Traffic Engineering
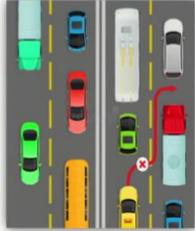**Professor Bhargab Maitra,**
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Lecture 06
Traffic Facilities and Traffic Stream Parameters

Welcome to Module B Lecture 1. In this module we shall discuss about Traffic Stream Parameters and their Relationships, and in today's lecture, we shall focus on Traffic Facilities and the Traffic Stream Parameters.

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In a traffic streams, individual drivers and vehicles are there. There are so many vehicles of different types, so many drivers are there, drivers characteristics are different, vehicle characteristics are different and these individual drivers and vehicles they interact in unique ways with each other and also with the elements of roadway environment, because the geometric design and all other roadway environment and the elements are very important, while they are in the traffic stream.

Because the drivers and vehicles are of different characteristics, as I said that so many vehicles are there, vehicle characteristics are different, their acceleration deceleration capabilities, speed capabilities are all different, drivers, not all drivers are same, their behaviors are different, so altogether, there is an element of variability. If you take drivers characteristics, it is not just one

value. If you talk about the vehicle characteristics, again it is not one value. So, when we are dealing with traffic streams, we have to deal with the variability.

Now, traffic engineers analyze, evaluate and plan improvement of traffic facilities considering this variability. How to consider this variability? We shall discuss further. But there is an element of variability and we have to consider this variability while we are trying to analyze, evaluate or plan improvement. For example, how this variability come into picture. In an unsignalized intersection when the drivers do the maneuver, the gap acceptance is very important. How much gap is there between the passage of two vehicles, maybe I am trying to enter from the minor streets to the main streets and try to do a maneuver, maybe I want to take a right turn. So, I am obviously looking for the gaps between the vehicles.

Now, not if you consider a particular gap, now, if you consider a particular gap, not all drivers are going to accept the same gap, not all drivers are going to reject the same gap. Obviously, I mean, as the gap is higher, more and more drivers are likely to accept and lesser number of drivers are going to reject it. Similarly, as the values maybe lower, the gap becomes lower, more and more drivers are going to probably reject it and lesser number of drivers are going to accept it. But question is given a gap not that 100 percent vehicles or drivers are going to accept that gap nor 100 percent are going to reject that gap. So, the variability comes into picture. Not everybody every driver is going to behave in the same manner.
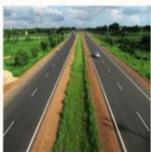
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Now, there are fundamentally two types of traffic facilities. One is called uninterrupted flow facilities, and other is called interrupted flow facilities. Please be careful because students often make mistake in terms of the fundamental understanding and the basic difference between the uninterrupted flow facilities and interrupted flow facilities. In uninterrupted flow facilities what we are saying there is no external interruptions to the traffic steam external to the traffic stream. What is external to the traffic steam?

If I install the traffic signal and try to regulate traffic, obviously, if I am installing a signal, when the signal is green the vehicle will pass, when the signal is red the vehicle has to stop. Or if I put a stop sign, if you are approaching from a minor streets and trying to enter into a major highway or a major road or higher order road and if you find a stop sign what it says, you have to stop and then look for suitable gaps. Once you find the suitable gap, you do the maneuver, but stopping is mandatory. Similarly, yield signs you have to slow down and if required you have to stop when you are trying to enter.

So, if these are external reasons for interruption to the moment of vehicles. So, if there are external factors, external interruptions due to traffic signal stops, yield signs, uncontrolled access, anybody anytime can come and enter into the main street and a vehicle is entering. So, the traffic which is moving along the primary facility will get interrupted, because the vehicle is entering from the side road. These are called uninterrupted facilities.

But speed still may be lower, because if more vehicles are using a given facility, even if it is uninterrupted flow facility, higher the traffic volume, the lower will be the speed. So, it does not mean that uninterrupted facilities means it is uninterrupted and you travel at any speed you want. No. It is related to the fact that there is no external interruption to the traffic stream which are external interruptions are frequently caused by factors such as traffic signals, stop or yield sign, uncontrolled access etc.

So, typical example of uninterrupted flow facilities may include, expressway, which is supposed to be completely access controlled, that means no at grade intersection, no access, uncontrolled access, no other interruptions to the traffic stream, traffic can move freely, all intersections are grade separated with proper ramps and everything. So, the there is no external interruption to the traffic stream. The vehicle speed may depend still on the volume, the nature of traffic that is going

to use and other factors which are internal to the traffic stream, because vehicles also interact among themselves. So, the freedom of movement will come down as this volume is higher.

Now, in also mid-block section of highways, highways are not access controlled, but sometimes you may be, you have 5, 7, 10 kilometer stretch and there is one intersection, practically in between there is no other interruptions, vehicle can move freely and everything is fine as usual. So, when there are long sections of highways in between two intersections and if you see the mid-block portion away from those intersections, the traffic operation is almost like uninterrupted facility. So, you can consider the traffic operations or the kind of facilities there is actually uninterrupted flow facilities. You can very well treat it as uninterrupted flow facility away from the intersections.

Stream characteristics for uninterrupted flow facility depend on internal factors, as I have said, individual vehicles their characteristics, driver characteristics, geometric and general environment of the roadway all this will influence the stream characteristics but not external interruption. That is the key.

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Going to the interrupted facilities or interrupted flow facilities, traffic flow is interrupted due to external factors by external devices and typically the flow is periodically interrupted by external devices, particularly say traffic signals, urban road network, if you consider urban facilities, all are largely interrupted facilities, because most of the intersections in large urban areas they are controlled by traffic signals, so periodically interrupted by external devices. Why is it periodically

interrupted, because when the city signal is green vehicles are passing, moving, when the signal is red vehicle has to stop, and periodically it is happening green, red, green, red, green, red. So, periodically vehicles are moving and stopping, moving and stopping, something like this.

And also, when the stop or yield signs are present, the facility will be treated as interruptive to facilities. So, examples I have said signalized intersections, urban streets, even the toll plazas, where the vehicle has to stop and pay the toll. So, these are all uninterrupted, interrupted flow facilities. So, these are all interrupted flow facilities. Now, due to stopping and starting phenomenon, interrupted traffic facility is more complex than the uninterrupted one. We shall discuss again in further details about various characteristics of these uninterrupted and interrupted flow facilities.

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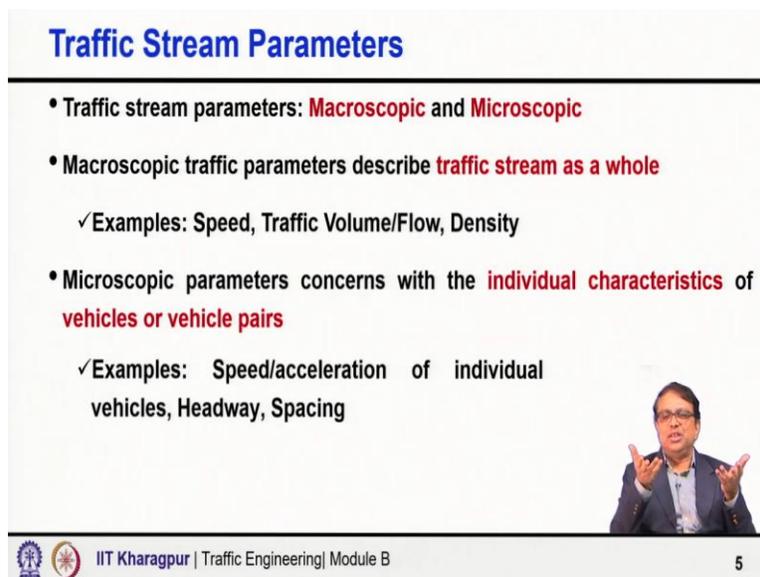
Coming to next, the traffic stream parameters, there are two types of parameters we deal with, one we call as macroscopic parameters, the other we call microscopic. By the name micro and macro you can understand what we are trying to indicate. Macroscopic means in gross level overall sense. So, for the whole traffic stream as a whole, we have, we are telling one value of the parameter, say for example, one speed for the whole traffic stream, one value of the flow, one value of the overall density. So, these are all called macroscopic parameters. They are macroscopic because these parameters describe traffic stream as a whole and for the whole traffic stream there is one value, through one value we are expressing or representing the traffic stream characteristics.

On the other hand, microscopic parameters concerned with the individual characteristics of vehicles or sometimes pair of vehicles. Say for example, individual vehicle characteristics could be speed, acceleration of individual vehicles they are all individual vehicle specific characteristics. On the contrary, if we talk about heading, headway, on the contrary if we talk about headway or spacing, then we are defining it for a pair of vehicles first vehicle, second vehicle, third vehicle, fourth vehicle, between first and second what is the headway, what is the time gap between passage of vehicle one and vehicle two.

Similarly, again vehicle two and vehicle three that is the pair of vehicle, what is the time gap, that is the time headway, another value, third and fourth vehicle another value. So, first and second one value, second and third another value, third and fourth vehicle another value, fourth and fifth vehicle another value like that.

Spacing is the distance again between pair of vehicles. So, the microscopic parameters are expressed with respect to individual vehicle or pair of vehicles. So, that is why they are called microscopic. And when for the overall traffic stream as a whole we are expressing the characteristics using a single value any such parameters such as speed, traffic flow, density, all these are macroscopic parameters.

Now, microscopic speed characteristics if we try to look into little bit more details, then vehicle groups passing a point or short segments, it could be a point, it could be a short segment, that also we are considering almost like a point, during a specified period of time, over time, or traveling along long sections of highway or that means over a length. So, the speed we are trying to characterize, trying to define for vehicle groups which are passing a point or short segment during a specified period of time or over a distance, over a section, relatively longer section we are trying to define.

Now, speed is considered to be a fundamental measure of traffic performance in a highway system and also is a key indicator in design or redesign of traffic facilities. The whole design, any geometric design of roads if you want to do, it starts with the basic input, which is speed, what should be the design speed. So, every element of design actually is done based on the design speed in mind, so very important parameter.

And speed is usually also input in simulation models, when we develop micro simulation models, often we do in traffic because of this variability element, particularly as I said the variability, the variability element to take into consideration of that and to analyze complex situation we use often traffic micro simulation. So, their speed is a vital input, a very, very important input. And we use such simulation models for estimation of fuel consumptions, vehicular emission, traffic noise and

all such things. Traffic analyst must be familiar with microscopic characteristics, a macroscopic characteristics. Traffic analyst must be familiar with macroscopic characteristics of speed.
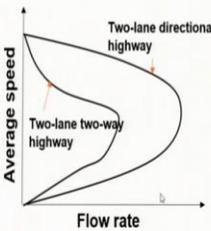
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Speed varies. So, it is not a fixed value. It varies in three dimensions or three manners you can say, over temporal scale, that means over time it varies, it varies over space in this such case, specifically it means location, so different place, different segments, different locations of the road speed may be different, different time, same location, speed may be different. So, three types of variation, temporal variation, spatial variation, and also modal variation, that means the same road facilities used by so many different types of vehicles. So, different vehicle types will have different speed, a car, a truck, a bus, not going to have the same speed.

So, coming to temporal variations, speed varies over time and influenced by several factors. Now, these factors we can classify as primary influencing factor and secondary influencing factors. The primary influencing factors are flow rate or flow capacity ratio, basically the demand. Any road is a physical infrastructure and any physical infrastructure will have a capacity and the more we load the capacity, load the facility, so the freedom of movement will go down or will be compromised. And obviously, as flow rate will be higher, speed is going to come down. Take any facility. In the early morning when you see, I have shown a graph here, early morning when you see there is hardly any vehicle.

So, if you measure the flow not many vehicles are passing through a section and you will have very high speed. The same road somewhere around 9 o'clock or 10 o'clock when a lot of people are on the way, they are using the road to their way to office, you will find that the flow rate will be higher, more vehicles and speed will come down. It is the same facility, but morning 6 o'clock and morning 9 o'clock or 10 o'clock, the speed is not same. Not same, because primarily the volume is different.

So, the flow rate would be different and sometimes you can express it as in terms of flow rate, sometimes you can express it in terms of flow capacity ratio, because as I say, flow rate is becoming higher that means actually flow to demand to capacity, volume to capacity ratio is also going to higher because capacity is fixed.

So, how much we are loading the facility with vehicles. A room has got maybe it can accommodate 50 people. So, when there are 1, 2 or 5 persons are in the room, they will feel very comfortable. Their freedom will be very high. But the same room exactly when 50 capacity and 50 people are there or 40 people at there, obviously, the situation is not same. The same thing is happening, exactly the same thing is happening for the roadway facilities as well.

There are secondary factors which also influence the speed, primarily say are such factors may include vehicle mix. All the vehicles which are there on the road if they are car, that will be something. If it is a mix of car, bus, truck, light commercial vehicle, semi commercial vehicles, even within the trucks itself, within the commercial vehicle itself different, multi-axle trucks are there things will be different. You add a few more non-motorized or even motorized but slow-moving vehicle, local vehicle which are mostly slow-moving vehicles, naturally the speed is going to get impacted.

So, the vehicle mix, drivers mix, driver behavior is again not same for everybody, the lighting condition, the overall weather condition, traffic incidents, if suddenly some lane is blocked, vehicle breakdown or a road crash has happened, depends on the design speed, whether there is any speed limit. So, all such factors also will influence the speed but we can call them as secondary influencing factors.

And here as I have shown here, two cars, one for two lane directional highway, another is two-lane two-way highway, obviously, you can see the highest or the maximum flow rate what is shown
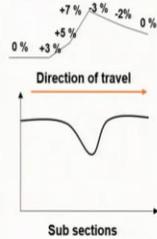
here is lower when it is a two-lane two-way highway. So, that means here I am saying the this road, the two lane two way high road how much it can take, how much load it can take, traffic load it can take, the two lane directional highway, or if there is a other even higher order of facilities directional can take even much higher. That is what is shown here.

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Speed varies over location. That is what I am saying as spatial variation. So, speed varies transversely across highway and also longitudinally along the highway and also direction wise. Why I say that it varies transversely across the highway? Our case sometimes things are not really orderly. But if you see even the lane wise the traffic distribution ideally should be like this. The slow moving should be on the left side in Indian scenario which is left hand driving where we, what we follow in India.

So, the slow moving, then the higher speed maybe the middle lane it is 3 plus three, so I am talking 6 lane highway 3 lane in each direction and the rightmost lane should be for the fastest vehicle. So, any vehicle you want to overtake, if that means you want to travel at a higher speed than the vehicle in front, you should use the right lane, available right lane, and then do the overtaking maneuver, complete the overtaking maneuver and comeback.

So, naturally, in all developed world also you will find that lane wise speed limits are there, because not every vehicle, based on vehicle characteristics, based on driver characteristics, not every vehicle is going to travel at the same speed even if the design speed is higher, but that does not

mean that all vehicle will travel very fast. I may, as well with a very good vehicle also I may like to travel slowly. So, the lane usage is very, very important. And this is one primary reason that in India we do not have the land usage very well defined.

So, you will find a slow-moving vehicle also using the fastest lane and continuously driving in the fastest lane and the vehicles which want to actually overtake that slow moving has to overtake from the left side, which is actually wrong and sometimes may cause even safety problem, bring the inefficiency in the overall vehicle operations.

So, there are influencing factors for transverse variation, say for drivers desire as I say, vehicle performance capabilities, origin destination type, traffic control measures, downstream conditions that means if the drivers are unsure of the route they may travel a little slowly and keep it on the left. There are several influencing factors for directional variation, difference in flows, design, control, incidents in other direction all these may influence. So, directional variation, the two way, the left to northbound and southbound traffic may not travel in the same speed.
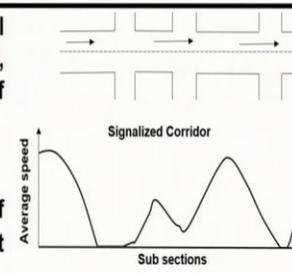
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Macroscopic Speed Characteristics

Spatial Variation

- Speed varies **transversely** across the highway and **longitudinally** along the highway and **direction wise**
  - ✓ Influencing Factors for Transverse Variations: **Drivers desire, vehicle performance capabilities, origin-destination** of trips, **traffic control** measures, **downstream traffic** condition (e.g. If drivers are unsure of the route, they may travel in left lane)
  - ✓ Influencing Factors for Directional Variations: **Difference in flows, designs, controls, incidents** in other direction etc.

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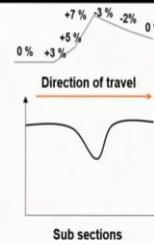
Also, there are longitudinal variation. Along the length the terrain may be different. I have shown it in the previous slide. The terrain may be different. The slope may be different, terrain may be different. So, along the length of the road also or there could be in between some minor access or other things so the speed may vary. Model variation also is there, as I have already said. The speed characteristics and pattern of different vehicle classes are different. For example, passenger car, bus, truck, they do not travel in the same speed. So, here the influencing factors may include vehicle performance, grades and all such kind of things.
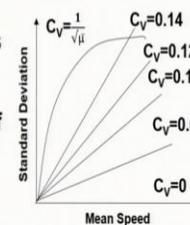
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Macroscopic Speed Characteristics

Importance of Mean-Variance Relationships

- As **speed variations** are observed in the field, it is necessary to **quantify mean** and **variance**
- **Co-efficient of variation (C_v)** is a measure of dispersion and **normalizes standard deviation**

$$C_v = \frac{S}{\bar{\mu}}$$

S = Standard deviation of speed sample

$\bar{\mu}$ = Sample mean speed

- Standard deviation of **5km/h** may be considered **small** if sample **mean speed** is **100km/h** ($C_v = 0.05$) but it may be **too large** if sample **mean speed** is **40km/h** ($C_v = 0.125$)

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Now, it is important to understand the mean variance relationship. Why? Because there is an element of variability. That variability is part and parcel of traffic engineering. So, as speed variations are observed in the field, it is necessary to quantify mean and variance and here we use the term what is called coefficient of variation and it is a measure of the dispersion and normalizes standard deviation. So, how we express Cv, coefficient of variation, it is, $Cv = \frac{S}{\mu}$. S is the standard deviation of sample, speed sample and mu is the sample mean speed. So, you will see that there are different Cv value, but different speed and different S & mu, the standard deviation and sample mean combination may give you the same Cv value.
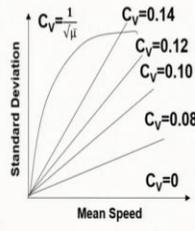
So, I have shown different lines here. Here the Cv is 0, that means the standard deviation is 0. And as you move in this direction anticlockwise, the Cv value is becoming higher and higher. And these lines, any point in this line shows that the same Cv can come based on different combinations of S and mu. Why it is important sometimes? With this example you will understand.

Standard deviation of say 5 kilometer per hour may be considered very small if the sample mean speed is 100 kilometer per hour, because in that case you were talking about Cv which is 0.05. But the same 5 kilometer maybe considered too large if the sample mean speed is 40 kilometer per hour, because in that case the resulting Cv is we are talking about 0.125. So, two cases are not same. So, it is not only the standard deviation, but standard deviation and mean by mean what we normally referred to as coefficient of variation that is important, so based on that we can judge.

Analysts can estimate speed distribution by selecting an expected mean speed with a particular Cv value to get the standard deviation and assuming a normal distribution. Speed varies and often such kind of variation we often express it using normal distribution, not that always bar only normal distribution is applicable, but often we assume it to be normally distributed.

Now, when we are talking about the average speed, there are two ways we can express speed; one is called time mean speed; another is called space mean speed. Time mean speed is the average at one point or location over a period of time. So, at one location I have observed multiple vehicles, the speed over a period of time, and mathematically trying to express it and it is actually the arithmetic mean of the speed observed at a point.

Macroscopic Speed Characteristics

✓**Space Mean Speed (SMS):** Average speed of vehicles occupying a certain road length over a period of time and mathematically expressed as the harmonic mean of speeds observed at a point

Example 1: Twenty five spot speed observations were made:

| 50 | 40 | 60 | 54 | 45 | 31 | 72 | 58 | 43 | 52 | 46 | 56 | 43 | 65 | 33 | 69 | 34 | 51 | 47 | 41 | 62 | 43 | 55 | 40 | 49 |

(i) Calculate time mean speed, (ii) Space mean speed

i) $V_t = \dfrac{\sum V_i}{n} = \dfrac{50+40+60+54+31+\cdots\cdots\cdots+62+43+55+40+49}{25} = 49.56$

ii) $V_s = \dfrac{n}{\sum \frac{1}{V_i}} = \dfrac{25}{\left(\frac{1}{50}+\frac{1}{40}+\frac{1}{60}+\cdots\cdots\cdots+\frac{1}{55}+\frac{1}{40}+\frac{1}{49}\right)} = 47.26$

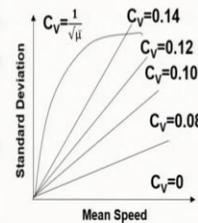IIT Kharagpur | Traffic Engineering| Module B — 12

Macroscopic Speed Characteristics

- Analyst can **estimate speed distributions** by selecting an **expected mean speed** with a particular C_v, to get the **standard deviation** and assuming a **normal distribution**

- **Average Speed:** Time Mean Speed and Space Mean Speed

  ✓**Time Mean Speed (TMS):** Average speed **at one point/location** over a **period of time** and **mathematically** expressed as the **arithmetic mean** of the speeds observed at a point

$C_v = \frac{1}{\sqrt{\mu}}$ — $C_v=0.14$, $C_v=0.12$, $C_v=0.10$, $C_v=0.08$, $C_v=0$

Standard Deviation vs Mean Speed

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On the other hand, the other expression of speed is called space mean speed. It is the average speed of vehicles occupying a certain road length over a period of time. Considering a road length over a period of time and then mathematically this is actually if you express you will see that it is the harmonic mean of the speedy observed at a point.

So, I have shown here to explain that. 25 spot speed observations were made at a particular location. So, I have observed 25 vehicles and their speeds. So, what is then the time mean speed?

Time mean speed I say average of speed measured over a period of time. So, I simply take the average of that, $Vt = \frac{\sum Vi}{n} = \frac{50+40+60+54+31+\cdots\cdots\cdots+62+43+55+40+49}{25} = 49.56$

Now, suppose, if we consider each of these 25 vehicles traveling a distance D or any distance you say and during that travel over the distance each of them maintaining the same speed, that means, if the first vehicle I have got 50 means, over D distance the vehicle has traveled maintaining that 50-kilometer speed. If you do then how much time that vehicle has taken. It is basically the distance by speed. Second vehicle again distance by speed, like that individual vehicle wise you can calculate the time. What is then the average time, 1 by n of that, D by, 50 plus D by 20, 40 plus D by 60 like that. Then what is the average speed over that length?

It will come down to be this expression as I have shown here.

$$Vs = \frac{n}{\sum \frac{1}{Vi}} = \frac{25}{(\frac{1}{50}+\frac{1}{40}+\frac{1}{60}+\cdots\cdots\cdots+\frac{1}{55}+\frac{1}{40}+\frac{1}{49})} = 47.26$$
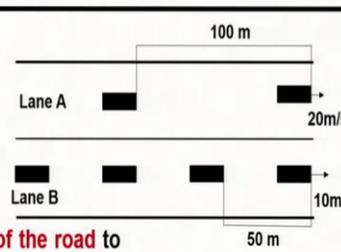
And what you will find here, what you observe here? That the space mean speed is lower than the time means speed. In fact, in all practical purposes, unless all vehicles are traveling at the same speed, you will always get the space mean speed lower than the time mean speed.

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Let me take up another example to explain this further. Suppose n and 2n number of vehicles are traveling at a speed of 20 meter per second and 10 meter per second respectively in lane A and

lane A. So, this is lane A, this is lane B. And here the vehicles are traveling at 20 meter per seconds. Every vehicle is traveling with that speed. And in lane B every vehicles is traveling with a speed of 10 meter per second.

So, if an observer is standing by the side of the road somewhere here we are standing and trying to count the vehicle, record the number of vehicle crossing, then one vehicle will pass at every 5 seconds for both lane A and lane B, because here it is 20 meter per second. So, what you will get? Every 100 meter here, 100 by 20, so every 5 seconds you will observe one vehicle. And here also in lane B also 50 by 10, here also every 5 seconds you will observe the vehicle. So, both in lane A and lane B you will observe the vehicle 5 seconds interval, every 5 seconds one vehicle. Thus, the observer will say same number of vehicles at any instance of time in both the lanes.

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Macroscopic Speed Characteristics

$\checkmark TMS = \frac{(20n+10n)}{2n} = 15 \, m/s$

- As SMS considers the **full stretch** of the road, there will be **twice** the number of vehicles in lane B than lane A

$\checkmark SMS = \frac{(20n+10 \times 2n)}{3n} = 13.33 \, m/s$

- **SMS is always lower** than TMS: TMS gives equal weight to all vehicles but SMS gives more weight to slower vehicles in the stream

- If **all vehicles** are travelling at **same speeds**: SMS and TMS will be equal

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✓ So, what will be the TMS, Time Mean Speed? $TMS = \frac{(20n+10n)}{2n} = 15 \, m/s$

It is 20 into n plus 10 into n, because he is observing only n number of vehicles. in lane A, he will also observe n number of vehicles in lane B. So, 20 into n plus 10 into n divided by 2n, so 15 meter per second. Now, at SMS we consider the full stretch of the road over the length. So, there will be twice the number of vehicles in lane B than in lane A under this particular condition. If any time if you consider a length of road, you will find n number of vehicles in lane A, you will find 2 n number of vehicles in lane B.

So, whatever we calculate your SMS will come as 20 into n plus 10 into 2n divided by 3n, total number of vehicles, so 13.33. $SMS = \frac{(20n + 10 \times 2n)}{3n} = 13.33 \, m/s$. Here also you find SMS is lesser than TMS. So, SMS is actually always lower than TMS, because TMS give equal weight to all vehicles. You are saying here in the first case when we calculate TMS, 20 into n plus 10 into n, equal weightage, here also n, here also n. But when we are doing SMS more weightage is given to slower vehicles in the traffic stream, because here you can say 20 into n plus 10 into 2n. So, SMS is lower.

Now, what will happen if all vehicles irrespective, even if you consider one lane, if you consider multiple lanes and consider all vehicles are traveling at the same speed, then the TMS and SMS will be same. Same value you will get. But that is unlikely to happen in reality, because in reality all vehicles will never travel in the same speed. There will be differences. And therefore, in reality any real data if you take and analyze, you will find SMS will be lower than the TMS.

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Now, there how SMS and TMS are related that is shown here. If you take measurements of time mean speed and the variance of the time mean speed, sigma t square and Ut is the means value, then you can use this formula to get the SMS value, space mean speed. So, from time mean speed I can get the space mean speed. From space mean speed also if you have the values, you can get the time mean speed. They are related. $Ut = Us + \frac{\sigma s2}{Us}, Us = Ut - \frac{\sigma t2}{Ut}$

And as you can see, if the variance is 0, if all vehicles are traveling at the same speed, obviously in that case Us and Ut will be same. Now, one thing may come into question that when we take two samples of speed measurements, we do not measure the speed of every vehicle. So, if we take measurements, two separate measurements, two separate samples, they are unlikely to, that the two samples of the speed measurements will have exactly the same mean, even if they belong to the same population. But then are they different?

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So, here actually some of the knowledge of statistics can be utilized to investigate such things. Although the knowledge of statistics is not a prerequisite for this traffic engineering and I do not really expect much. I will neither be able to, neither I expect nor I will be able to really go into much details to discuss each and every aspects of the basic knowledge that is required in the statistics subject, but some of the things I will mention very quickly. And if you are interested you, those who know already have some elements, basic elements known, you can relate very easily. Other also, if you want to know more details, you can refer to the book, any standard book or take a course on statistics, basic statistics.

Some difference may not be statistically significant. So, the question is the numbers may be different always. But are they statistically significantly different that we need to judge. So, let us consider, you take two samples from the same population. One case the mean is 30.8, 6.2 is the standard deviation, sample size is 100, another case 32, standard deviation is 5.4 and sample is

200. So, what we can do? I am just showing quickly. Not I will be able to go into much details. It is not possible within this course. But we can make initial assumption like differences in means are not statistically significant. Then what we can do, certain steps we can follow.

We can calculate the standard deviation of the difference of means using this very simple formula S1 square by n1 plus S2 square by n2 and the whole thing root of that. So, S1 and S2 is the standard deviation. As I have said here, standard deviation 6.2, here 5.4, n1 number of samples, 100, 200. So, you can easily get this value. Now, what we are trying to see, if the measured difference between these two means which is 1.2 here, 32 and 30.8, so 1.2 is the difference.

If it is greater than 3S, standard deviation of the difference of means as you have calculated, then we can say that the assumption is wrong. If not, then our assumption is correct. That means difference in means are not statistically significant. In this particular case, what is the 3S value? $S^\wedge = \sqrt{\frac{S12}{n1} + \frac{S22}{n2}} = 0.73.$ It is 2.19. And what is your actual difference in the means, 1.2.

So, 1.2 is less than 2.19. So, we can conclude that the differences in means are not statistically significant. That is what we can conclude.
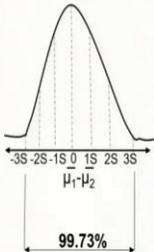
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So, in this case, the hypothesis is accepted and there is no significant variation between two means. Similarly, you can test whether the difference between the variances is also statistically significant

or not. So, hypothesis here again could be that variances are identical. So, one can carry out, again I will not be able to go into details. You may refer to book. But as I said, the knowledge of statistics is not a prerequisite for this course. So, I will not focus so much. I will not expect you to solve problems or answer two questions which require really lot of knowledge about statistics. But very elementary thing I will include. And I want to tell you how you can utilize that subject knowledge in the traffic engineering context.

So, here you can carry out F-test, is used to compare the ratio of two sample variances, that means ratios we want to take it such that it is always greater than 1 or equal to 1, because when you take two variances, one will be higher, one will be lower, but we take the ratio in such a manner that it is either 1 or higher. So, if the ratio of variance is less than F critical, then the hypothesis is accepted. Otherwise, it is rejected. So, in this particular case, suppose the calculated ratio is 6.2 square by 5.4 square, so 1.318 and F critical value is 1.32 with alpha as 0.05. So, you can see that the hypothesis is accepted in this case.

(Refer Slide Time: 42:38)

Now, microscopic speed characteristics defines the speed characteristics of individual vehicles passing a point or segment during a period of time. And as speed of individual vehicles vary, it is also necessary that we express then using a central tendency and a dispersion to represent the speed characteristics of the traffic stream. So, it cannot be that all of them will travel at the same speed.

So, it follows certain distribution. And therefore, we need to express them using a central tendency and a dispersion.

So, if there are ungrouped samples, that means whatever number you have taken, you have taken that is all, individual measurements. They are ungrouped. And sometimes we do grouping. Say every 5 kilometer we make all the observation. 30 to 35, how many observations, 35 to 40 how many vehicles that is grouped sample. So, in case of ungrouped sample, I have shown here, how you can calculate the mean and variances.

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And also here, I have shown here, if there are grouped sample, then how you can calculate the mean and standard variance. So, here the F will come into picture. The number of observation and speed group i. So, 30 to 35 one speed group, and how many observations are there. So, that number will come as the frequency.

Now, as I said that all vehicles are not going to travel at the same speed, so naturally if we have to express speed of vehicles that how individual vehicle speeds are happening in a microscopic, macroscopic characteristics is find, TMS, SMS, one value is fine for the traffic stream, but microscopic characteristics, individual vehicles we are talking here.

So, it has to follow a distribution. So, it is desirable to find appropriate mathematical distribution to represent the measured speed distribution for two reasons. First, each mathematical distribution

has unique properties. Once you know it is a normal distribution, there are so many properties. So, by default you will assume that your data will have those properties. And if measured distribution follows any mathematical distribution, then the same properties can be applicable to the measured distribution. That is one reason.

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Second is, computer simulation also such type of distribution. If you want to simulate a traffic stream, you have to give what, how you generate the speed of individual vehicle, because there you will not work only with one SMS or TMS value, but it is more on the individual vehicles speed. So, how you generate the speed of individual vehicle when you are doing the simulation? If you know that, my speed follows normal distribution with mean mu and standard deviation sigma, then with that you can generate the speed to represent speed in the simulation model as realistic as possible.

So, how to then evaluate. This is also again another interesting part I want to mention without expecting that you will go into great details not as a part of this traffic engineering course. But I want to link that and to tell you that connection that is very important. And those who were interested tomorrow you want to collect some data and want to see that really what distribution, my measured speed, individual vehicle speeds are following, you should be able to do it if you are interested. Maybe you need to little bit study the basic statistics course or refer to a book and try to learn on your own. All those are possible. So, I am just giving up to that. That connection I want to give you.

So, here how to decide that whether a measured speed follow a particular distribution? First is to assume that the initially measured speed distribution follow a certain distribution, maybe normal, maybe lognormal, maybe other kinds of distribution. Then numerical checks are made of central

tendency and dispersion from the measured speed distribution. If numerical checks are satisfactory, then next what we do. Then graphical plot has to be made of the measured speed distribution on normal probability paper.

If the distribution appears as a straight line, then the measured distribution has to be evaluated using a chi-square test. Those who are familiar can connect it very well. Other is you have to little bit spend time on your own to understand if you really want to know more. Otherwise, as I said, I will not expect you to answer too many questions or not going into too many details as a part of traffic engineering but I want you to know, I want to know you the connections. Because in reality tomorrow if you want to really do something that you want to measure speed and you want to try to fit the car, you know that there are certain steps and procedures and maybe little bit additional study you have to do.

(Refer Slide Time: 47:59)

Microscopic Speed Characteristics

- If hypothesis is accepted, then that mathematical distribution can be selected

- Problem2: Find appropriate mathematical distribution using the group speed data given below

μ_i	f_i	Cumulative f_i	% Cumulative f_i	$f_i\mu_i$	$f_i\mu_i^2$
33	1	1	1	33	1,089
34	2	3	2	68	2,312
35	1	4	2	35	1,225
36	1	5	2	36	1,296
37	-	5	2	-	-
.....					
61	3	186	93	183	11,163
62	6	192	96	372	23,064
63	3	195	98	189	11,907
64	3	198	99	192	12,288
65	2	200	100	130	8,450

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21

Microscopic Speed Characteristics

- In cases where speed observations are grouped,

$$\bar{\mu} = \frac{\sum_{i=1}^{g} f_i \mu_i}{N}$$

$$S^2 = \frac{\sum_{i=1}^{g} f_i(\mu_i)^2 - \frac{(\sum_{i=1}^{g}(f_i \mu_i))^2}{N}}{N-1}$$

Where,
g= Number of speed groups,
i= Speed group,
μ_i=Mid-point speed of group i,
f_i=Number of observations in speed group i

Mathematical Distributions

- It is desirable to find **appropriate** mathematical distributions to represent **measured speed distributions** for two reasons

  ✓ Each mathematical distribution has **unique properties** and if measured distribution **follows** any mathematical distribution, then **same properties** can be **applicable** to the measured distribution

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So, if hypothesis is accepted then the mathematical distribution can be selected. So, this is a problem, where I have given the mu and the frequency. It is the, as I said, what it is, it is the grouped data. So, that is why the mu values and f1 values are given, cumulative, percentage cumulative, f1 mu1, f1 mu1 square all these are given just as an example.

(Refer Slide Time: 48:31)

Microscopic Speed Characteristics

Ans- Assume the **data** follows **normal** distribution

Numerical Checks:

i) Mean= 52.3, median= 52.5, mode= 53.0 i.e., these three are in close agreement

ii) **Standard deviation** should be approximately **one sixth** of **total range** since mean+/- three standard deviations covers 99.73% of the observations: S.D= 6.3 and Range=32, S.D $_{Est}$= 32/6= 5.3, hence S.D~ S.D $_{EST}$

iii) **Standard deviation** should be approximately **one half** of the **15th to 85th percent range** (since mean+/- one standard deviations covers 68.27% of the observations) S.D$_{EST}$= 6.15, hence S.D~S.D $_{EST}$

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Then what we do. We first do the numerical checks. We find mean, median, modes are in close agreement generally. Standard deviation, in this case, should be approximately one sixth of the total range. So, since mean plus minus three standard deviation covers 99.73 percent of the observation. So, you can calculate the SD. You know the range. So, this data is 32. So, SD you

estimate, 32, as I said, the 6S, so it is 5.3. So, therefore, you can say SD is approximately somewhat nearer to SD estimated, not that bad.

Then third thing you can do. Standard deviation should be approximately one half of the 15th to 85th percent speed, percentile speed. Since mean plus minus one standard deviation covers 68.27 percent of the observation in this case. So, again you calculate SD. Your estimated value is 6.15 and that you find that SD estimate and SD are again somewhat in agreement.
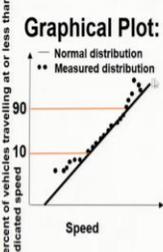
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So, normal distribution has little skewness and therefore coefficient of skewness should be close to 0. In this case also, coefficient of the skewness which is, you can calculate easily is you are getting as 0.1. So, then what we are doing, we are doing the graphical plots here. And you can see in the middle portion 10th to 90th percentile range the fit appears to be very good. The straight line and the points are coming exactly more or less matching. And in the extreme lower and upper end, here and here, fit is not so good, rather poor. So, overall, the graphical fit is reasonable and suggests that it is more likely to be normal distribution.

Microscopic Speed Characteristics

Chi-square test:

$$\chi^2 = \sum_{i=1}^{I} \frac{(f_0 - ft)}{f_t}$$ Where, f_0, f_t = Observed and theoretical frequency in interval I

I = Number of intervals = $\frac{Range}{1+(3.322)logN}$

- Hypothesis: There is **no difference** between **measured** distribution and **normal** distribution
  - ✓ If $\chi^2_{cal} < \chi^2_{Tab}$: **Accept** the hypothesis, Else reject
- **Theoretical frequency** can be calculated using **sample mean** and **Standard deviation**, $Z = \frac{X-\mu}{\sigma}$
- Using **α=0.05** and **degrees of freedom=6**, χ^2_{Tab}=**12.59** (Chi-square table) and χ^2_{cal}= **4.09**
- Hypothesis is **accepted**

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24

Then we do a chi-square test. $\chi 2 = \sum_{i=1}^{I} \frac{(f0 - ft)}{ft}$. Here are the basic elements. I am not going to do that. And here also you do the hypothesis that there is no difference between the measured distribution and normal distribution. So, you do the, calculate the what is the chi-square calculated. And if it is less than chi-square table value, then you accept the hypothesis, else you reject. And for this given example using alpha equal to 0.05, degrees of freedom 6, your chi-square table value is 12.59 as we obtain from the chi-square table and the calculated value is 4.09. So, the hypothesis is accepted. So, altogether we can say.

Microscopic Speed Characteristics

Upper speed class limit (1)	$Z=\frac{X-\mu}{\sigma}$ (2)	P(Z) (Using table) (3)	P(Z1-Z2) (4)	Theoretical frequency(f_t) (Column 4× Number of observations)
35.5	$=\frac{35.5-52.3}{6.3}=-2.67$	0.0038	0.0038	0.76
38.5	-2.19	0.0143	0.0105	2.1
41.5	-1.71	0.0436	0.0293	5.86

- **Numerical checks**, **graphical plots** and **chi-square** test suggested **normal distribution** to be a good fit
- But, if any of these **test fails**, then the **same procedure** has to be repeated using another distribution such as **lognormal** etc.
- In case of **log-normal** distribution, the **measured speed distribution** appears as a **sloping straight line** on **graph** and then other test needs to be carried out

Microscopic Speed Characteristics

Chi-square test:

$$\chi^2 = \sum_{i=1}^{I} \frac{(f_0-ft)}{f_t}$$ Where, f_0, f_t= Observed and theoretical frequency in interval I

$$I = \text{Number of intervals} = \frac{Range}{1+(3.322)logN}$$

- **Hypothesis:** There is **no difference** between **measured** distribution and **normal** distribution
  - ✓ If $\chi^2_{cal} < \chi^2_{Tab}$: **Accept** the hypothesis, Else reject
- **Theoretical frequency** can be calculated using **sample mean** and **Standard deviation**, $Z = \frac{X-\mu}{\sigma}$
- Using **α=0.05** and **degrees of freedom=6**, χ^2_{Tab}=**12.59** (Chi-square table) and χ^2_{cal}= **4.09**
- **Hypothesis is accepted**

And here I have shown you some of the sample calculation you can read on your own that we have defined the classes and then how many class you can do using this formula. I equal to number of intervals. Then how many intervals you can take. And then each case what is the upper place speed limit and how I am calculating the individual value. Just for some sample calculations I have shown.

So, the numerical checks, graphical plots and chi-square test suggests that normal distribution to be a good fit. But if this test fail, then the same procedure has to be repeated for some other distribution. Maybe if normal did not work and if there are indications you should type lognormal. So, in case of lognormal distribution, the measured speed distribution appears as a sloping straight

line on graph and then the other test need to be carried out. So, like that if you have the data, you can actually try to see that what distribution the field data is following closely. So, these kinds of things become very interesting.

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So, in summary, I would say, individual vehicles and drivers interact with each other in unique ways with the roadway environment in the traffic stream. And there are two types of traffic facility uninterrupted, interrupted. There are macroscopic parameters, there are microscopic parameters and I discuss little bit about those parameters. With this, I close this lecture. Thank you so much.