Introduction to Multimodal Urban Transportation System
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Lecture-28
Non-Motorized Transportation (NMT) Planning: Pedestrian Flow Models

Welcome friends, now that we have looked at the different macroscopic flow models from the vehicular realm and how it is it can be applied in the pedestrian transport realm, let us look deeply into how these different models can be applied for different situations.

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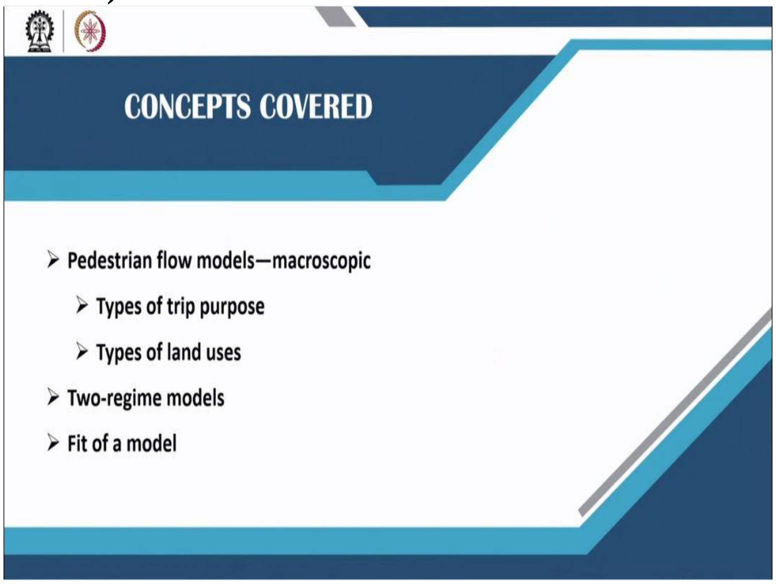

So, in this in this lecture we will be looking at how the flow models differ by trip purpose, by different types of land uses, how they can have two different regimes in their models. In the models one regime can be for congested flow and one can be for uncongested flow. And what do we say when a model fits the data? Well, so how do we determine the fit of a model? We will just quickly look at it.

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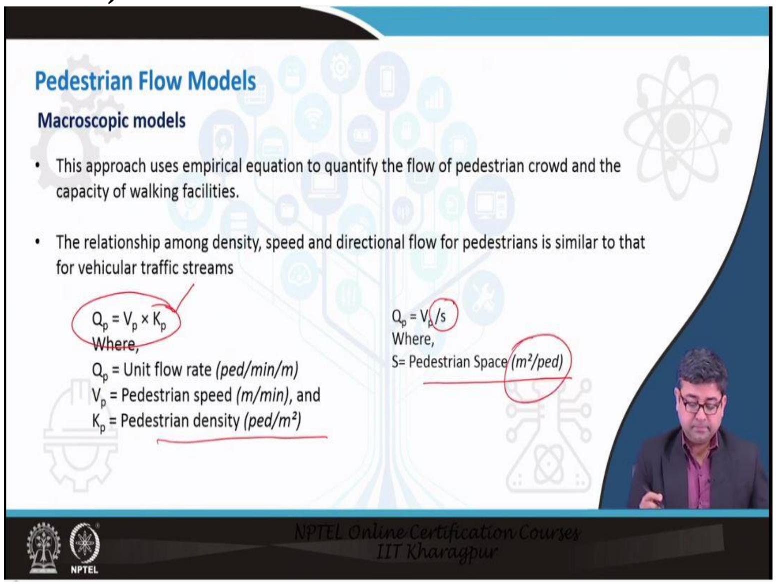

Now, we have looked at the Greenshields macroscopic model. And this is kind of the big picture of those models, where the relationship between speed, directional flow, the speed and flow and density is given by $Q_p = V_p * K_p$. So this is something that all of you should remember. Sometimes, in case of pedestrians, we also say that we do not use density K_p instead we use something called "pedestrian space", which is just the inverse of density. So, density is pedestrian per square meter whereas space is meter square per pedestrian. So, just to make it clear, how many people are there in an area (per meter square) is called pedestrian density whereas, how much space does one person need is called pedestrian space. So, I need about certain amount of area to move freely in a space. So, that is called pedestrian space which is meter square per pedestrian.

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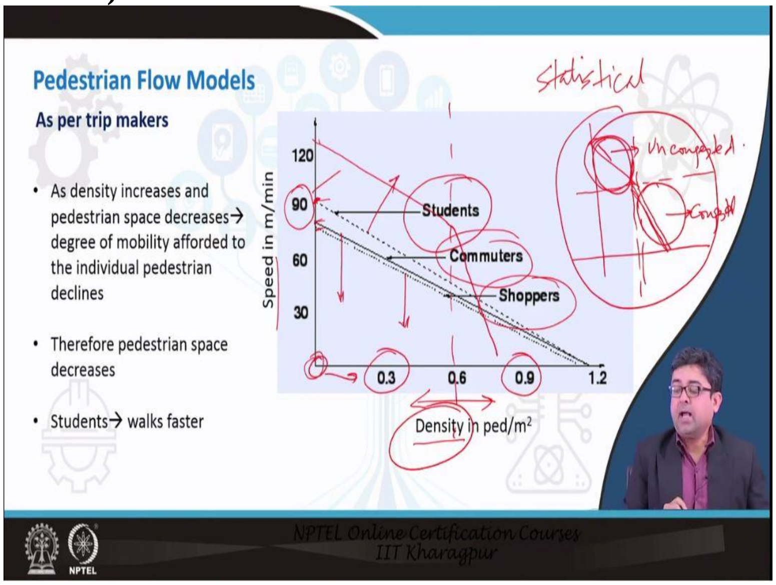

So, now when we look at different types of trip makers, so, everybody who is walking on a pedestrian facility may not be walking for the same purpose, some could be students who are walking to go to school, college or wherever they are going. Some could be commuters, the office goers that are walking along the street, whereas broadly another group could be shoppers or leisure travelers who are walking along a street. So, it has been noticed that there are some significant differences between these three kinds of trip makers along the street. So, when you plot this graph again, between speed and density, you will see that the students usually have a greater free flow speed. So when the density is 0, the speed is called free flow speed. So that means that students usually tend to walk faster, and that is faster when compared to commuters or shoppers. And that is intuitive also in another sense that students are usually younger in age. So they would also tend to walk faster and then you will see that their free flow speed is very different. Whereas when it comes to commuters and shoppers, although the free flow speeds are very close to each other, but also they are different because commuters tend to walk a little bit faster as compared to the shoppers, shoppers walk very leisurely, they are shopping so they are not in a hurry to go anywhere. Whereas, commuters may be going to their workplaces or running an errand for their office so they will be walking faster. So that is what many researches across countries have shown.

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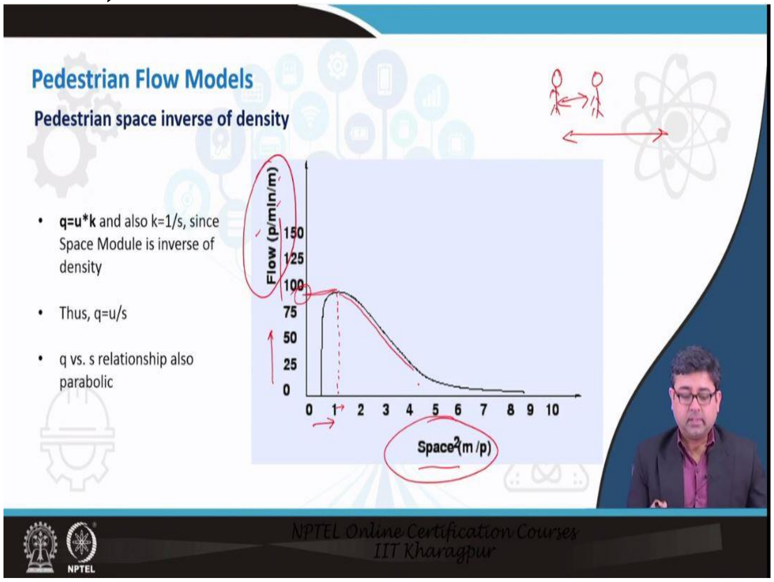

Next also now, we have seen the macroscopic models for vehicles, where we have seen the relationship between flow and density. But now here if we see the relationship between flow and space, because remember in pedestrian realm, we sometimes use space instead of density. So, when we see the graph between flow and space, we noticed that as flow increase space increases, so, there is a need for space. So, I may need a little less than 1 square meter to walk freely, whereas some may need a little bit more than 1 square meter. So, as the space increases, the flow also increases, but the increase is only up to a certain point. The increases maybe just be about 1.1 meters square per person. So space is nothing but if there is a person and the distance between the next person this is hypothetically the space. If this space keeps on increasing that means, there are very fewer number of people walking because the distance between two people is too much. So, when there are fewer number of people walking, the flow, which is the number of people per minute per meter also reduces. So, a sidewalk may have a lot of open spaces. A person is walking very freely, yes, they have their freedom to walk, but at the same time, there are not enough people to then justify such sidewalks. So you will see many times there are wide footpaths, but hardly any people are walking on that. So 1 or 2 people are walking, and they have enough ample amount of space. But the flow which is the total number of people moving across a certain point per minute is very less. So, optimally you see just about 1.1 meter square per person is optimal enough to have a very high flow rate, if one keeps on giving more space to people actually the flow rate starts to reduce or the flow starts to reduce. So, when we are designing sidewalks, we have to be very careful as to how much width of the sidewalk should be there versus the number of people that are going to walk on that sidewalk. We do not want to give too wide sidewalk if the volume of people actually who are going to use it is very less because that was that will mean that the flow is very low, which usually means that you are not utilizing the capacity of that sidewalk to an optimal extent or maximum extent.

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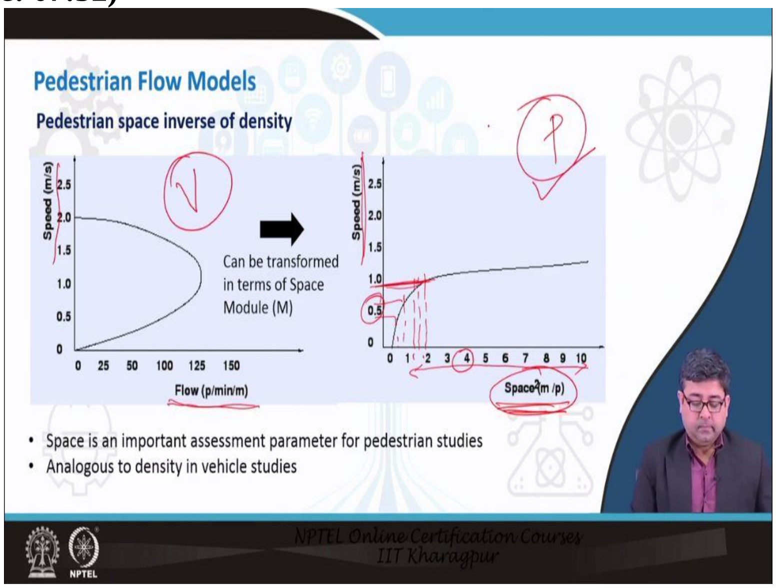

Then similarly, the third kind of macroscopic model that we have seen for vehicles earlier is for speed and flow, similarly, if you convert it for pedestrian case into speed and space, we see that again similarly, if we keep on increasing the space between for each person, space meaning meter square per person, so, if we keep on increasing the space beyond a certain point, the speed is no longer going to increase. Because again what happens is people can walk only at a certain pace, certain speed, just because there is too much free space available to them, they cannot walk any faster because that is beyond their physical ability to walk any faster. So, on average maybe people walk at around 1 meter per second. One may think that well let me build a wider sidewalks where I am giving about 4 meter square per person. So I am giving 1 person almost 4 square meter to walk comfortably and you would and maybe the thought is that if I give more space people can walk faster, but it has been noticed that any space more than about 1.5 to around 1.75 square meter does not bring about any increase in speed. However, yes, if the space is less than 1 then there is a large reduction in speed. So, when in congested situations when 1 person does not have enough space or less than 1 meter square for himself or herself, then their speed does get restricted. So that is the idea of space, developing relationship between space and speed versus developing between flow and speed which is more of a vehicular relationship and this is more of a pedestrian relationship, and this is more of a vehicular relationship.

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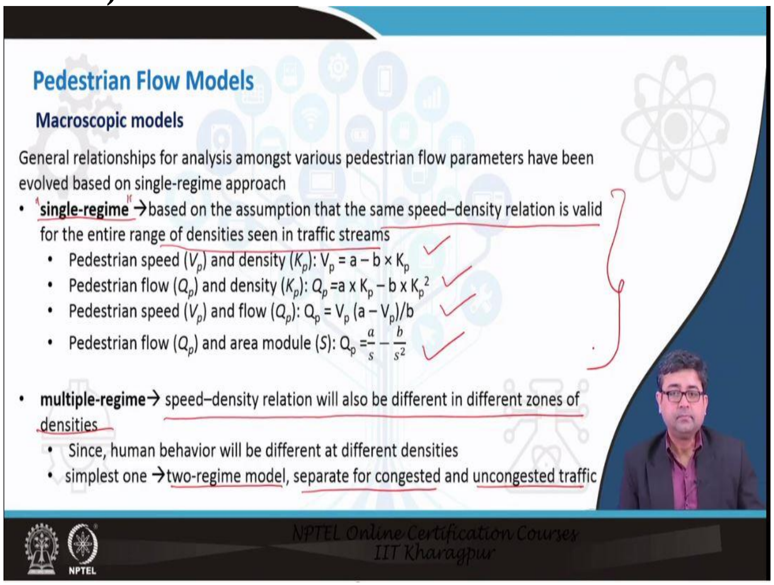
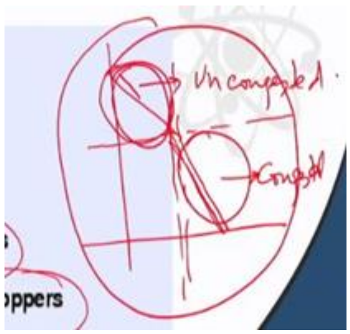


So now the other thing to remember is in all of these relationships, we have looked at say the relationship between speed and density, flow and density, speed and flow, or flow and space, we have looked at it saying that they are single regime models. So, what do we mean by single regime models is that we assume that the same speed and density relation is valid for the entire range of densities in the traffic stream. So, if we say go back to the speed and density relationship let us see the speed and density relationship, we are seeing one model. So, each of this is a model we can develop: a model for the students, a model for the commuters and the bottom one is a model for the shoppers, when I say model these are statistical models. So, what we are looking at simplistically is to say that, even at this density, the slope of these lines is the same as versus at this density. So, we are always saying that the slope of this line is constant be whatever be the density. However, people have found out that there is a cutoff point at certain density where they say the model has a different regime. So, for example, this slope may be this whereas after that point the slope is very steep, when you have such a model they are called two regime models. So, if I can draw the same thing here, if it is a two regime model, what usually happens is that the slope here up to a certain density is this whereas, beyond the density the slope kind of changes. So, then you can make a distinction that these two are both representing the students only, but beyond a certain density they have different behavior, i.e., the student population that are walking have different behaviors. So, these are usually called two regime models and why people are looking at as they become more and more mature in this field. Why are they trying to look at these things are they are saying that it is an uncongested flow situation. So, there is some density or some density cutoff or threshold at which, beyond which the footpath of the sidewalk becomes congested as the density increases it becomes congested so, in congested flow people walk or people's behavior towards walking changes vis-a-vis their behavior or walking under uncongested situation.



So, the top part usually is the uncongested situation because here the density is 0 and so, you can have free flow speed from here. So, as the density increases your speed reduces, but beyond a certain density now, it is not uncongested flow situations. So, this half is a congested flow situation, whereas this is an uncongested flow situation and your behavior changes. So, what people are now looking at more and more are, speed density relations may also be different in different zones of densities, they are saying that they are multiple regime densities, two regime models they are separated for congested and for uncongested. Whereas, for simplicity of understanding, we have looked so far at all of these models as just single regime model. So, we are not making any distinction between uncongested flow and congested flow. Mostly single regime models are usually used in regular application of these models whereas, in theoretical studies and to improve models people start looking at two regime models.

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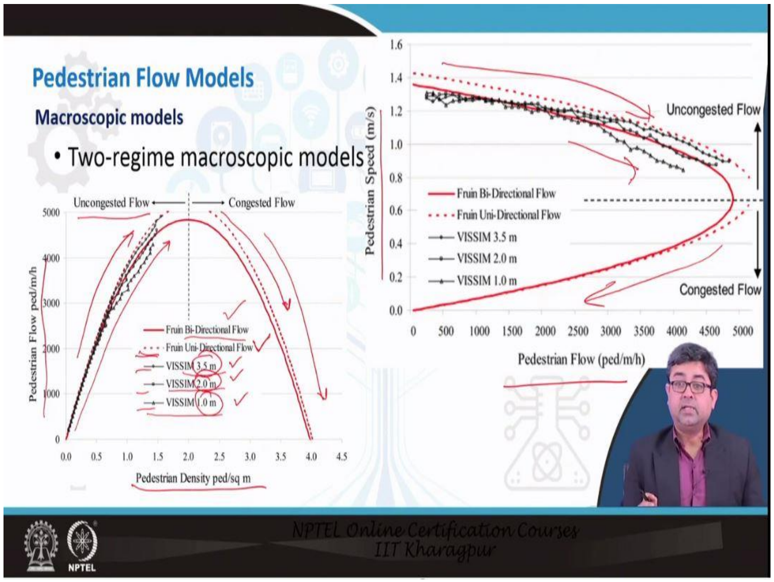

Let us see this is an example again. So, this is a simulation software VISSIM 1.0 the different meters is what they have developed this for. Fruin was the initial researcher, who had developed this model back in the 1970s. And when he had developed it, for bidirectional flow, the red line, he had made no distinction between congested and uncongested flow. And he had said that this one model fits the behavior of all the pedestrians be it on an empty sidewalk or be it in a congested sidewalk. However, when he started looking at unidirectional flows, he saw that so, unidirectional flows, meaning people moving in the same footpath people are moving in only one direction. Otherwise bidirectional meaning on the same footpath they are moving both directions. So, when you start having that kind of a sidewalk, he saw that if you see the dotted red line, he saw that there are 2 different models in the uncongested flow. The model kind of goes like this, whereas in the congested flow model goes like this so, there are 2 different models their dotted dashed lines. Similarly, when VISSIM model simulations are done, VISSIM could actually model the uncongested flow pretty well, all the black lines you see, but it was not able to model the congested flow pretty well. So, there is essentially people have started to make this distinction as to how there are 2 different regimes of the same model. Similarly, this is an example of pedestrian flow and pedestrian speed. Again, they have been able to model the uncongested flow pretty well. Whereas when it comes to the simulation tools as well as the unidirectional flow, it becomes very difficult to model the congested flow.

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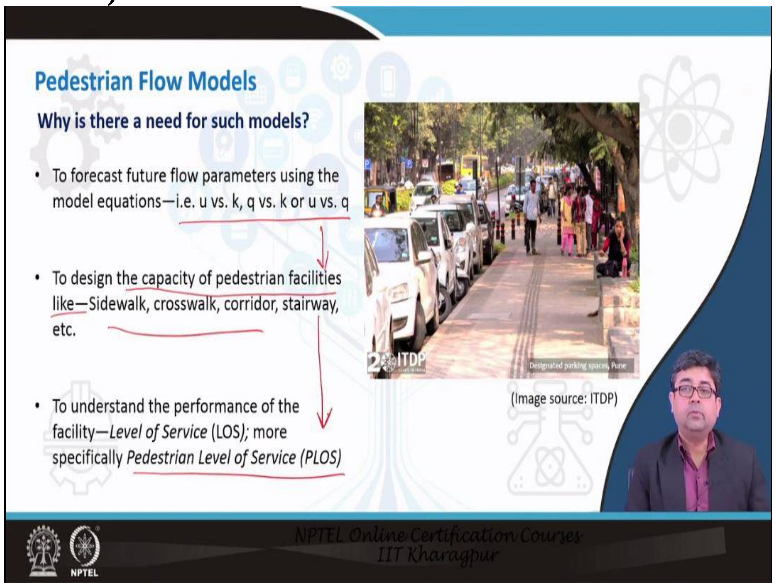

Now why are we telling you about all of these models? Why should so much focus be paid towards these models and these relationship between the 3 basic parameters speed, density and flow? Because these are utilized to design the capacity of pedestrian facilities. Capacity meaning what should be the width? How long should you build the size of a pedestrian facility for? If you do not know the relationship between the flow and the speed parameters or the flow and space parameters, then you would not be able to say, you would need a 2 meter wide sidewalk for the next 1 kilometer or do you need a 5 meter wide sidewalk for the next half a kilometer. You cannot estimate the right capacity of the sidewalks and then you make sidewalks that are underutilized or not utilized at all, and that has policy implications. So, that is one of the reasons and then that eventually affects what is called pedestrian level of service. The pedestrian level of service we will get into in the next few lectures, classifies how many pedestrians flow for a given width of a sidewalk for example, one of the ways of measuring pedestrian level of services to see how much width of a facility you have, and how many people are flowing through that facility. So, if you do not design it accurately, then your level of service, which is an indication of how well the pedestrian facilities are serving the users, will be affected. So, the basis for everything is to know the relationship between the flow parameters, which in turn tells you to what capacity you should construct your pedestrian facilities, which in turn affects the level of service that is being provided by the pedestrian facilities. Hence, it is very important that you know about these models.

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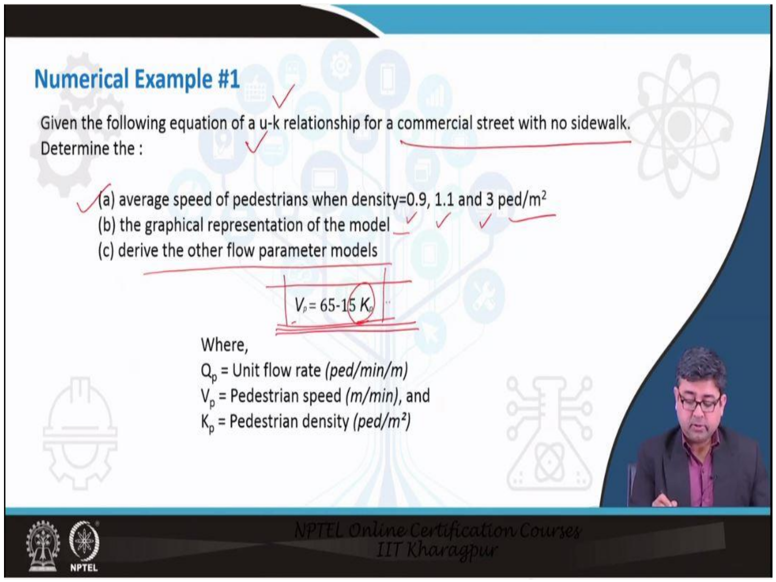

Now, quickly again, let us take you through an example of this model and how to solve it. So given is a speed and density relationship along a commercial street with no sidewalk. So, they have no sidewalk facility, but we have observed that the people that are walking are can be modeled using this relationship. So, speed has a relationship with a pedestrian density we have shown you the curves. This is the relationship now, the question is asked, what is the average speed of pedestrians when the densities are 0.9, 1.1, 3 pedestrian per meter square, the graphical representation of this model and derive the other flow parameter models. So, you know that the other flow parameters other than speed and density or speed and flow or flow and density. So, how do you derive that? So, now, the first question is to the speed of pedestrians at different densities.

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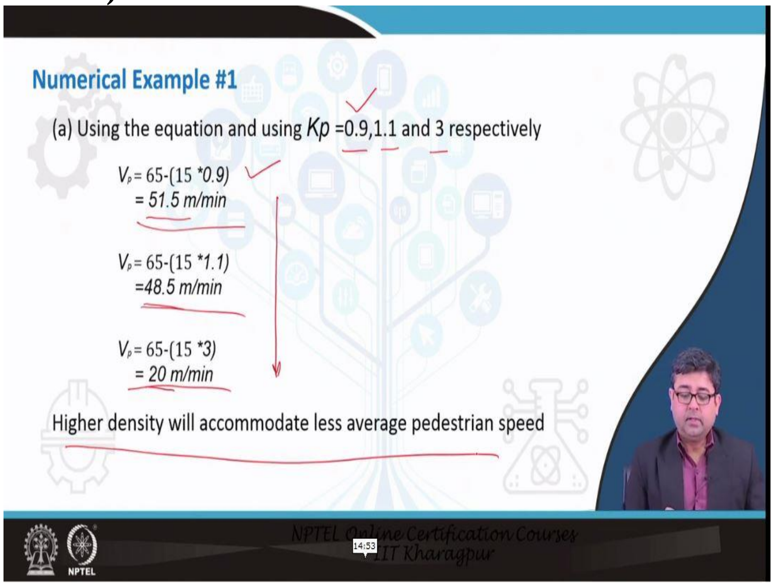

So, it is just the very simple you have the equation so, you put in the K_p values and it will give you the speed values. However, the interesting thing to notice again, like you already know by the curve that has been shown earlier, the relationship that has been shown earlier is that as density increases from 0.9 to 1.123 the speed decreases. So, speed for K_p=0.9 is 51.5 then decreases to 48.5 and then finally, it decreases to 20. So, this is how usually the relationships are. So, the higher the densities, higher density will correspond to lesser average pedestrian speed.

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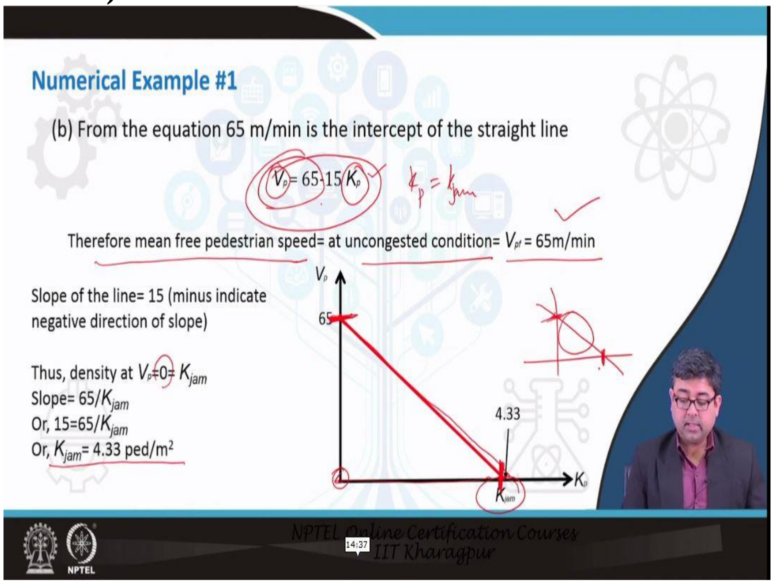

Now, how do you show it? How do you show it in a graphical manner? So, to show it in a graphical manner, we know that it has an inverse relationship, but where does this cut the Y-axis and the X-axis you have to know. So, we all know that the graph cuts the Y-axis that point is called free flow speed. So, at free flow speed what happens, the density is 0. Therefore mean free pedestrian speed at uncongested condition V_{pf} should be = 65 meters per minute, which gives you the free flow speed. So, now you know that your first point is here. Secondly, what you know is that the slope of the line is -15* K_p value, but also what you know is the point at which this curve cuts the X-axis is called the jam density. So at jam density what happens is the speed becomes 0. So, if you put the value of 0 for V_p, this $K_p=K_{jam}$. So if this is 0, you put it as K jam. And you know that K jam now is for 4.33 per meter square. So now you know your mean free flow speed, you know your jam density. So, you can draw this curve. So, whenever you are told to graphically represent an equation, you have to know all the parameters

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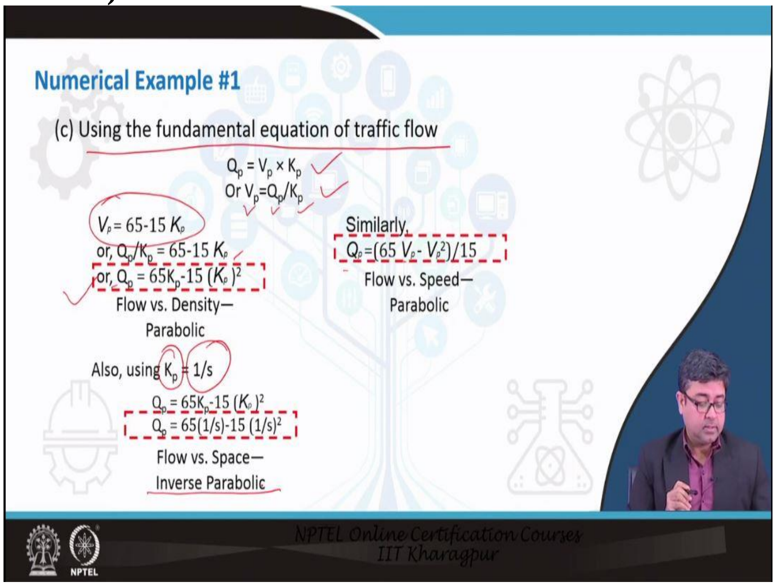

And then we know how to measure or how to estimate the other parameters of the macroscopic relationship, because we know the formula. You can convert V_p in terms of Q and K. Put Q and K here. You will get the parabolic equation between now the relationship is between Q and K. So flow and density, which is parabolic we already know. Similarly, if you convert this into a relationship between Q and V_p that is also a parabolic flow and speed, let us convert this into a flow and speed relationship. And now if you want to convert you do not want to have density, which in many cases, pedestrian cases, we do not see the density like that, but see it in terms of space, then this becomes an inverse parabola.

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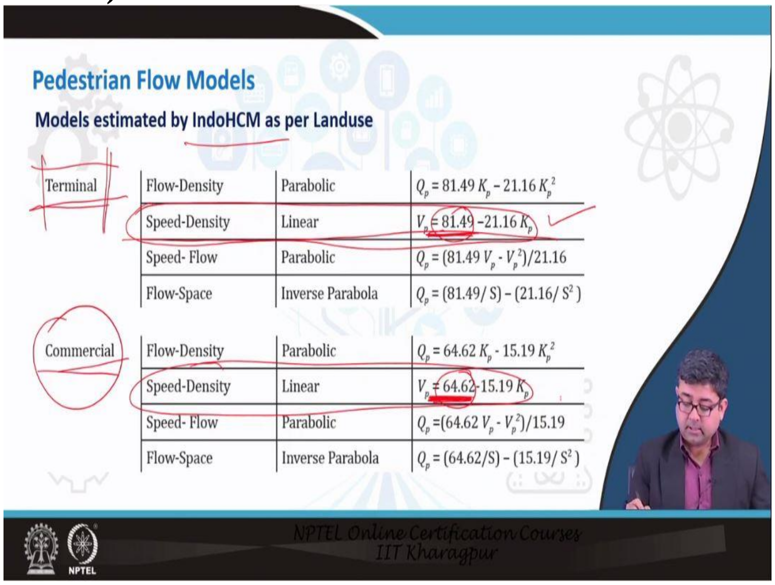

Why we are telling you all of this is because in the very recent Indo HCM that has come out, these relationships have been depicted for different types of pedestrian facilities. So if it is a terminal facility, meaning it is an endpoint, so it is like a last stop or bus stop, a bus station or something like that, then the flow-density curves are the simplest curve let us look at the simplest speed density curve, the speed density curve is given by $V_p=81.49-21.16K_p$.

Whereas, if the facility is in a commercial place, so, it is a sidewalk in a commercial place, then you see that the speed density relationship is $64.62-15.19K_p$. So, what immediately this should tell you is that at terminal places the free flow speed of pedestrians is higher than when compared to commercial places. In commercial places people will usually walk slower. Where they are shopping so, the commercial areas and usually the number of people in the commercial area is also high. The speeds will be low and hence the free flow speed is lower. In case of terminal spaces where people usually have got a got off bus or got off a metro rail and then they want to walk pretty fast, they want to get to their homes or offices or something. So, that is the easiest relationship to be understood.

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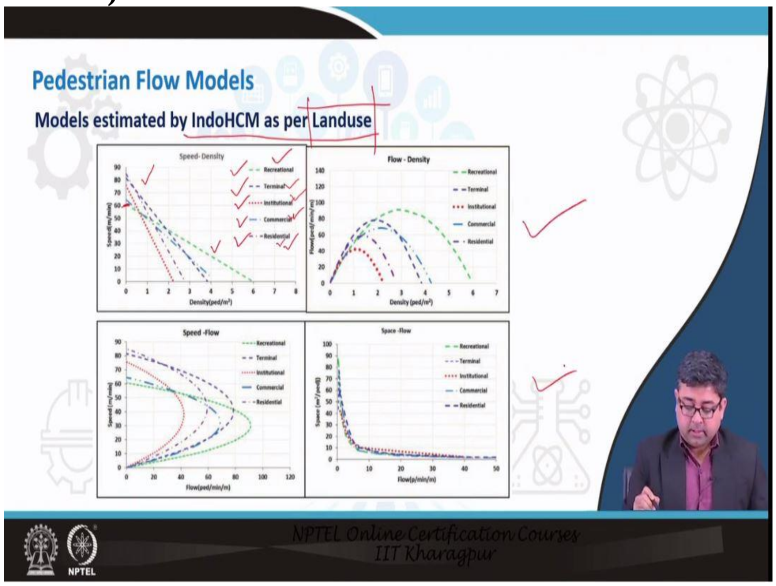

So, here are Indo-HCM models for different types of land uses. So, you see that there are these 1, 2, 3, 4, 5, there are 5 different land uses for which these models have been developed, i.e., recreational land use, terminal land use, institutional land use, commercial, residential. So, when I say land uses, so it is the land use that is abutting this facility or containing this facility. So, if recreational land use meaning maybe it is there is a footpath that is alongside a park. For example, institutional meaning maybe there is a big office building or a big school or a big college, some kind of institution, there is a sidewalk along it. Commercial meaning again, market area. Residential meaning near your homes. So, it has been seen that people behave differently. We showed you earlier also if you are a student versus if you are a shopper versus if you are a commuter, your behavior is different. Further, it has been found that if the sidewalk is along different types of land uses, people behave differently. So, you see that the green one which is the recreational, for which you see the slope is very gentle, and the free flow speed is much less than for the others, meaning that people usually want to walk very leisurely, very slowly along footpaths that are closer to recreational facilities or abutting recreational facilities. Whereas if there are other ones, they walk usually faster than that, that is the relationship. Similarly, the other relationships are depicted.

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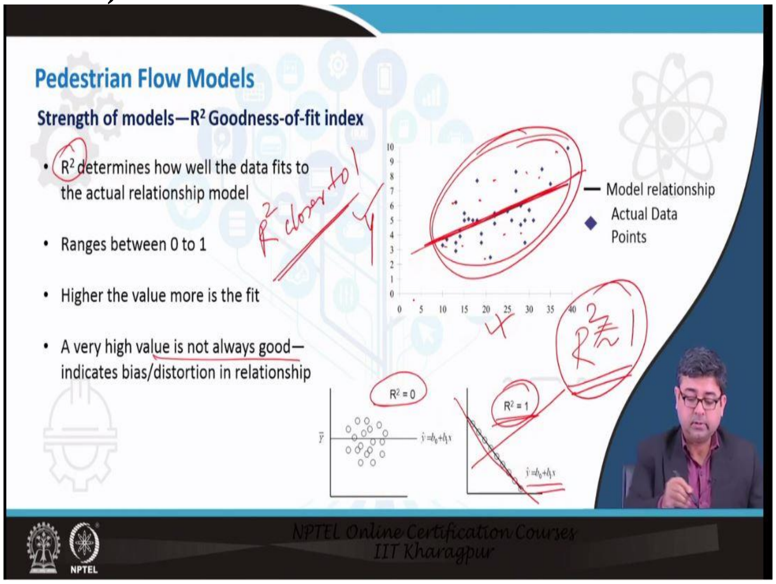

Now, whenever people want to know how good the model that you have developed is, what people usually is calculate what is called an R^2. So, these are all simple linear regression equations. So, for linear regression equations, what usually they want to see is a trend line like this, is there a trend line that explains all of your data sets. So, these may be all of your data set and relationship between x and y. So, these may be all your data sets, but is there a common trend line that can explain the behavior a majority of the time. The higher the R^2 of the model, the better fit it is to the data. If the R^2 is closer to 1, then you usually say that that model fits your data very well. So, R^2 of the model can have a negative slope or a positive slope, does not matter, it could be like that also, but if it is closer to 1, now, in this case, it is saying is equal to 1, which also sometimes is not very good, because it might depict that you have done something with the data set and removed outliers, which maybe are important for your situation, but you have removed them and you got a perfect fit which is always not good. You have to always work towards R^2 that is tending towards 1. That should be good which should not be not necessarily be equal to 1 and if it is something like that, is no relationship then you have to look at other types of models which can explain your data if there is no relationship between x and y, then it is no linear relationship between x and y, then you start looking at other kinds of models. So, R^2 is the goodness of fit index.

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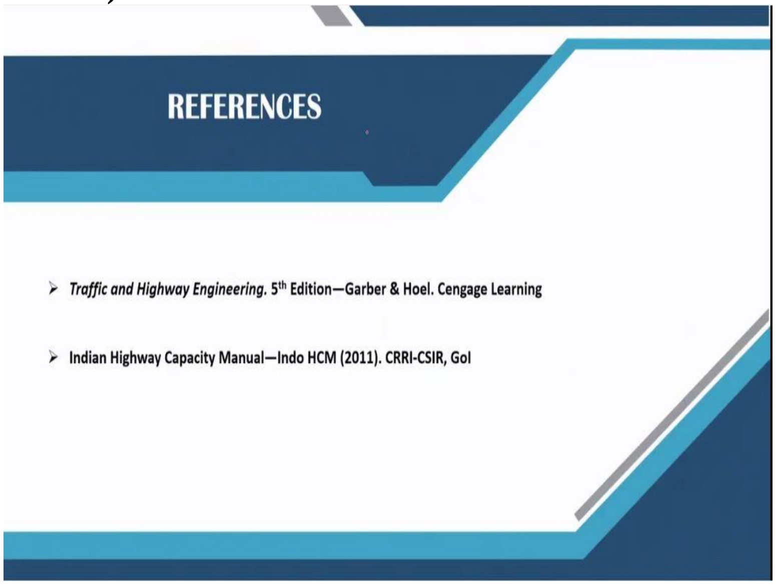

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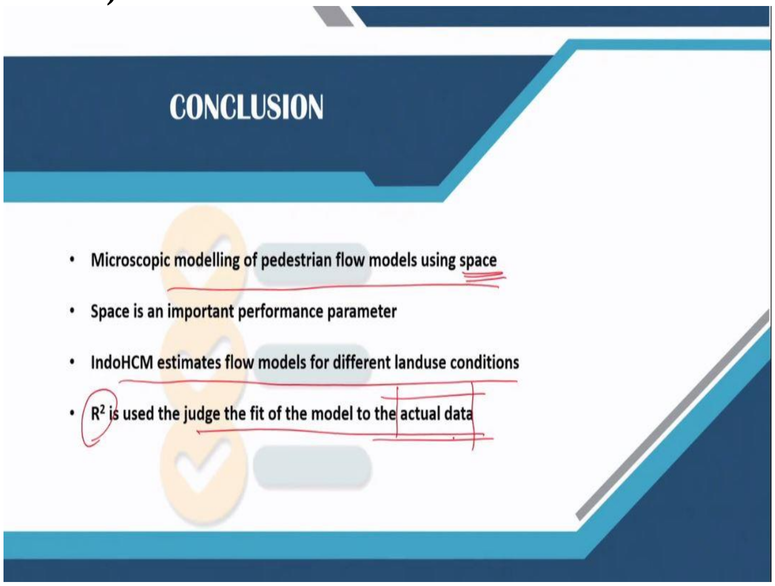

So, that is all about flow models for this lecture. Again, the references are provided. So, in conclusion, what we have looked at is the macroscopic modeling of flow parameters using space particularly, but also using the other 3 parameters. We have also looked at how for different land uses or for different trip purposes, the relationships vary, and we have introduced you to this terminology called R^2, which is a judge of how good you are model, is performing in relationship to the actual data. Thank you.