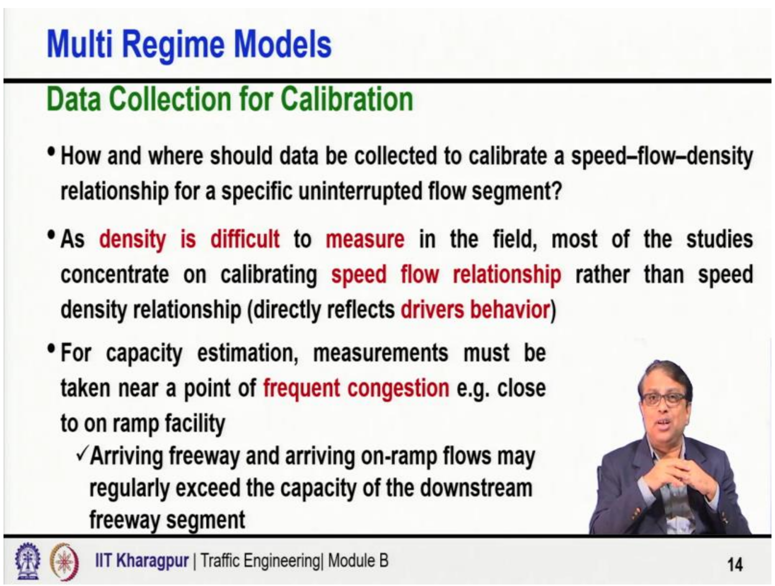

Because, suppose, look at this figure, it is a freeway and there is a ramp here. So, V1 is the freeway flow, V2 is the ramp flow and it is quite possible on, in many sites, you will find it that this together when they adds up, when they add up, the resulting flow V3 demand will not be adequate, not be, will be higher than the capacity of the downstream section. So, as long as they are operating on a lower scale V1 plus V2, fine. All the flow can pass through. All the demand can pass through. But this is the location where V1 and V2 together sometimes they may be higher than the capacity of the downstream section, possibility.

So, under stable condition flow and speed should be recorded sufficiently downstream. Before we say that, let me complete this sentence once again. Arriving freeway and arriving on ramp flow, what I have shown here V1 and V2 together, may regularly exceed the capacity of the downstream freeway segment. When they add up together, then the total flow may exceed the capacity of this downstream section. So, therefore, we should capture the flow, measure the flow around this point.

Under stable flow condition, as long as the flow is less than the capacity of this downstream section, we should record flow and speed sufficiently downstream of the ramp, not at the face of the ramp, but sufficiently downstream. Why sufficiently downstream, as shown in point, as point 1, maybe that is the location. And why I am saying sufficiently downstream of the ramp. The reason is, ramp vehicles will then be able to accelerate to ambient speed. When the ramp vehicle is entering, you should give them some opportunity to accelerate to the ambient speed and then I am capturing. And there is no problem, because we are actually collecting the data under stable flow condition. So, the V1 plus V2 is still less than the capacity of this downstream section. That is location 1 which could be ideal.

Now, once queue starts forming, it could be this plus this together is the demand is higher than the capacity of this downstream section assuming that there is no downstream, further downstream no signal or that effect is not there, no other effect is there. Then once queue starts forming, measurements under unstable or oversaturated state should be made within the queue forming behind the on ramp location, because we want to measure the unstable or oversaturated state that is the, that is our target, that is the measurement we are aiming for. So, we should do it now.

Upstream within the queue forming behind the on ramp location, so somewhere maybe around this location 6 on the freeway, because vehicle accumulation has already started. So, once the queue starts forming measurements under unstable or oversaturated state should be made within the queue forming behind the on ramp location that is somewhere around location 6.

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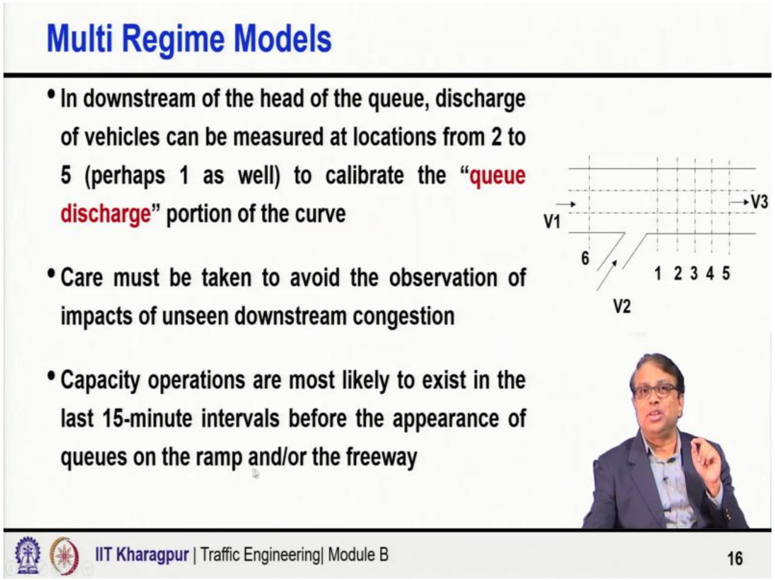

Now, one more is remaining. What is that? In downstream of the head of queue, you are already in the bottleneck section, in the downstream of the head of the queue, discharge of vehicles can be measured from any locations 2 to 5 assuming that there is no other effect of queue in the further downstream. It is only this phenomenon V1 plus V2 is becoming more than the capacity of this immediate downstream section. So, this becomes the bottleneck.

So, I want to measure now the queue discharge. So, where I should make the queue discharge, where I should measure. I should measure it at any point between 2 to 5, any location I should do it. Probably I said also perhaps 1 as well, because now 1 also will operate with queue discharge. So, it could be any point 2 to 5 and perhaps 1 as well.

Now, altogether, we must keep in mind that we need to take care or precautions to avoid the observation of impacts of unseen downstream condition. If there is something going wrong further downstream that effect also may come. So, you must be careful about that, must keep that in mind when we are collecting the data.

And capacity operations are most likely to exist. You are getting here queue discharge, you are measuring here queue discharge now 1 to 5, but then how to get the capacity flow. So, I am saying capacity operations are most likely to exist in the last 15-minute interval before the appearance of the queues on the ramp and/or the freeway. Before the queue formation really starts, it is reaching, going increasing, and at some point the capacity is becoming inadequate, so the queue is forming, either on ramp or on freeway or on both. So, what we are saying, capacity operations are most likely to exist in the last 15 minute intervals before the appearance of queues on the ramp and/or the freeway.

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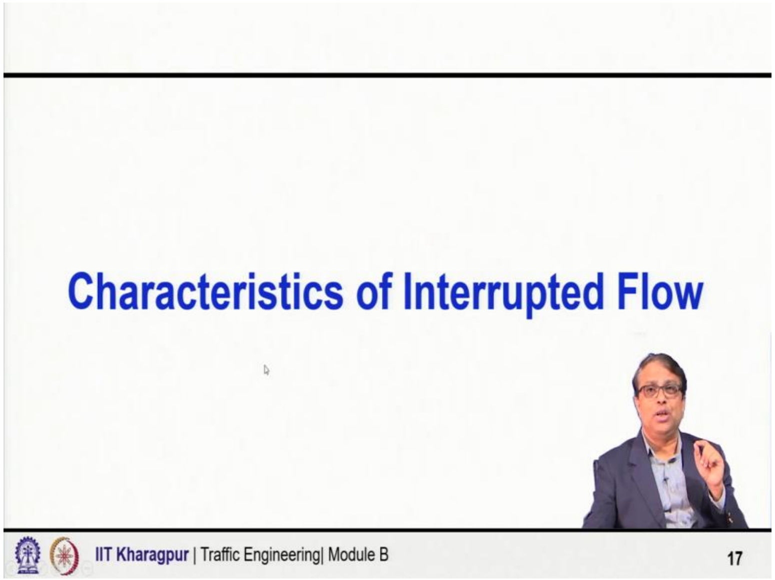

Now, before I close, very quickly I discuss some basic characteristics of interrupted flow. And in Module E I am going to come back and we shall discuss in details about interrupted flow, especially how the traffic operations happen at intersections and signals, but here a very brief.

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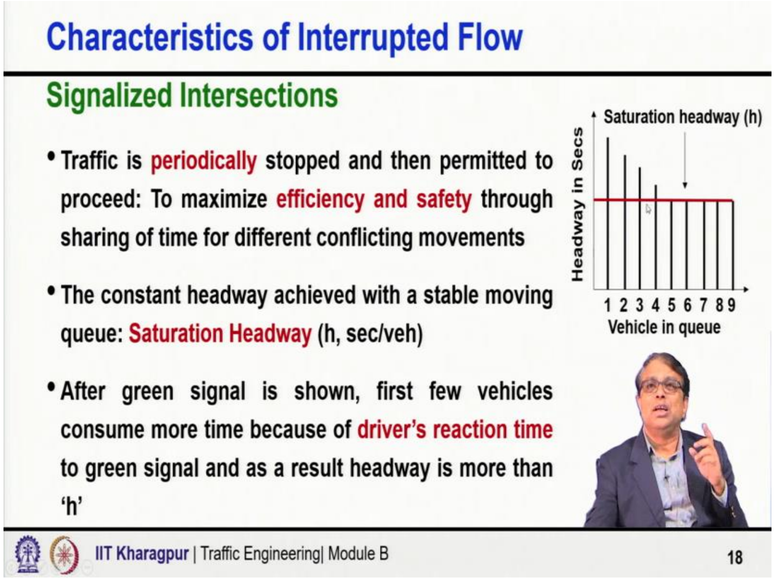

In signalized intersection traffic is periodically stop and the permitted to proceed. When you have green, traffic can move. When you have red, traffic cannot move. And we do that, why we do time segregation of vehicle movements, because we want to maximize the efficiency and safety by time sharing for different conflicting movement.

Now, the constant headway achieved with the stable moving queue is called the saturation headway. That means once the signal becomes green, you will find in a homogeneous, perfectly disciplined condition, first vehicle to second vehicle time gap will be quite high, second to third, third to fourth, fourth to fifth, after a few vehicles you are almost going to get it constant that is the steady state assuming that there are enough vehicles got accumulated during the red time, so there is continuous demand, then you will get discharge like this.

Now, this constant headway is called the saturation headway. But two things are important. Once the signal becomes green, the first few vehicles will consume more time that means the headway will be higher than the saturation headway as shown in the figure. So, there are incremental times. So, if we add up all this extra time, above the saturation headway h for the first few vehicle that is the time lost solely because the signal turned from red to green. If the signal is continuously green and if there is continuous demand, enough demand, then we would get a steady discharge with saturation headway h. These first few vehicles are taking longer time simply because the signal is turning from red to green.

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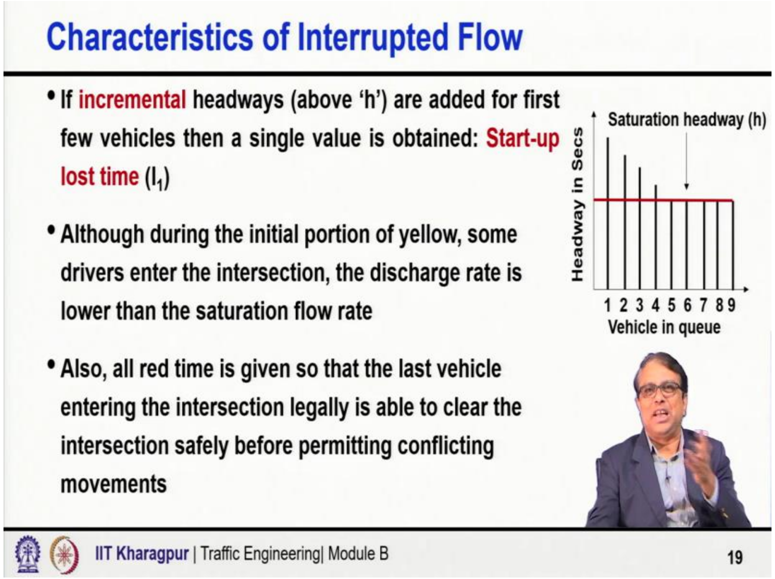

So, the incremental headway if we add for the first few vehicles we call it as start up loss time. Similarly, when the green is over we give amber or yellow then we give red. Now, during amber some vehicles are discharged, because those who cannot stop safely are permitted to cross the stop line and clear the intersections legally that is what is the amber. If you cannot stop safely then you should cross it. So, few vehicles will get discharge in the amber time.

But that discharge will not happen at the same rate with a saturation headway of h. So, that amber time is not as productive in terms of getting the throughput or vehicle flow as the green time. So, there is one component of loss there. And another component of loss is we need to give a all red time. Why, because the last vehicle which is legally entering the intersection in the amber time or yellow time that vehicle should be able to cross the intersection safely before a conflicting movement starts.

So, I just give red which was amber and before that green, and the moment I give red, I give green to a conflicting movement. So, what will happen? The last vehicle which entered legally before it clears the intersection the vehicle will come and crash may occur. So, you need to insert something what is called all red. Here also it is red, conflicting movement also is red. And how much red we give, we give that much red which should be adequate for the last vehicle which have entered legally in the intersection that vehicle should be able to clear. So, both these also bring some loss time. And that why it is happening? It is happening because now the signal is changing to red. So, that is called the end loss time.

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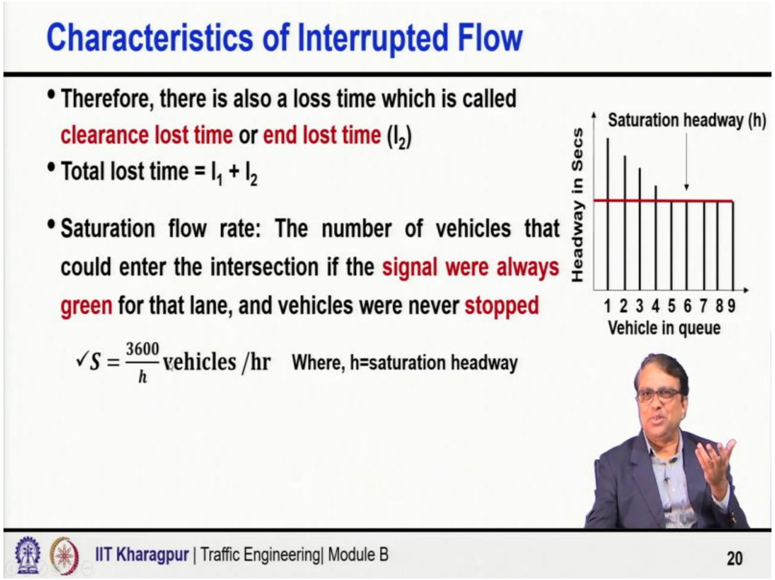

So, altogether we have total loss time $l_1 + l_2$, start up loss time and clearance loss time. And whatever flow rate you get at the steady condition with a saturation headway of h that is called as saturation flow rate, that is like capacity, that much maximum discharge is possible. So, that rate is 3600/h, h is often expressed in seconds. So, 3600 seconds in an hour by h so that many vehicles per hour.

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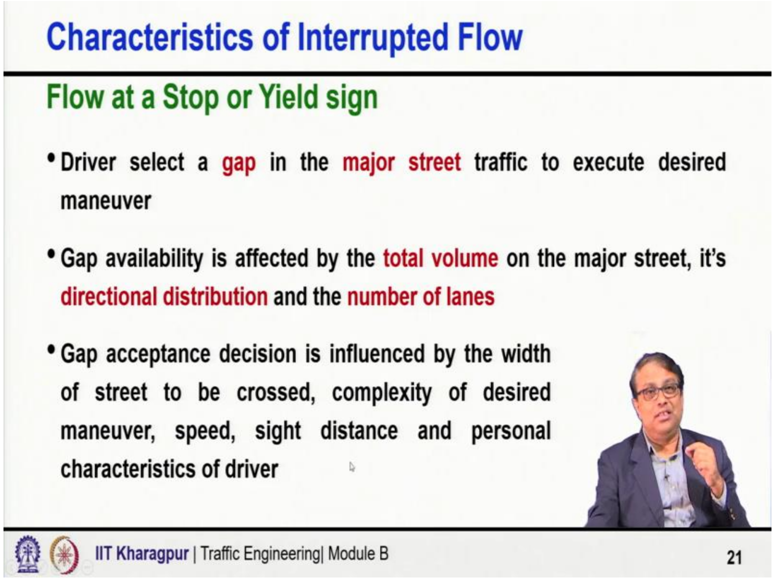

Now, driver select gap in a stop or yield sign. When there is a stop sign means you have to stop. Yield means the priority is for the other movement. You are approaching from minor road you will get a yield sign so you have to slow down and you can only do the maneuver when there is adequate and safe gap. And if it is a stop sign, you must stop. Then look for the opportunity. And then do maneuver when you get suitable gap.

So, the driver select gap in the major street traffic to execute desired maneuver. Driver select a gap in the major street traffic to execute desired maneuver. Gap availability is affected by total volume on the major street. How frequently and how likely you are get to get, you are able to get a gap depends on what is the total volume and what is the directional distribution and how many lanes are there. If you are taking the right turn maneuver, you have to cross so many lanes once you are trying to do a right turn in Indian condition. So, gap acceptance decision is influenced by the width of the street to be crossed, complexity of desired maneuver, speed, sight distance and also the personal characteristics of the driver.

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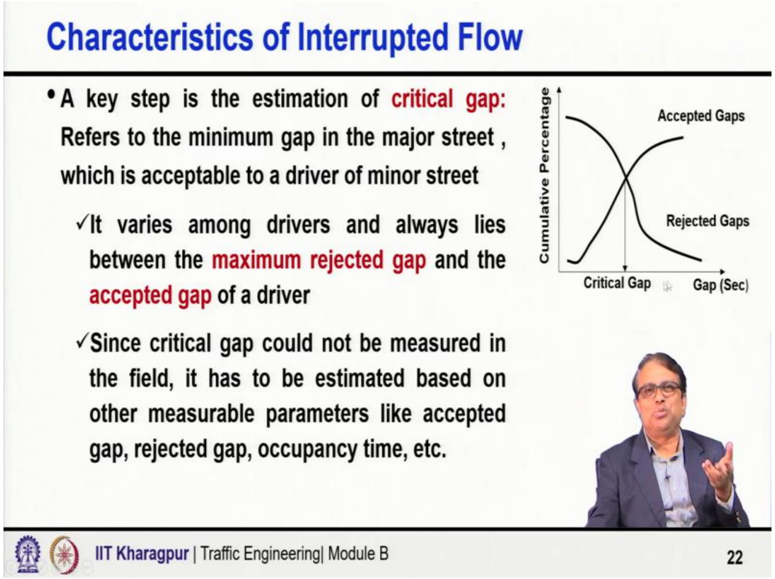

So, a key step or a critical point here aspect for any uncontrolled intersections which are not signalized, signal means we are regulating, otherwise it depends on the gap acceptance behavior. So, in this concept, the concept of critical gap is extremely important. You can see here, I have shown here, you consider a gap not all vehicles are going to accept the gap, not all vehicles are going to reject the gap. Of course, as the gap is more, the acceptance will be higher, more and more vehicles are going to accept this and lesser and lesser number of vehicles are going to reject it.

Similarly, if the critical gap is on the, the gap is on the lower side then more vehicles are likely to reject it and very few vehicles are expected to accept it. So, the critical gap is where these two curves intersect. So, refers to the minimum gap in the major streets that we should consider which is acceptable to a driver of minor street. It is again some kind of a design consideration. So, that is the way, the concept of critical gap is very important.

It varies among drivers and always lies between the maximum rejected gap and the accepted gap of driver. Since critical gap could not be measured in the field, it has to be estimated based on the other measurable parameters, mainly as I have shown, we can say that what are the accepted gaps, what are the rejected gaps, occupancy time with all these you can actually plot and find out what is the critical gap.

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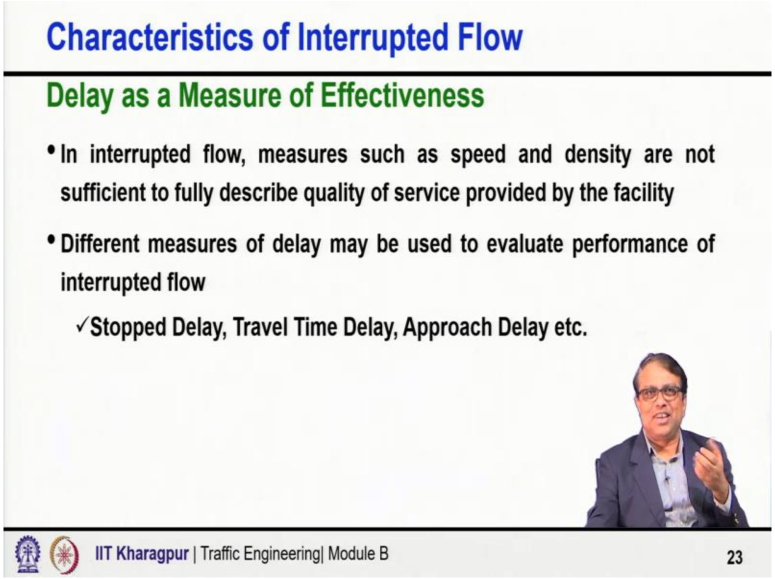

In uninterrupted facilities we often use speed, density as the measures to describe the traffic stream. But in interrupted flow, measures such as speed and density are not sufficient to fully describe the quality of service provided by the facility. So, what we use? We use different measures of delay for the purpose of evaluating the performance of uninterrupted flow stopped delay, travel time delay, approach delay, control delay, there are so many ways the delays are defined and measured. Now, as I said, I will stop it here and I am going to come back to you in Module E to discuss in further details about the interrupted flow facility and various characteristics and including the design of signals. So, with this I close it.

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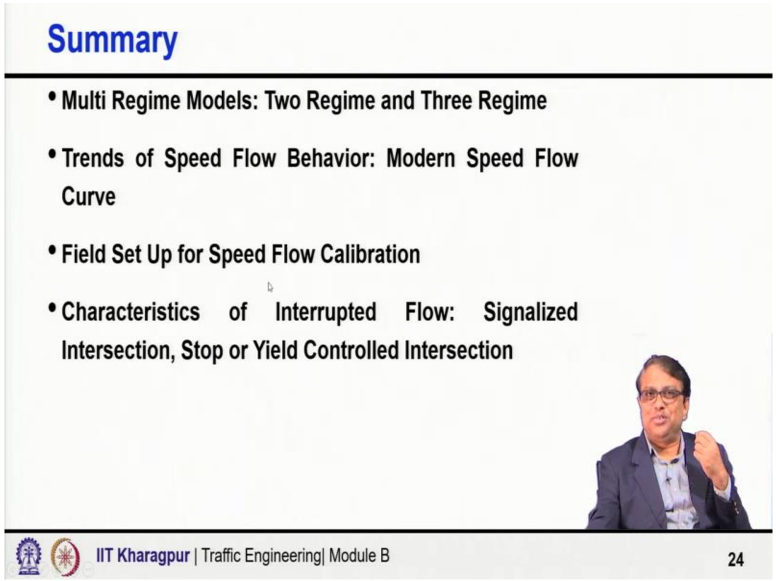

So, we discussed here about the multi-regime model, two regime and three regime. Also told you about the trends of speed flow behavior, how the modern speed flow curve look like for freeways and expressways and other kinds of facilities, some ideas about the field set up for speed flow calibration and briefly mentioned to you about some characteristics of an uninterrupted flow, start up loss time, end loss time, total loss time and the critical gap. With this, I close this module. Thank you so much.