Introduction to Multimodal Urban Transportation Systems (MUTS)
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Module No # 01
Lecture No # 05
Overview of Urban Transportation: Vehicular Level of Service (LOS) overview

Hello friends, welcome to the next lecture in this series. In this lecture we are going to give you an understanding of the vehicular level of service capacity concepts.

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Like we had discussed in the earlier lectures, there are also several NPTEL courses that go in depth into the vehicular level of service calculations and capacity calculations. However, since our course deals with multimodal transportation we still want to give you an understanding of the vehicular concepts but we would go more in depth into the non-motorized and public transport concepts. So in this lecture we are going to tell you about quality and level of service concepts, explaining what are service measures or performance measures, and then get into the step by step process of determining level of service for multilane highway and signalized intersections.

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So when we talk about quality of service, this is something that describes how a transportation facility operates, from a traveler's prospective. So we have often seen, or we have often looked at transportation facilities from the point of view of the operators or the service providers, but what quality of the service does is it allows you to judge a facility, the determine how good facility is, from a traveler's prospective.

So for example, factors that would have effect the quality of the service include travel time, speed, delay for the people who are using other facility. Travel time also will be further discussed in relationship to its reliability. Comfort and convenience is something that is more and more becoming relevant in the field of transportation when it comes to measuring quality of the service and then also the availability of the information of services.

So now a days, in the digital era, we all want information before hand, of where a bus is or where a train is or when is the next bus coming or what is the congestion level at a street where we are going to next drive. So all of these affect the quality of the service that is been provided. So the quality of the service is been provided by either the bus system or a metro system or even by a highways in your urban area.

So that is what is mean by quality of service. Now the quality of service, since it is a qualitative measure, it is then converted into a quantitative measure by something called a level of service. So what level of service does is it is stratifies the various performance measures into different

categories and each one of them representing a quality of service. So level of service is the quantitative stratification of a performance measure or measures that represents quality of service.

So you can convert the qualitative measure into a quantitative measures and then the level of service often is represented or shown in A through F scale, just like how we get grades in a class or a school; A being the best and F being the worst. So often you will see in case of highways, there are different levels of service for different facilities. So what they depict is that, if the level of service is A then from the point of view of the users that facility is providing the best service possible sevice, whereas if it is F it is providing worst service possible.

Now this, although it is from the point of view of the users, it also takes into account the operators possibilities. So the operators may require huge amount of money in order to maintain the services that is expected by the users but that may not be feasible. So then a middle ground is often reached to determine what is level of service A, B, C, D and so on and so forth.

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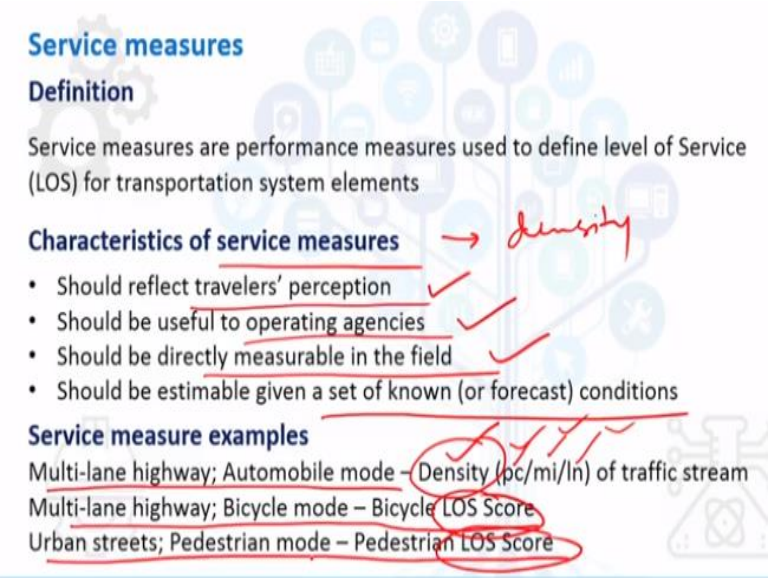

So in all of this, i.e. in quality of service and level of service, essentially the measure that is being used is called the service measure. So service measures are performance measures used to define the level of service for transportation system elements. So what should this service measures have? So this service measure should obviously reflect the traveler's perception but it should be also useful to the operating agencies. So here is the way in which quality of service or

level of service that is associated not only with the traveler's perceptions but also with the operating agencies.

It should be directly measurable in the field, otherwise it is very difficult to quantify them. If it is purely qualitative then it is very difficult to quantify so it has to be directly measurable in the field and should be estimable, given a set of known parameters. So if you know some parameters you should be able to estimate this service measures. We will explain all this in terms of a few level of service examples in this lecture. Service measures examples, when we talk about the automobile mode of transportation in case of multilane highways, usually what we measure is density. Now density of a traffic stream is measured by, it should be directly measurable in the field, number of passenger car units, that is PCU, or the number of passenger cars per mile per lane. Since these all terms where developed in the United States so they use miles we could use kilometers that is not a problem. So passenger cars per mile per lane is the directly measurable in the field. Now how does it reflect traveler's perception you would ask? So density is nothing but it is the ability to maneuver within in a traffic stream.

So it almost represents "ease of maneuverability". So when you ask a driver he or she is driving on the road if he or she cannot maneuver the vehicle in a proper fashion then he or she would say that the maneuverability is poor or density is very high. So that is how traveler's perception is included in this service measure, which is density. Again it is useful to the operating agencies because density is directly a measure of how congested a road is.

If the density is high, the road is congested, if the road is congested then the travel times are very long so it helps the operators determine the level of congestion along a street so they can route traffic in different ways and so on and so forth. So you see, 1 measure, 1 service measure, i.e. density, is a service measure which can be used in the case of multilane highways for automobile mode that reflects a traveler's perception, is useful to operating agencies, is measurable in the field and also if you know certain parameters you can estimate density, and we will tell you what those parameters are and how density can be estimated?

Similarly if you talk about the same multilane mode and how bicycle level of service can be calculated so it can calculated using a bicycle level of service score and similarly for urban

streets the pedestrian level of service can be estimated using a service measure called pedestrian level of service score. So this is how you make the connection between service measures, quality of service, and level of service.

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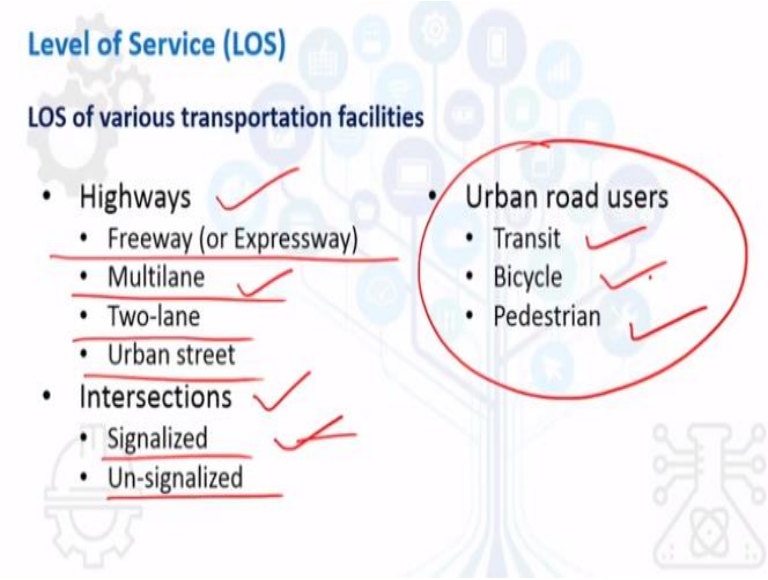

So now if you start looking at the level of service of various transportation facilities, they can be determined for highways, for intersections, for other types of road users including transit, bicycle and pedestrians. So even within highways you can determine the level of service of the expressway or freeway, or multilane highway, or 2 lane highway, and also an urban street.

So similarly for intersections you can look at signalized and un-signalized intersection and so on and so forth. So in this lecture series since we are concentrating on giving you an understanding of the vehicular level of service we will explain to you about a multilane and signalized intersections. Why did we choose multilane and signalized intersection because our overall topic of this NPTEL courses urban transportation facilities.

In urban areas mostly you will find multilane roads and multilane highways and also a lot of signalized intersection. So you should be able to gauge how well these are performing from your point of view, from a user's points of view, which is also useful to an operators. In the other lectures that follow after the first set of lectures, we will look in-detail into the transit, bicycle and pedestrian modes, which is the focus of urban transportation systems in this course.

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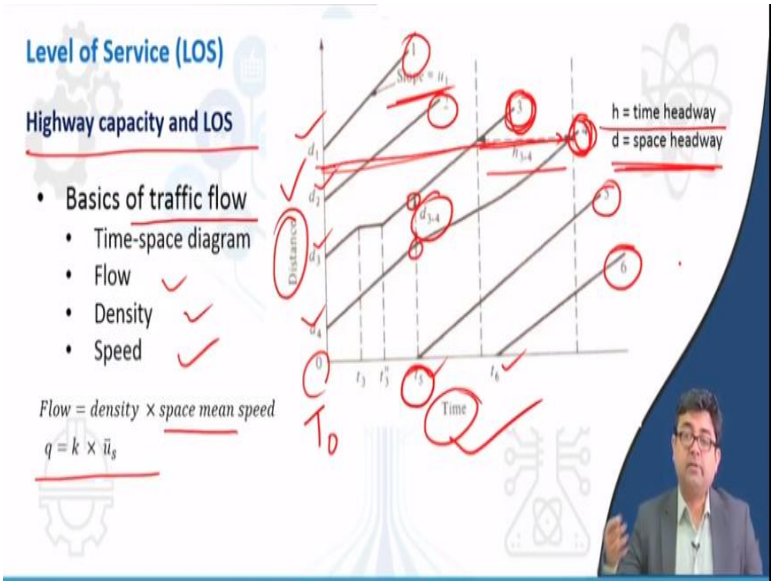

So when we are talking about highway level of service level of service, capacity goes hand in hand. The basic concept of highways, if you have taken other NPTEL courses of highway engineering or highway transportation and highway operation, you would know that in the basic understanding of level of service, or capacity, is in the understanding of traffic flow. And traffic flow can be given by the time-space diagram, and the 3 parameters of flow, speed and density which are related to each other in this fashion where flow is equal to density times speed, where speed in this case we use space mean speed.

And this is a very common and basic diagram of time and space where if you say that there are 6 different vehicles and these lines indicate their trajectories. So at any point at any point in time 0 you will see that this vehicle 1 is at distance d1 from that point, vehicle 2 is at distance d2, vehicle 3 at distance d3, and so on. Whereas vehicle 5 and vehicle 6 will arrive at that point at a later time; they have still not arrived at that point where T = 0, they are still approaching that point.

So if it is space time diagram, slope of each of the trajectories will give you the speed and the distance between 2 trajectories can give you either what is called as time headway or a space headway. So the time headway is the time distance between 2 vehicles at any point. So at this point, this distance point is at that point, the two vehicles, the vehicle 3 and vehicle 4 have a time gap or a time headway of h3 – h4.

So time headway is nothing but the time when the front of the first vehicle crosses a point and the front of the next vehicle crosses the same point that is called a time headway. And similarly space headway for 2 different vehicles so that same the 3 vehicles or the third vehicle and the fourth vehicle would be at any particular point in time what is the distance between the 2 vehicles.

So the distance between the 2 consecutive vehicles at any point in time is called the space headway. So this is the basic understanding of traffic flow when you are trying to develop a level of service of highways.

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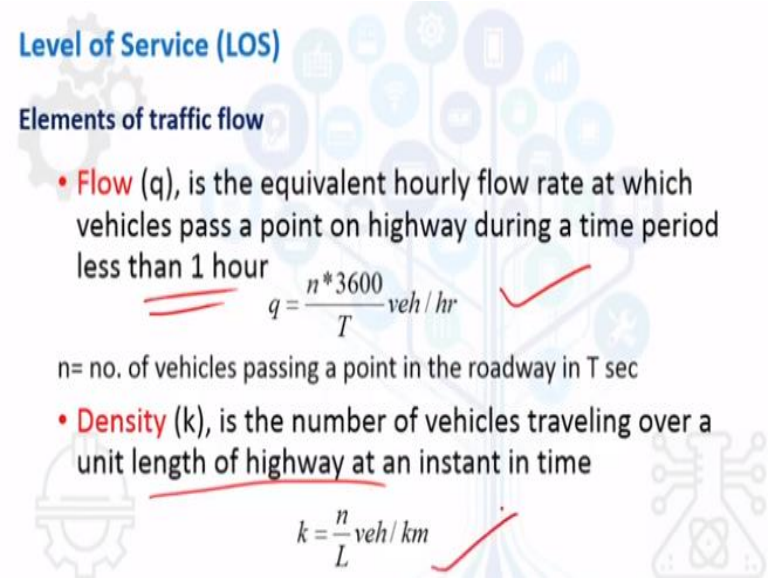

So these are basic definitions of all this. Flow is the equivalent hourly flow rate at which vehicle]pass a point at a highway during a time period that is less than 1 hour. So it is given by this equation and density as is very common, it is the number of vehicle travelling over unit length of a highway at any instant, given by this.

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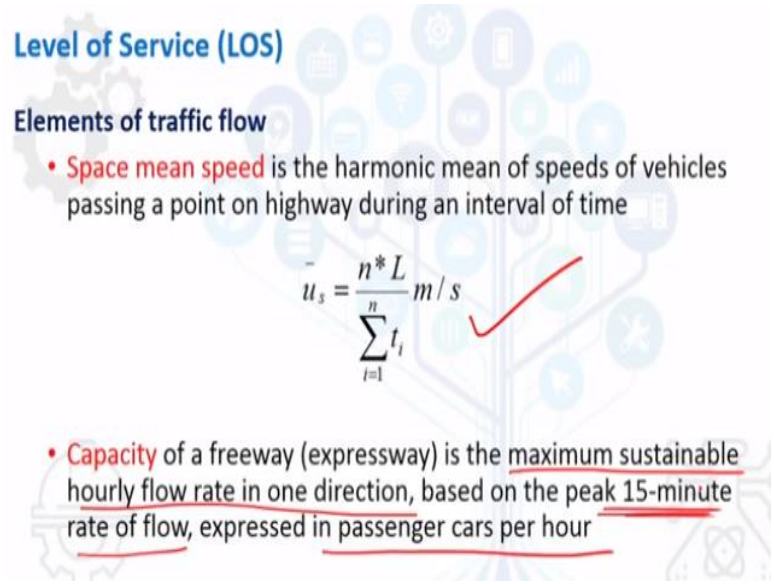

Similarly space means speed is the harmonic mean of speeds. When we are talking about speed, we use usually, in traffic engineering or in development of level of service, space means speed and not time mean speed and it is given by this simple formula. And capacity of a freeway or a expressway is the maximum sustainable hourly flow rate in one direction based on peak 15 minute rate of flow and it is expressed in terms of passenger cars per hour.

So it is the hourly flow rate, i.e. number of vehicles passing a point per hour based on 15 minute peak period. So this is the another concept in level of service – we always look at the peak 15 minute period because that is the worst traffic condition, so we have always design our facility by keeping in mind the worst condition. So if you fulfill the worst condition then any condition better than that will also be fulfilled. So we are always looking at the worst condition and designing facilities for that.

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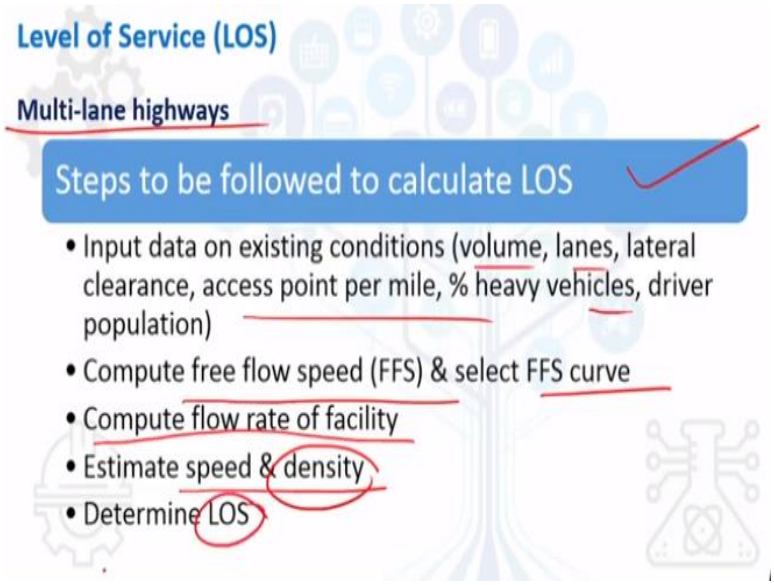

So now let us go through quickly these steps that should be followed to calculate the level of service of multilane highways. So in the first step you need to have a set of inputs of the existing conditions which include the volumes, the lanes, the lateral clearance, the access point per mile, percent of heavy vehicles, and driver population, all these are inputs to your highway level of service calculations.

After knowing these inputs you calculate what is called as free flow speed and select one of the free flow speed curves. There are multiple curves. After knowing the free flow speed you calculate the flow rate of the facility and then estimate the speed and density from which you will get the level of service.

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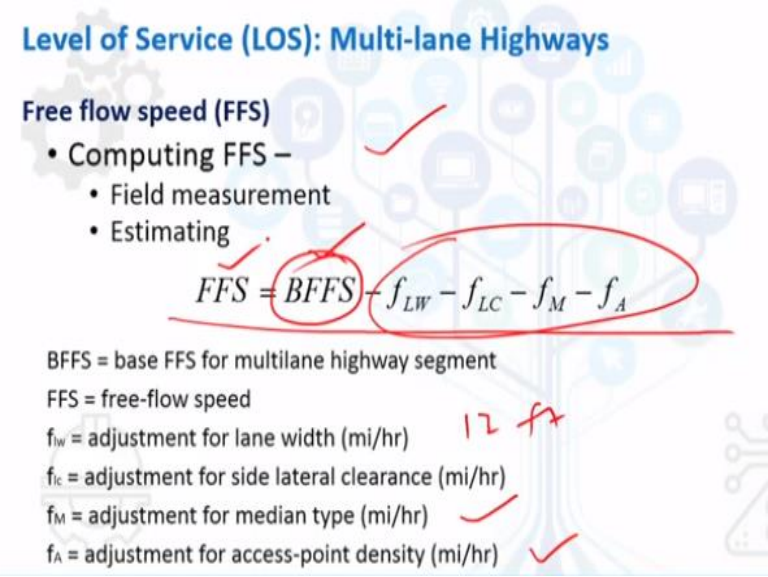

So let us look how you compute free flow speed. It is given by this empirical equation the base free flow speed of the multilane segment minus a bunch of adjustments. So the base free flow speed is always developed keeping in mind ideal conditions, ideal conditions meaning the lane which should be 12 feet wide, there should be certain amount of lateral or side clearance, that means there should be enough space for the vehicles to move within the lane. There should be a type of median, if there is no median then the speed is affected. So capacity will be effected and in-turn level of the service will be affected, versus if there is a wide median grassy median or even just a barrier between the downstream and the upstream flow, then there will be variations in level of service. So we have to adjust for all of this and we have all standard values that are given in the highway capacity manual that has developed in the US and now India has also adapted and used the values as per our local conditions.

So these are the different types of adjustments that you have to do to determine the free flow speed of your particular facility or estimate the free flow speed of the your particular facility.

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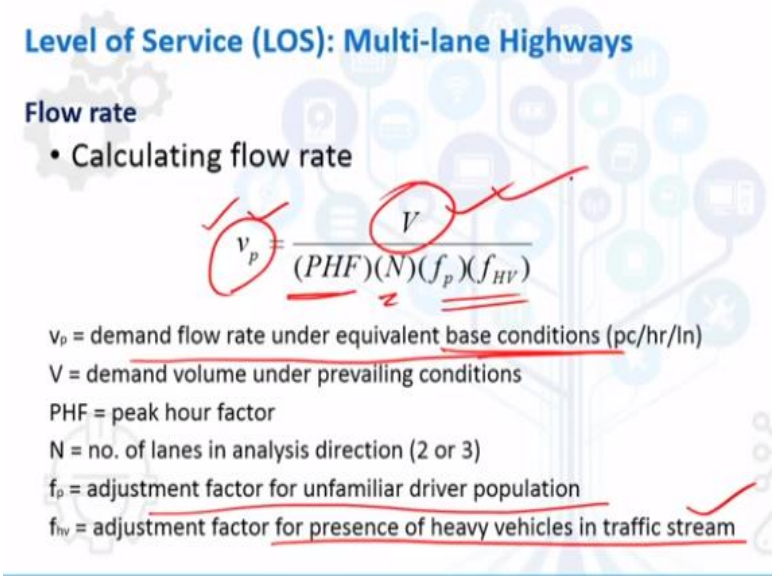

Then once you know the free flow speed you have to determine the demand flow rate. So you may already know the volume, because volume is one of the inputs you already know, but you have to know the demand rate and again this has to be adjusted based on the peak hour factor. So which hour you are calculating the flow rate, the number of lanes, and then use another set of adjustments which is adjustment factors for unfamiliar driver population and adjustment factor for percentage of heavy vehicles. So if any traffic stream has a lot of people who do not understand or who are new to the facility then your level of service will differ and also if a facility has a lot of heavy vehicles your level of service will differ. So that is how, for that reason you have calculate the demand flow rate equivalent to the base conditions. You know already the volume, that is an input.

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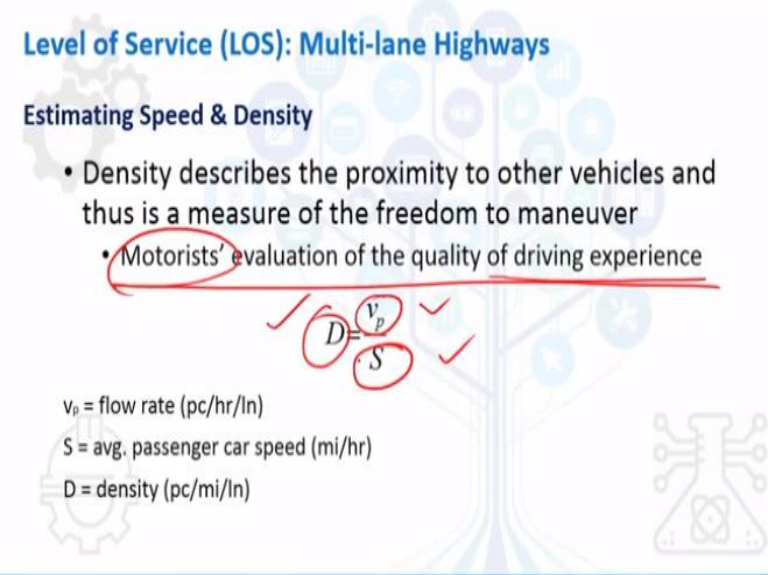

So once you know that, and once you know your flow rate, and you have estimated your space mean speed, you can now determine density using this simple formula and this is what I was referring to when I was saying that if you know certain parameters you can estimate density. So density is the service measure that is used to develop level of service for multilane highways.

So in the evaluation of the quality of driving experience, again remember if it can be estimated in the field, it is useful for the operator, and also reflects the quality of driving experience from the point of view of the motorist. That is how you should choose a service measure to determine the level of service.

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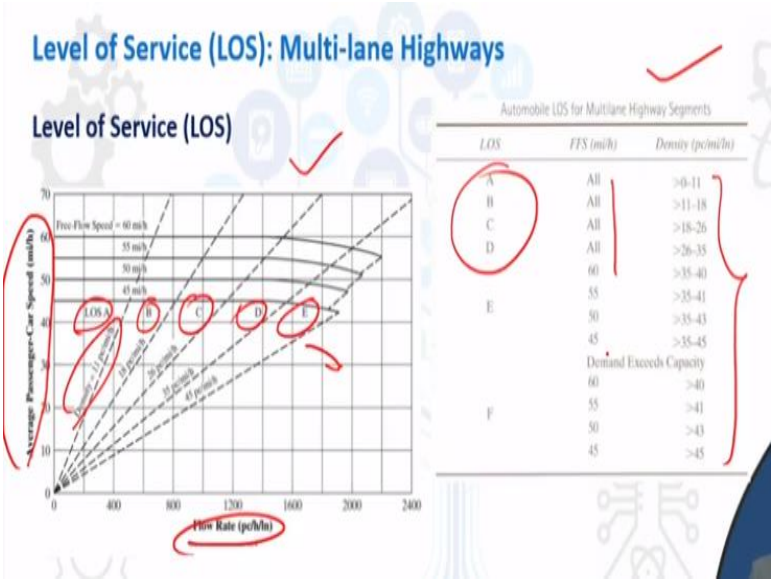

Then there are standard curves that are developed. In standard tables that are available to you depending upon the density, depending upon your flow rate and depending upon your passenger car speed / average passenger car speed, you can find out whether your multilane highway is a level of service A, i.e. is operating at level of service A, B, C, D or beyond E or F. So you can find out this using either a chart or you using the standard using the density values and against the density values you can calculate the level of service given the free flow speed.

So that is how in a nut shell you can determine the level of service of a multilane highway facility that is existing in your urban areas.

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Similarly let us look at determining the level of service of signalized intersections at your urban area. Now, level of service of signalized intersection is a little bit more complex because it involves an in-depth understanding of the traffic flow in your area, and especially in our case, in the Indian case, as the traffic flow is heterogeneous.

You have to convert a lot of vehicles into equivalent PCU's passenger car units, i.e. non-motorized vehicles, 2 wheelers, 3 wheelers all have to be converted into a standard equivalent PCU. So it takes a lot of calculation and assumptions however there is a structured way of doing it so as long as you follow or understand the way the latter's operational details, you can always pickup. So first is to understand or determine the movement of lane groups, we will tell you what

the lane groups are, because that is very important metric in determining the level of service signalized intersections.

Then you determine the movement groups' and lane groups' flow rate, we already know what the flow rates are. After knowing the flow rate, you determine what is called an adjusted saturation flow rate, you determine how much proportion of the vehicles are arriving at that intersection when the signal is green. It is very important you do that, i.e. determine what the signal phase duration is, then understand what the capacity and the volume to capacity ratio is, and estimate delay, which is the service measure on which the level of service of signalized intersection depends. So it depends on volume to capacity ratio and delay, then that will give you the level of service.

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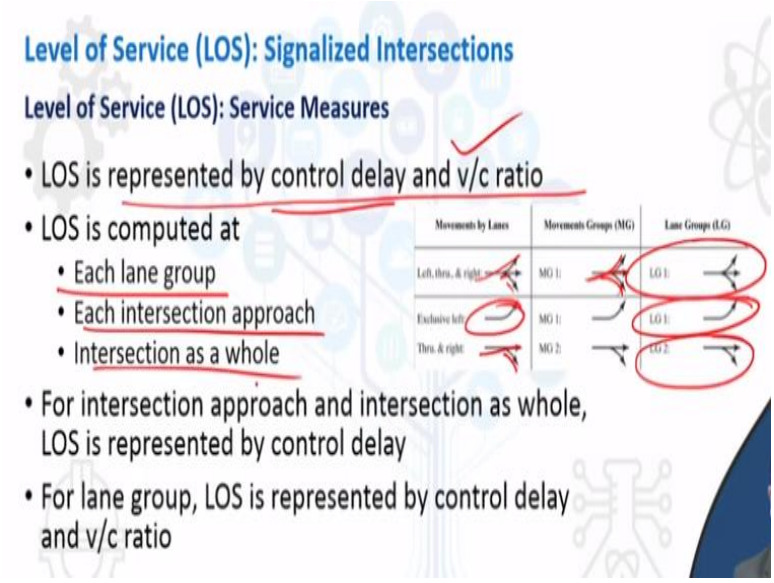

So, quickly again, level of service is represented by control delay, control meaning it is the control device or it is the device that is controlling that intersection, that is why it is called as control delay. So you can always change the signal timing, and that is under control. If it is un-signalized intersection, for which also level of service can be determined, that delay at an un-signalized intersection is called uncontrolled delay because there is no control there, you have no control over that intersection.

So in this case LOS is represented by control delay and v/c ratio, and LOS is computed for each lane group. So now what are lane groups? You see, at an intersection you can go in all 3

directions, and your movement groups at each green could be in all the 3 directions, then you can group all those movements into one, saying that, that is 1 lane group. However if you have exclusive left, you see this is again in the US, in our case it will be exclusive right turn, and then you have a through and right, in our case through and left, you can have 2 lane groups.

1 lane group is your exclusive left, in our case exclusive right, and the other lane group is through and right, in our case through and left. So, there are 2 different lane groups that can go through the signal at 2 different times. So when you are developing a level of service, you are looking at each lane group, the delay to the vehicles incurred within each lane group, i.e. delay per vehicle incurred during the operation of a lane group, and then you can add it up, you can sum it up, to tell the total approach delay.

So at one approach there may be 3 lane groups so if you have individual lane group delays you can sum it up to say approach delay and then you can sum up all the approach delays to know the delay of the entire intersection. You can do it any 3 ways, the lowest unit is the lane group delay so delay for each lane group, or each intersection approach, or intersection as a whole.

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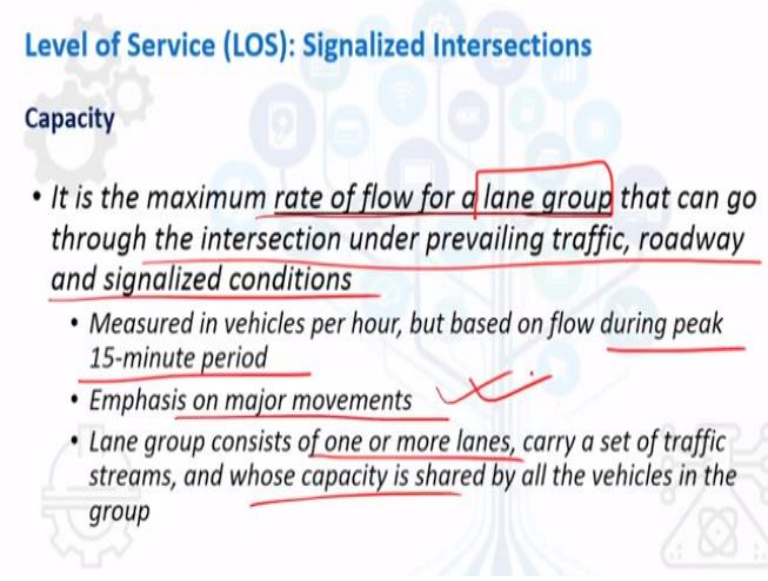

Now the capacity of a signalized intersection is the maximum rate of flow for a lane group. So we always concentrate on that lane group that can go through the intersection under prevailing traffic, roadway, and signal conditions. Again this is measured for the peak 15 minute period.

Emphasis is on major movements and lane group consisting of one or more lane groups, as we already know.

So usually, if a signalized intersection is on a major road with one minor road, we usually emphasize the major road movements so that majority of the traffic is catered for. Although we also keep in mind the minor roads, but cater for the major roads.

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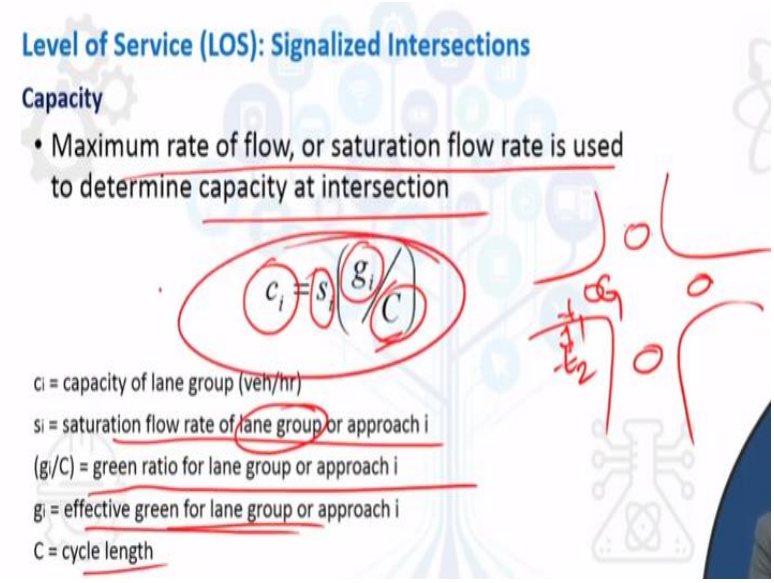

Now, the capacity, the maximum rate of flow or the saturation flow rate is used to determine the capacity at the intersections of the capacity of the intersection is given by a product of saturation flow rate of each lane group multiplied by ratio of it is called the green ratio of the effective green time and the cycle length. So here way we are not going to much detail about what these things are but if you want to know cycle length so the cycle length is the green time given to.

So the start of the green in one leg and time elapsed before the green again comes to that the lane group right. So if you have 4 lane groups then it starts at time t1 and again the green this green here then this green here then it is green here and the time elapsed till again the certain time t2 that has elapsed till again this intersection as green. So the different between these two time is the entire cycle length. Effective green time is essentially you do not get the entire green time to cross there is a yellow or amber time and red time.

So if you subtract those times, and some lost times that are start up lost time and time to decelerate and stop all those times, if you subtract from the green time, it is called as effective green time. So the capacity of the intersection is given by this equation.

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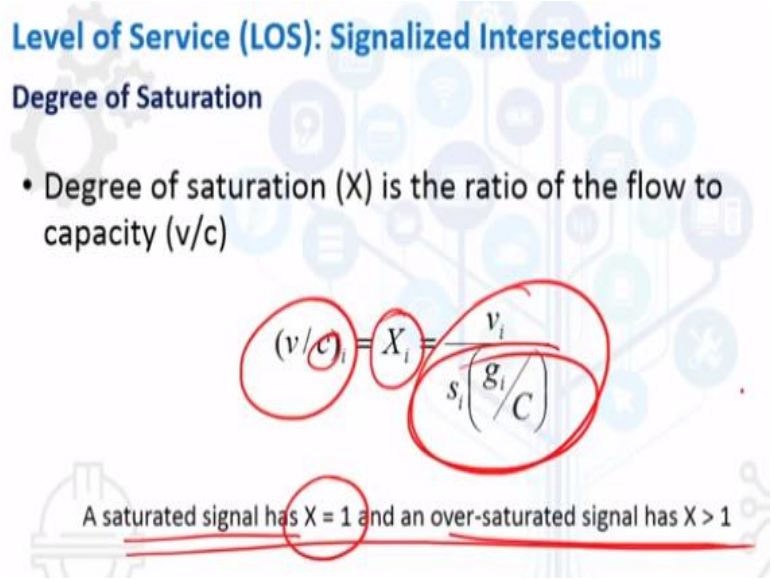

And then you have to know v / c ratio so the v / c ratio or it is depicted by X of any lane group is given by this equation which is that direction derivation from the previous equation. So if you just divide this by v / c it becomes v by we already know the capacity equation for the capacity is this so divide this and v / c ratio so if any signal as saturation signal as an X = 1 it as an over saturated signal X greater than 1 saturated signal meaning vehicle that are approaching the signal during the green time will cross the signal that is either saturated or unsaturated.

Whereas over saturated meaning all the vehicles that are approaching the green time will not be able to cross during this cycle and there will be some queue left over, that is called an over saturated situation.

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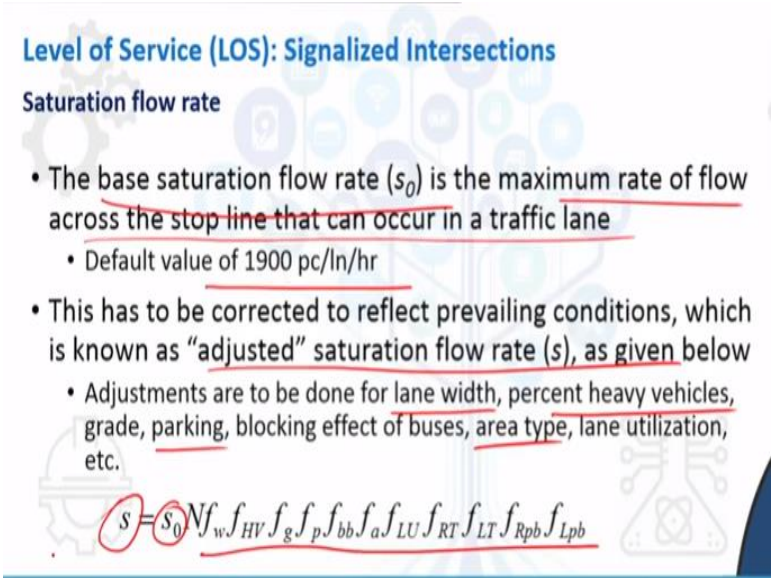

Now we always have a base saturation flow rate which is usually a default value of 1900 passenger cars per lane per hour, which is the maximum rate of flow across the stop line that can occur. However this is again ideal flow rates, as base saturation flow rate is always ideal it has to be adjusted and again for adjusting it you have to use a lot of factors multiply them with lot of adjustment factors which include adjustment factors for lane width, percent of heavy vehicle, area types of the CBD versus an sub urban area, if there is lot of parking around there, etc.

So all of these factors have to be adjusted for, in order to know the adjusted saturation flow rate

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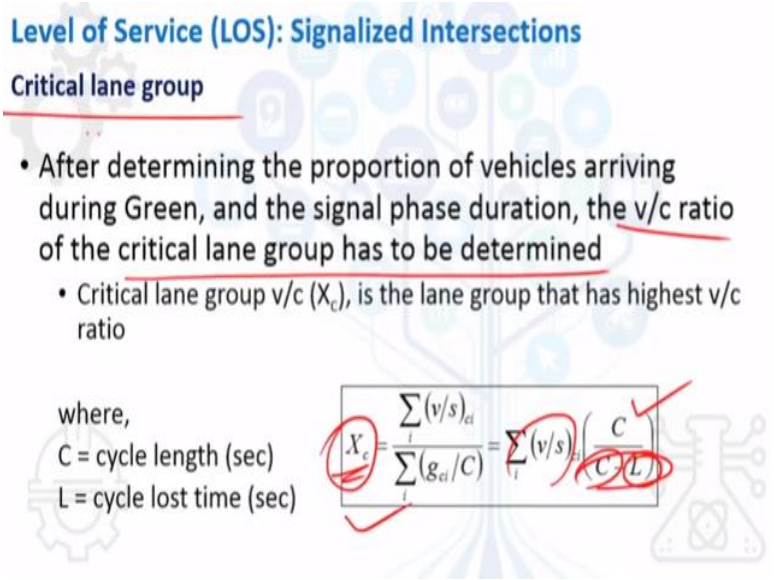
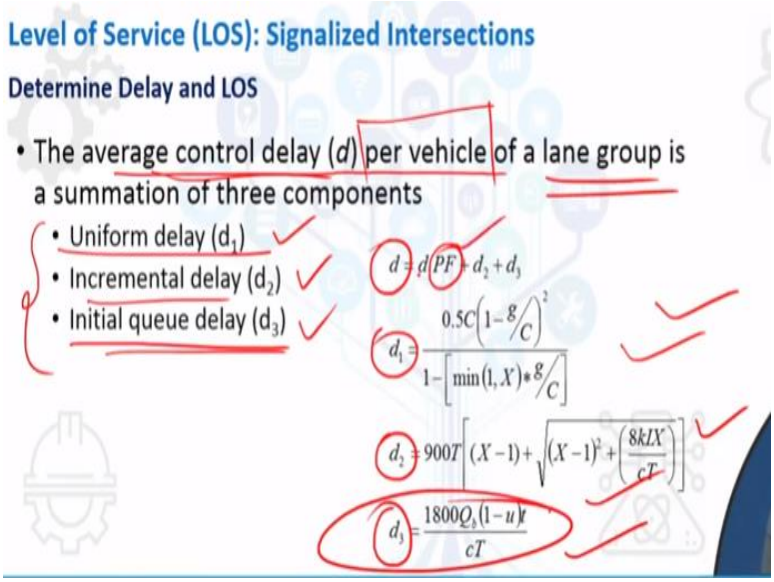


Once you know the adjusted saturation flow rate you determine what is called a critical lane group. So if an approach has 3 lane groups, there would be one lane group that would have the maximum v / c ratio, that would be called the critical lane group. So if you have to cater for the maximum or the worst condition, so that lane group requires the maximum green time in order to go through the signal. So if you take care of that lane group you would be able cater to other 2 lane groups automatically.

So we already know the equation for v / c ratio and this is the cycle length and this is the effective green time cycle length by effective green time meaning cycle length minus all the lost times. So if you do this using this formula you would be able to calculate the v / c ratio of the lane group which is critical. **(Refer Slide Time: 28:25)**



Once you know the critical v / c lane group you then calculate what is called the control delay or the average control delay per vehicle for that lane group. The average control delay is the summation this is the average control delay the summation of 3 different types of delays one is the uniform delay, incremental delay, and initial queue delay. Uniform delay is nothing but it assumes that all of the vehicles arrive at a signal uniformly at uniform rate.

Whereas incremental delay says that, no they do not arrive at a uniform rate they arrive at a non-uniform rate and what it says is that it may be the case that demand may exceed capacity, thus incremental delay takes into account that the demand may exceed capacity. Whereas uniform

delay says that the saturation rate would never be arrived at and there is always a uniform way of arrival.

Whereas initial queue delay says that well even if incremental delay is there increment delay says that there will be over saturation but there may be demand that is exceeding capacity but there will no queue left at the end of the green. So all of the vehicles arriving will be moving through the green time whereas initial queue delay says that no there may be situations when there is a queue left over from the previous green time because the green time was not sufficient to move all of those vehicles.

So there may be these 3 different types of delays and the summation of those 3 delays gives you what is called as average control delay. So these are all empirical formulas that have been developed over years. The incremental queue delayed in the newer version of the HCM has a more detailed formula than this. This maybe from the previous highway capacity manual but these 2 formulas are empirically still valid and if you just see in this case progression factor is used to multiply with the uniform delay.

Progression factor is nothing but if the signals are coordinated with each other, or at the isolated signals if there are isolated signal there will be very little progression of the vehicles moving from one signal to the other, whereas if they are coordinated signals there will be some progressions and that progression factor is this kind multiplied with the uniformed delay.

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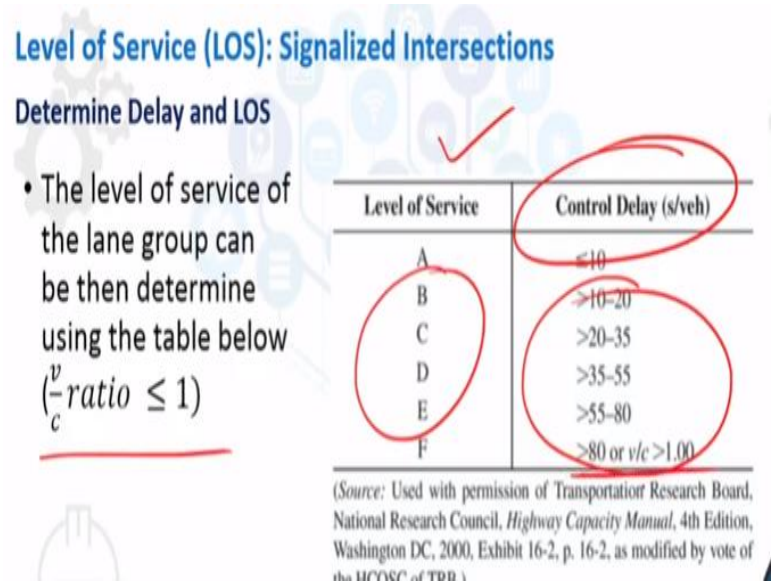

So once you know the control delay you can then determine the level of service depending upon what you delay numbers are, we will be able to determine whether they are in A, B, C or D, E or F. This table is for all v / c ratio all conditions where v / c ratio is less than or equal to 1. So they are not at oversaturated conditions, they may be under saturated or just at saturation level. Anything over-saturated will always have a level of service F.

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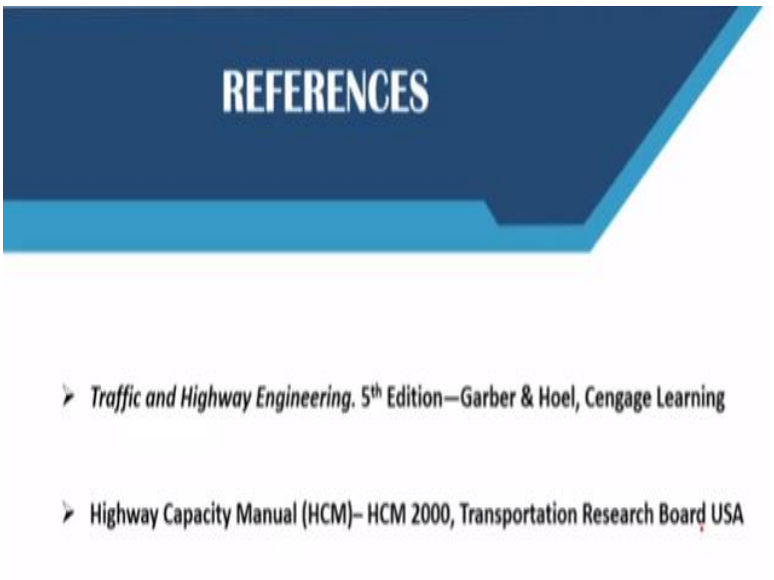

So that brings us to the end of this lecture these are your references for your further understanding and most of the topics have been taken from from the Garber and Hoel textbook or the highway capacity manual.

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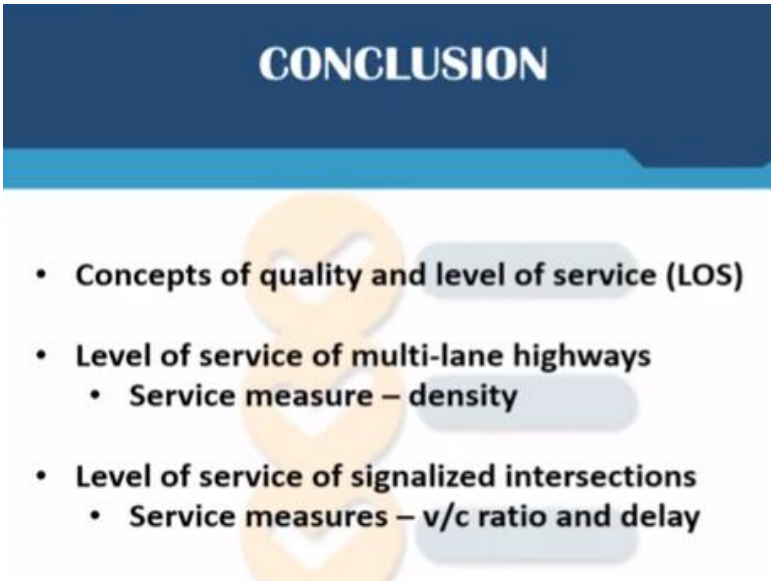

So in conclusion what we have looked at in this lecture series is the concept of quality and level of service and how all of them are integrated with each other through this service measures and how level of service is calculated for vehicles or a multilane highway as well as on a signalized intersection. There are different service measures, for each of them we looked at how density can be calculated in case of multilane highways, and we also looked at how v / c ratio or delay can be calculated at a signalized intersection. Thank you.