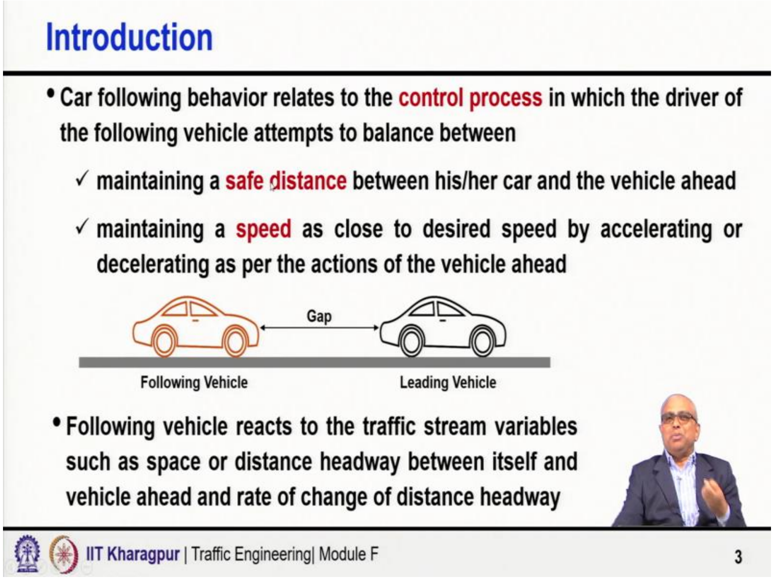
Traffic Engineering
Professor Bhargab Maitra
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 44
Car Following Theory-I

Welcome to module F lecture 1. This module is on Car Following models and traffic simulation. And in today's lecture, we shall focus on car following theory or car following models.

(Refer Slide Time: 0:33)



Car following behavior relates to control process in which the driver of following vehicles attempt to balance between two aspects or two things. First, maintaining a safe distance between his or her own car that is the following car as I have indicated here in the sketch and the vehicle in ahead or the leading vehicle.

So, two vehicles are involved in the process when we are driving on a traffic lane vehicle in front which we may call as leading vehicle and a vehicle which is following is called following vehicle. Now, the car following relates to the control process in which drivers of the following vehicles attempts to balance between as I say one is maintaining a safe distance between his or her vehicle and the vehicle ahead that is what is shown here.

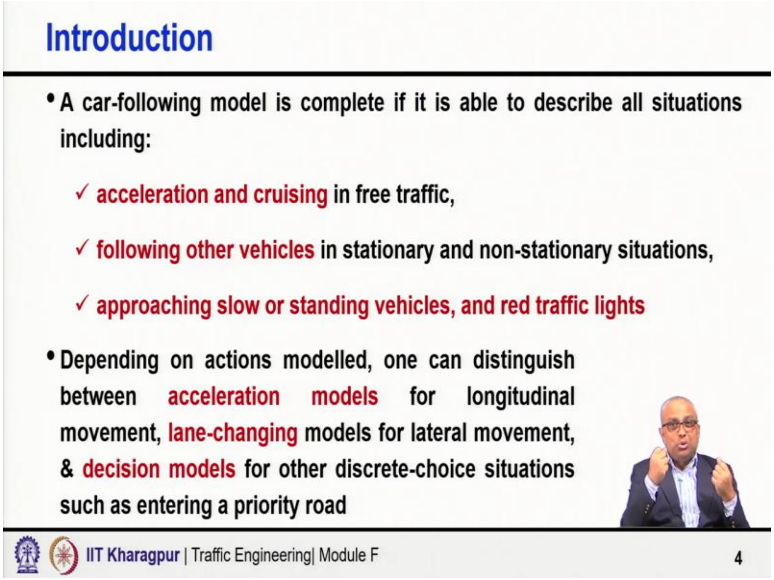
Maintaining a certain gap even though always when two vehicles are moving, how there are or what gap they are maintaining and also maintaining a speed as close to desired speed as close to desired speed that will depending on the prevailing situation what best is possible by accelerating or decelerating as per the action of the leading vehicle.

So, the leading vehicle may accelerate. So, the following vehicle may also follow that accelerate if the gap is getting reduced or the leading vehicle has decelerated, then what response the following vehicle is going to do, in terms of speed and also the acceleration and deceleration, and what minimum distance, safe distance they try to maintain under different conditions between the following vehicle and the leading vehicle.

Now following vehicle will obviously react to the traffic stream variable such as speed or distance headway say if you are going too close to the leading vehicle and if you find the distance is really not a going to be unsafe that means it is getting reduced and you should not go beyond the threshold value then accordingly you act.

So, following vehicle reacts to the traffic stream variables such as space or the distance headway between itself and the vehicle ahead and also the rate of change of distance headway how the distance headway is changing depending on the action of the leading vehicle leading vehicle may travel at constant speed may accelerate may decelerate and accordingly what the following vehicle is going to. So, the whole control process we are trying to understand or capture in car following models or using car following theories.

(Refer Slide Time: 4:11)



A car following theory is complete if it is able to describes all the following situations three aspects or three major situations first accelerating and cruising in free traffic not much congestion nearly free flow or no congestion situation then following other vehicles in stationary or non-stationary situation extreme case it may be stationary.

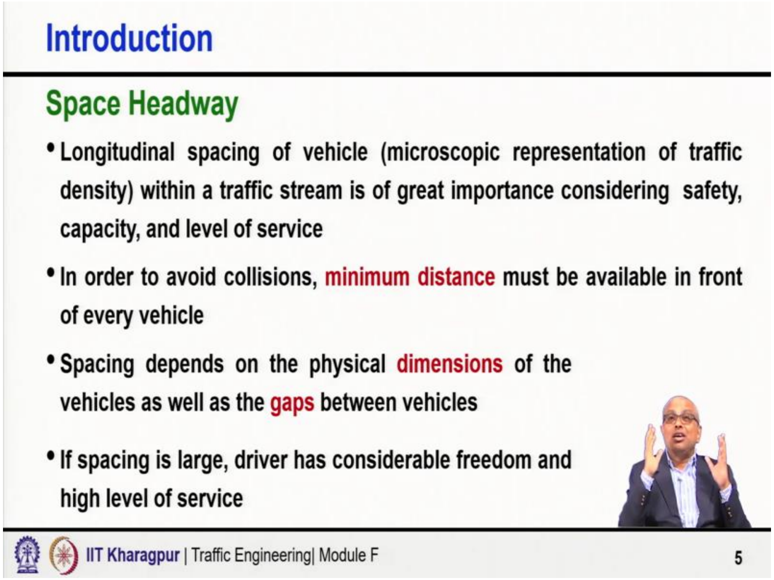
In all other cases it may be non-stationary but congested situation. They are the mostly the car following things happen largely and approaching slow or standing vehicle and red traffic lights, this is a special or a very unique scenario which you often encounter depending on actions model what actions we are modeling.

Because you know there are there could be many actions and all actions we may not be able to model also in a single model we may not be able to capture in a single model depending on actions model one can distinguish between acceleration model for longitudinal movement. So, you just maybe only using the car following model we are trying to model the acceleration and negative of acceleration is deceleration.

So, acceleration deceleration we are trying to model for longitudinal movement along the lane in the same direction two vehicles are moving and then that we are trying to model. Second it could be lane changing model for lateral movement, how the lane change is happening that is also behavior a maneuver.

And also, third decision models for other discrete choice situations such as entering a priority road whether you should enter or not whether you should accept the gap or not accept the gap and do the maneuver or wait for the suitable gap. So, different decisions may be modelled and accordingly you will see what model it is it may be a decision model, it may be lane changing model, it may be an acceleration or deceleration that is what we are trying to model depending on what we are trying to capture.

(Refer Slide Time: 7:09)



Now, in all these contexts the space headway or the distance headway sometimes we call it a space headway sometimes we call it a distance headway these are all synonymous. So, it is very important this space headway or the distance headway concept. So, although you know it we have already discussed about what is time headway, what is distance headway, or spacing or space headway but again I want to little bit discuss because it is so, important in the context of car following.

Again, to recap, space headway is the longitudinal spacing between vehicles or longitudinal spacing of vehicle within a traffic stream and it is also a microscopic representation of traffic density because one by spacing is actually the density we say meter per vehicle. So, one by that dimension wise also so, many vehicles per unit length that is what is the density.

And you know this spacing or space headway is the microscopic parameter and density is the macroscopic parameter. And why this is so important because these are directly related to the safety to vehicle crash may happen or in general what all of us who say accident but we engineers traffic engineers prefer to call it as crash not accident.

And it also influences or affects the capacity and also the overall level of service because the density is often for so, many facilities that density is actually used as a measure service measure for defining the level of service. And in other contexts, also even if you are using not using density, but in a macroscopic parameter if we consider the speed flow density are related flow equal to speed into density.

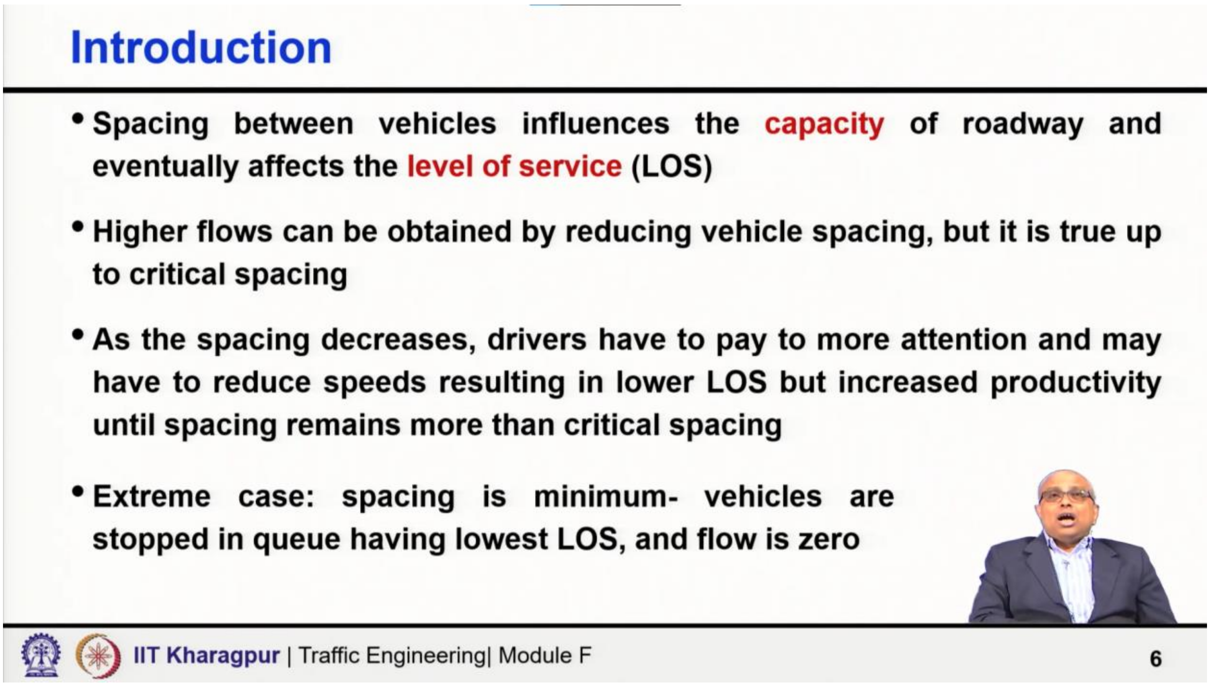
So, the speed flow density are related for uninterrupted flow facilities. So, spacing is so, important space headway is so, important. And in order to avoid collision or crash some minimum distance must be available in front of every moving vehicle or even a stationary vehicle also when the vehicle also stand one after another they also still maintain a gap maybe that gap is very minimum gap much lesser as compared to what they maintain when both vehicles are moving.

But some minimum distance must be available in front of every vehicle. And this spacing depends on the physical dimension of the vehicle as well as the gaps between vehicles. Because gap is really the clear distance and spacing when we say front to front it need not be even front to front it may be any position to the same position for the following vehicle.

But as traffic engineering sense most of this most cases we use the front bumper because that is what is actually detected by the sensor or the detector. So, often we use front to front, front bumper to front bumper that is the common way of expressing the space headway or the spacing.

So, front to front means the length of the leading vehicle or vehicle in front and plus the clear gap between two vehicles. So, if spacing is large driver obviously has considerable freedom and high level of service. So, as the gap reduces, because of the density is increasing simply. So, the freedom of movement will be lesser and the level of service will be lower.

(Refer Slide Time: 11:40)



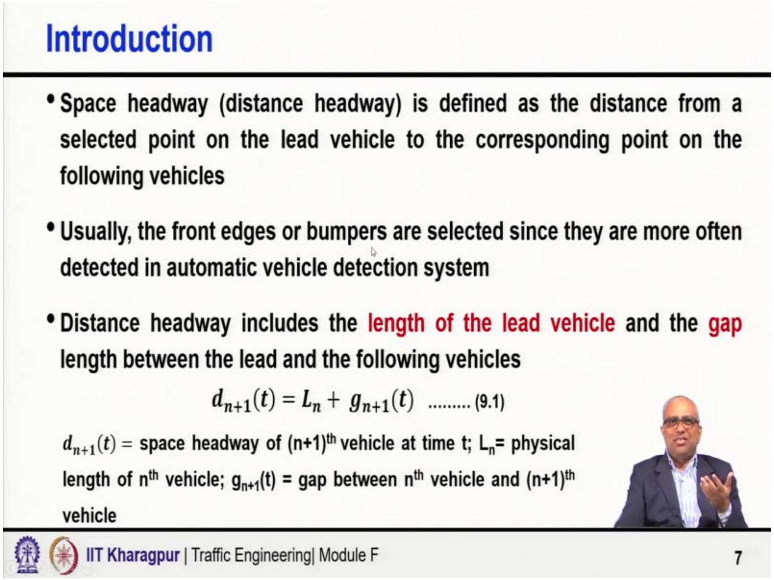
Spacing between vehicles influence the capacity of road and eventually therefore affects the level of service as mentioned higher flow can be obtained by reducing vehicle spacing. Yes, that is true, but it is true up to critical spacing beyond which it will the flow will no more increase because the flow may even reduce.

As the spacing decreases drivers have to pay more attention and may have to reduce speed and resulting in lower LOS but sometimes this may even increase the productivity but again up to certain point until the spacing remains more than the critical spacing. If the if you are beyond critical spacing, then obviously the flow will decrease.

You can easily read it to your understanding about the speed flow speed density and flow density relationship then it will be clear what I have said in Module B we discussed probably in Module B I discussed this speed flow, flow density, and speed density relationship for uninterrupted flow facility.

So, you can easily understand why I am saying so you have seen that the density increases up to certain point very low to some point then the flow will increase but beyond that the flow is actually decreasing. So, always at certain density in between that is the optimum one we can say where the maximum flow occurs. And in extreme case the spacing is minimum where vehicles stopped in the queue having the lowest LOS and obviously the flow is also 0. That is the jam density condition. The other side of the flow density curve where the flow is 0 densities maximum and speed is also 0.

(Refer Slide Time: 14:16)



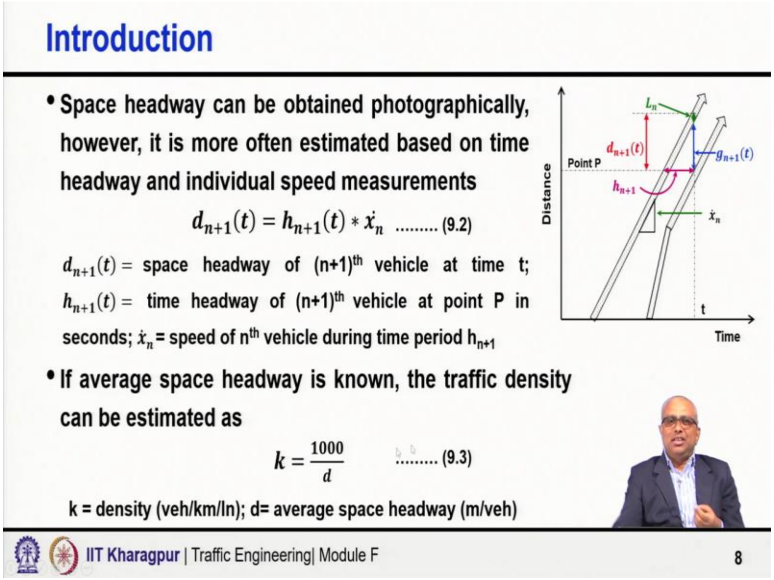
Now, space headway or the distance headway is defined therefore, as the distance from a selected point on the lead vehicle to the corresponding point on the following vehicle. Any reference point you can take but usually the front edges or bumpers are selected simply because they are more often detected in an automatic vehicle detection system. So, we take front to front, distance headway, as I said includes the length of the vehicle because front to front. So, you have the vehicle whole vehicle length plus a clear gap.

So, therefore I am saying that distances it may include the length of the lead vehicle and the gap length between the lead vehicle and the following vehicle. So, mathematically if we want to say dn plus one t, the distance of the space headway between a net vehicle and n plus 1 vehicle, we can call it as a headway for distance headway for n plus 1 vehicle equal to what length of the nth vehicle.

$$\boldsymbol{d_{n+1}(t) = L_n + g_{n+1}(t)}$$

Vehicle in front of the lead vehicle plus the clear gap between the nth vehicle and n plus 1th at again time t. Because this distance headway is going to change over time the clear gap is also going to change over time. So, both are as a function of t and the length is the fixed length of the vehicle leading vehicle is fixed. So, this is not certainly function of t.

(Refer Slide Time: 16:01)



Now, the space headway can be obtained photographically and if you can get that you can directly I have shown here this is the time this is the distance axis. So, this the time distance domain. So, what is really the headway the distance headway is basically this gap in the distance axis. So, this is the gap.

So, front to front if we take so, front to front includes the length of the vehicle in front of the leading vehicle plus the clear gap, that is why gn plus 1 in t as time t gn plus 1 t it is the clear gap and we can if we have the photography if we take a snap, we can always find out what is the gap length of the vehicle plus what is the clear gap, but it is more often estimated based on time headway and individual speed measurement simply considering the ease of measurements of all these parameters in the field.

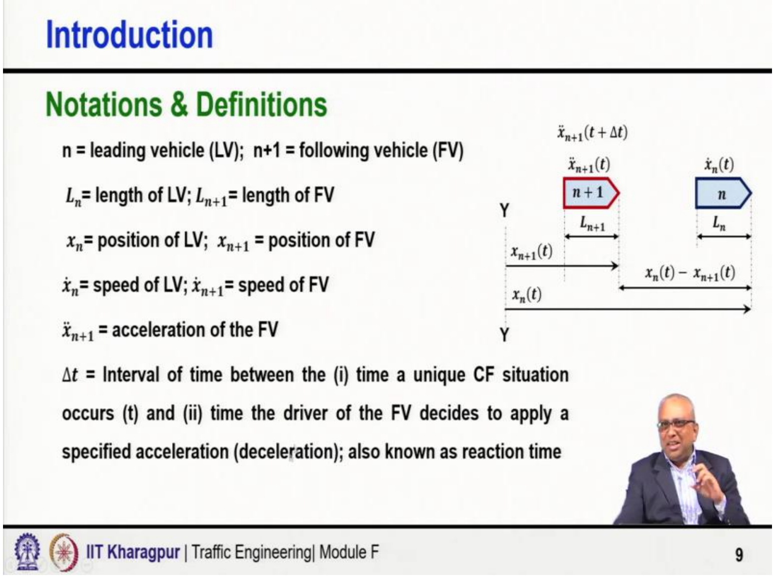
And if we want to then express it in terms of the time headway then distance headway can be expressed like this as a function of time headway. So, distance headway of n plus 1 vehicle at time t equal to time headway of n plus 1 vehicle again the time gap between front to front passage of front of two successive vehicles into x dot n, dot is indicating the speed x is the distance x dot is the speed double dot is the acceleration or deceleration.

$$d_{n+1}(t) = h_{n+1}(t) * \dot{x}n$$

So, that way we can express simply what we are saying that we want to find out this one. This is what how we are finding out, we are finding out this time headway and what we know is the speed the slope that way we can find out. So, in the average space headway is known, you can obviously calculate the density that is what is indicated in this equation 9.3 in this slide.

$$\boldsymbol{k = \frac{1000}{d}}$$

(Refer Slide Time: 18:31)

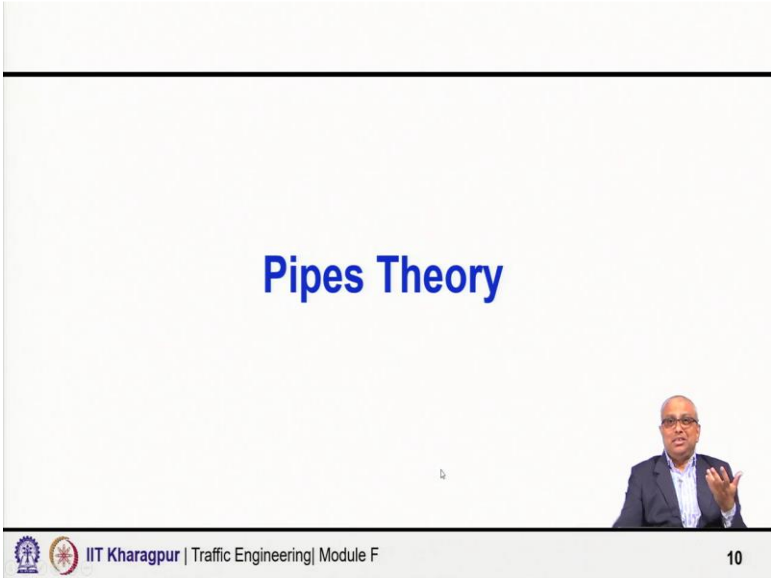


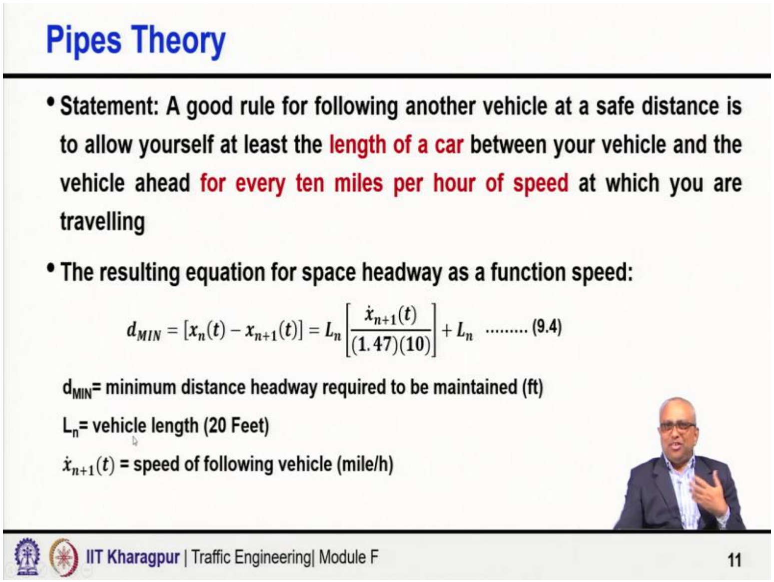
Now, let us familiarize ourselves with some of the notations n is called the leading vehicle, n plus 1 is following vehicle, Ln is the length of vehicle lead vehicle or LV, Ln plus 1 is the length of following vehicle. I have shown here this is the length of lead vehicle this is the length of following vehicle n denotes the lead vehicle n plus 1 to denote the following vehicle.

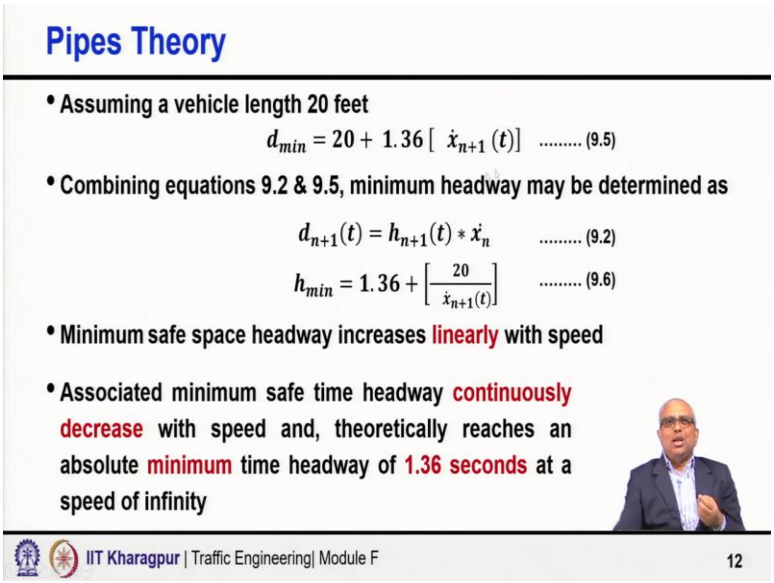
xn is position of lead vehicle this is xn with reference to some reference point or benchmark, xn plus 1 is the position of the following vehicle from the same benchmark, x dot n is the speed of the leading vehicle x dot n plus 1 is speed of the following vehicle and x dot n plus 1 is the acceleration of the following vehicle.

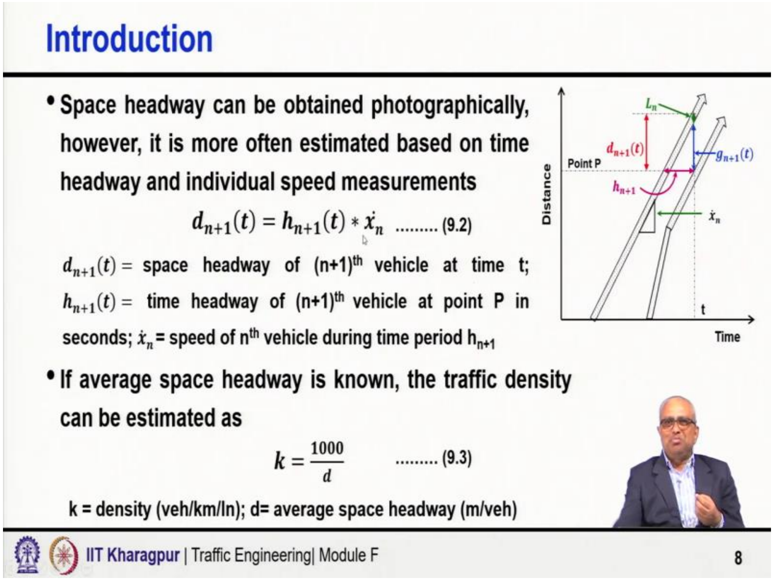
And delta t is the basically the reaction time of the following vehicle and we can call it or we can express it in a slightly different way also but it is essentially the reaction time. It is the time gap between two times. What? Time a unique car following situation occurs time t and the time the driver of the following vehicle decides to apply a specific acceleration or deceleration that time gap which is nothing but what is basically the reaction time.

(Refer Slide Time: 20:22)









Now, with this let us discuss the pipes theory, there are many models today we shall discuss two such models in this lecture are two such theories given by the researchers first is pipes theory. What pipes theory says based on a very important statement based on that only the mathematical model is developed.

It says that a good rule for following another vehicle at a safe distance is what to allow yourself at least a length of car between your vehicle and the vehicle ahead between your vehicle means the following vehicles and the vehicle ahead means the lead vehicle for every 10 mile per hour of speed. So, every 10-mile speed give 1 length of vehicle gap clear gap in between.

So, 20-kilometer 2 vehicle gap particular with a 3 vehicle gap like that I did again so, allow yourself at least a length of a car 1 car gap that much length gap you give between your vehicle and the vehicle ahead for every 10 miles per hour of speed at which you are traveling. So, then what will be the clear gap? Clear gap will be x dot n plus 1 into t what the following vehicle speed at what speed it is going divided by the 10 because that many car length into Ln length of the car this 1.47 is coming because of the converse and mile per hour and then feet and all this.

$$d_{MIN} = [x_n(t) - x_{n+1}(t)] = L_n \left[\frac{\dot{x}_{n+1}(t)}{(1.47)(10)}\right] + L_n$$

But this is the clear gap then what will be the distance headway xn at time t minus xn plus 1 at time t this will include this clear game plus length of the vehicle Ln. Now, this is the minimum distance headway required to be maintained because it is at least So, this is the minimum headway distance headway if you take Ln or length of the vehicle as per this condition 20 feet then this equation can be written as 20 plus 1.36 into x dot n plus 1 at time t.

$$\boldsymbol{d_{min} = 20 + 1.36\,[\ \dot{x}_{n+1}\,(t)]}$$

Now, combining this equation 9.5 and what I said here as 9.2 this equation. Reference to this figure, I have also reproduced it here this is the one if we combined these two then we can also think when two vehicles are really following each other then the speed of the vehicle in front and the speed of the following vehicle lead vehicle and following vehicle must be equal when we are continuously following it as it is shown here also in this situation, you can see these two lines are parallel.

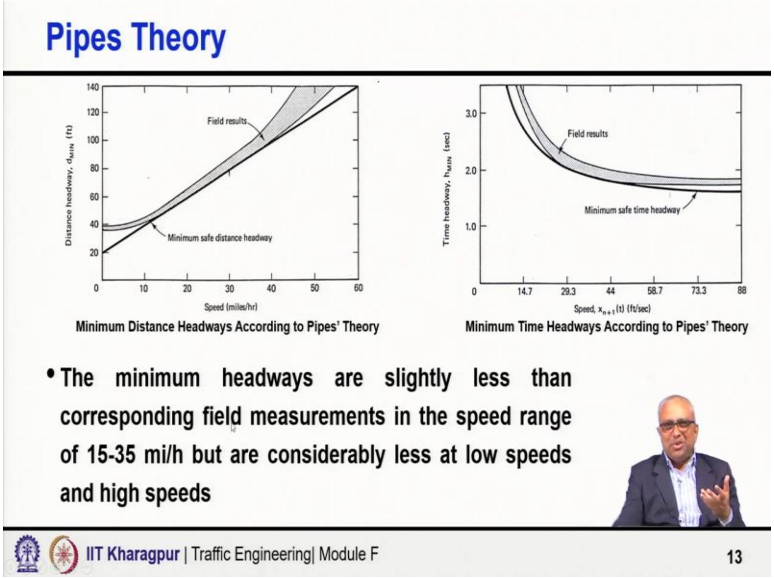
So, when these two lines for this segment, the speed the slope is same these are two parallel lines. So, the front vehicle and leading vehicle traveling at the same speed. So, whether I write x dot n or x dot n plus 1 it is the same thing. So, considering this as x dot n plus 1 then you can get it. So, divide dn plus 1 t is the d minimum in this case when they are following.

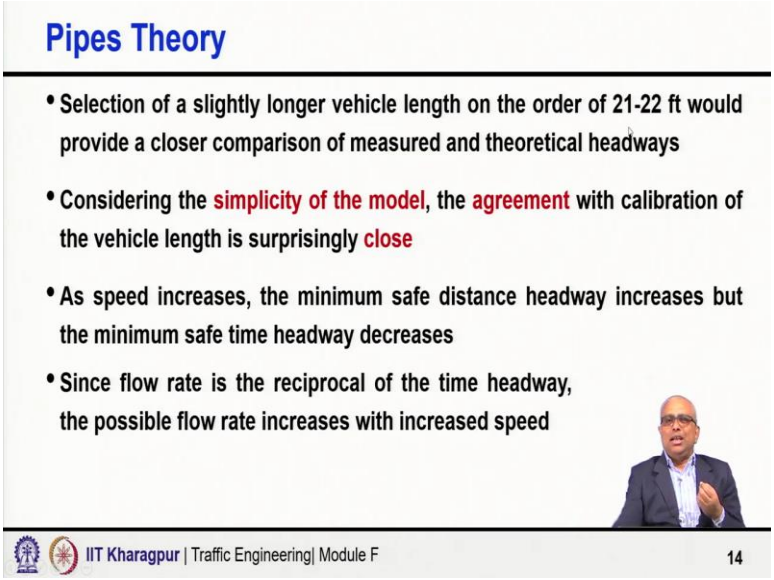
So, the headway will be then what? Headway will be 1.36 because you divide take this like divided it h n plus 1 then the minimum divided by x dot n. So, the minimum is the minimum headway, this is the time headway equal to 1.36 plus this 20 divided by x dot n plus 1 t. So, what it shows associated, this is the minimum time headway and this is the minimum distance headway or space headway. So, these two are the equations then, as per pipes theory.

$$\boldsymbol{h_{min} = 1.36 + \left[\frac{20}{\dot{x}_{n+1}(t)}\right]}$$

Now, what it says then associated minimum save time headway continuously decrease with speed if the speed is going to be higher than 20 by this because it is in the denominator so, 20 plus this will be progressively lower value as the speed is increasing. So, as the speed is increasing minimum safe time headway will decrease. And theoretically if we consider speed has reached to infinity, then this component may be considered as 0 and then 1.36 seconds will be the absolute minimum headway for the speed of infinity theoretically.

(Refer Slide Time: 26:34)





Now, here we are showing what the field results gave all the field experiments were done and we are only showing the results without going into details of that field experimentation what and then this solid line is shown the pipes model. This is for distance headway and this is for time headway again this area shows how the data points came from the field and this solid line is indicating as per pipes theory or pipes model.

What you can find here from this minimum distance headway graph that the minimum headway are slightly less than the corresponding field measurement in the speed range of 15 to 35 mile per hour, but are considerably less at low speeds than high speed if you see this range, this is around 15 kilometer and this is around this point is 35. So, within this range, it is fairly close just touching.

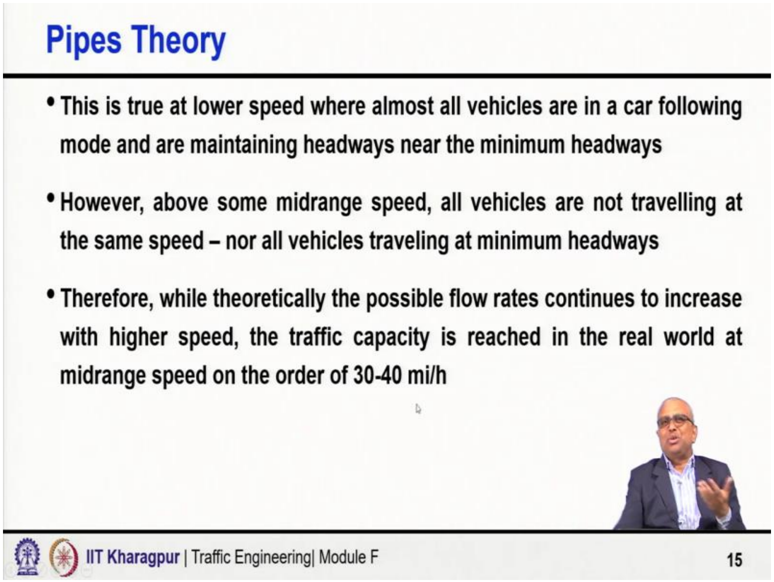
So, reasonable match but at lower speed and at higher speed what this line or the model is predicting and whatever is the field data is showing they are not matching significant difference or considerable difference. Selection of is slightly longer vehicle length 21 22 feet if we take instead of 20 then obviously, what will happen this layer line model line will laterally shift upward.

So, the model line will pass through this area rather than just touching the edge that gives us a slightly better fit no doubt. But considering the simplicity of the model very simple basis just keep one vehicle gap but every 10 mile per hour speed very simple thing. So, considering the simplicity of the model the agreement with calibration of the vehicle length is surprisingly close.

Yes, we are not able to explain the whole range but the whole mid-range it is really matching nicely the as speed increases the minimum safe distance headway increases. But the minimum safe time headway decreases you can see that the distance headway as the speed is increasing that distance is always increasing both as per the model and as per the real data.

And as the speed increasing the time headway minimum time headway is actually decreasing. Here it is increasing. Here it is decreasing both as per model and per real data. Since the flow rate is reciprocal of the time headway, the possible flow rate also increases with increased speed. That is what you are getting because the time headway reciprocal of time had one by time which is actually the flow. So, time headway is reducing that indicates the flow is increasing.

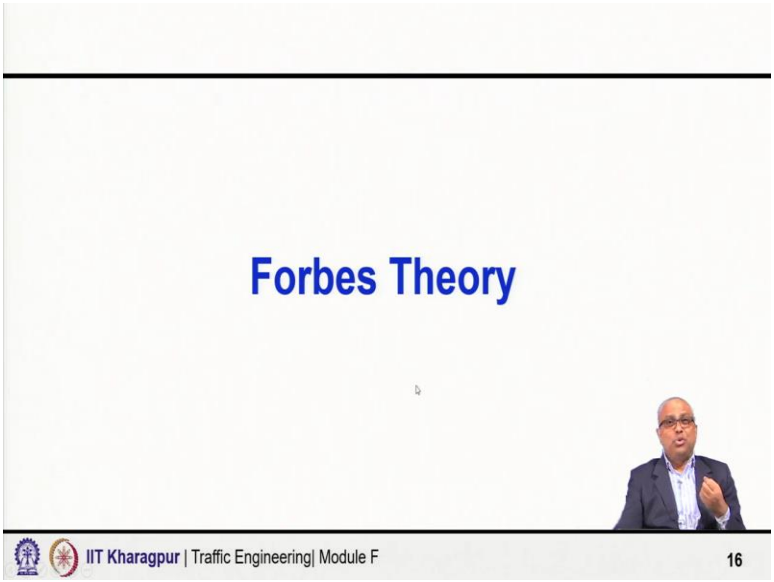
(Refer Slide Time: 29:50)

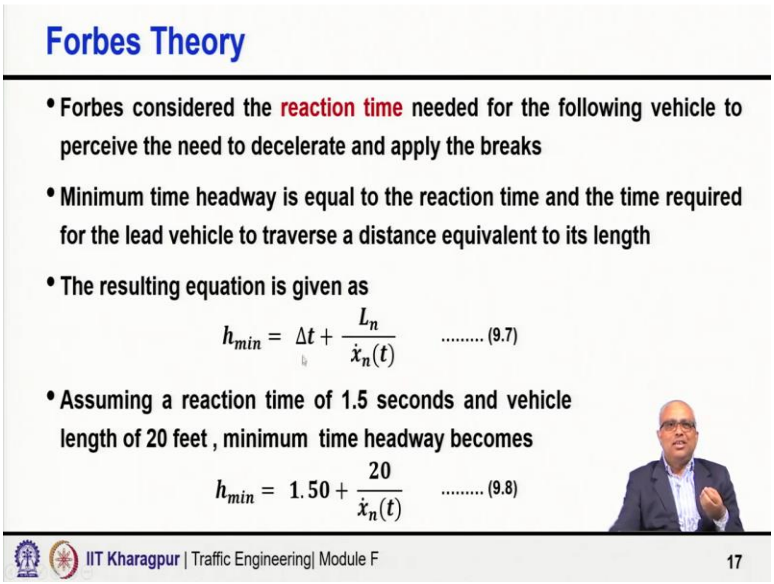


But this is true at lower speed. Because what happens at lower speed almost all the vehicles are in a car following mode. They travel at the same speed and they are actually in a car following more or less ideal car following mode and are maintaining headways near minimum headways. But what happens above some mid-range speed when the speed is further higher, all vehicles are actually not traveling at the same speed the car following really in true sense is not happening for majority of the vehicles not all vehicles traveling at minimum headways.

So, therefore, while theoretically possible flow rate continued to increase with higher speed. But you get actually you get capacity at some mid-range and beyond that it takes a different trend that is not is explained here. So, the traffic capacity generally is found to reach in the mid-range in the order of 30 to 40 miles per hour.

(Refer Slide Time: 31:02)





The next is the Forbes theory. The Forbes theory considered the reaction time as the basis again very simple model but very interesting because it gives reasonably close match again. So, the forbes considered the reaction time needed for the following vehicle to perceive the need to decelerate and apply brake.

The reaction time is taken as the basis how much reaction time is needed to perceive the need to decelerate and therefore apply the brake. The minimum time headway is equal then to the reaction time. But that is what is the clear gap we are talking about the clear gap segment, but actually time headway if you say the length of the vehicle is also important.

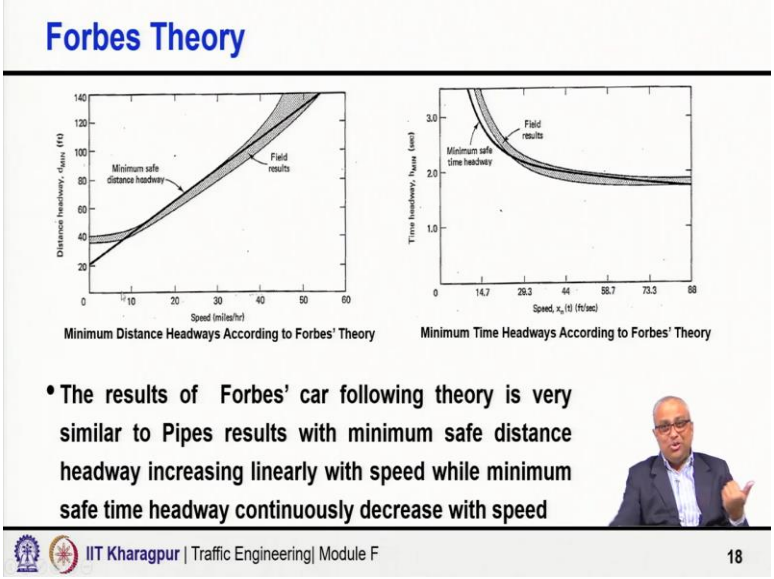
So, the length divided by the speed of the following vehicle leading vehicle sorry following not following but speed of the lead vehicle. So, that is the time taken to for the leading vehicle to cross its own length. So, L by x dot n plus this delta t reaction time that is what is the minimum headway requirement and assuming that reaction time of 1.5 seconds and again vehicle length of 20 feet again as we considered earlier in the beginning.

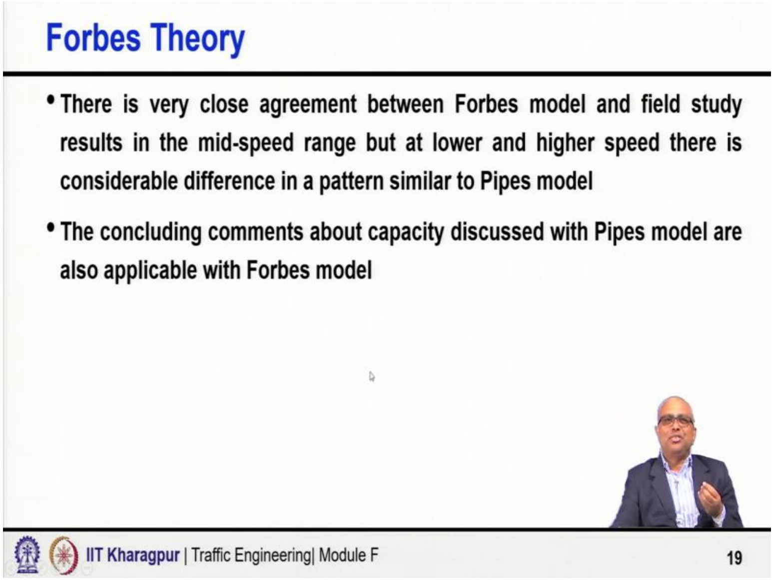
$$\boldsymbol{h_{min} = \Delta t + \frac{L_n}{\dot{x}_n(t)}}$$

The minimum headway becomes then 1.5 plus 20 divided by x dot n simply applying this formula only thing we are putting the value of Ln as 20 feet and the delta t reaction time was 1.5 seconds.

$$\boldsymbol{h_{min} = 1.50 + \frac{20}{\dot{x}_n(t)}}$$

(Refer Slide Time: 32:55)



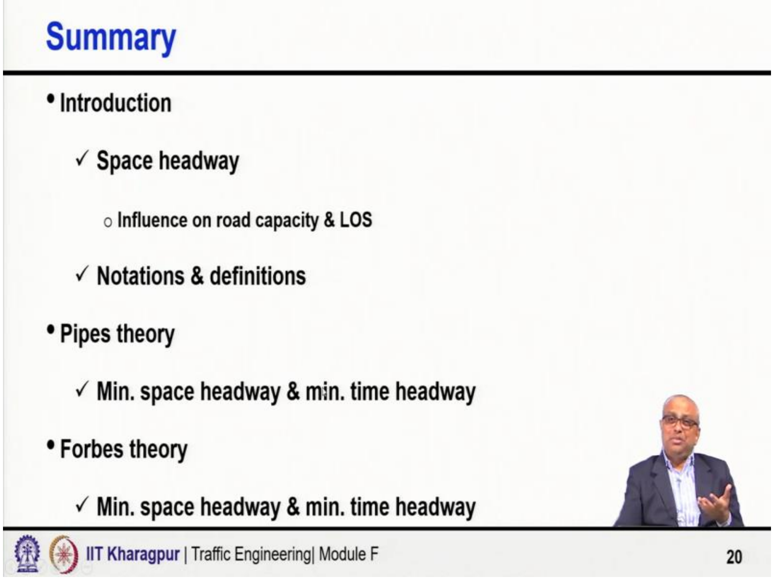


Again, the field measurement vis-a-vis actually if we fit this model both again distance headway and time headway. So, what again can be observed that the results of Forbes car following theory is very similar to pipes result with minimum safe distance headway increasing nearly linearly with the speed while minimum safe time headway as shown in the gap continuously decrease with speed. Same trend same kind of fit, we are getting reasonably good fit.

So, there is very close agreement between Forbes model and field study results in the mid speed range. Again, as you can see that the Forbes model in the mid field range is giving quite good and satisfactory results with the field study results. But at lower and higher speed there is a considerable difference and the pattern is very similar to what we observed in case of pipe model. The remaining concluding comments about the capacity what we discussed in the pipes model context are also applicable with forbes model.

So, that means, why the capacity may increase and but then may not increase continuously may again come down at lower speed the car following things happen more often majority of the vehicles they are traveling at a speed similar speed and then as the speed increases the more deviation will happen not majority of the vehicle will be in car following mode, they may not maintain the same headway as well. So, the capacity does not reach continuously but you will get in a mid-range the capacity value will come and so, the capacity will be maximum at a mid-range and at higher and lower the values will be lower than the flow will be lower than the capacity.

(Refer Slide Time: 35:22)



So, what we discussed in this lecture is about the importance of the space headway in the context of car following and told what we mean by car following and all the notations leading vehicle, following vehicle, all this we know now. And we discussed pipes model and the Forbes model. These two models we discussed and said that how the space headway and the time headway how they are matching as per the models and with the real field experiment data. So, with this I close this lecture. Thank you so much.