

Traffic Engineering
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Lecture 07
Traffic Volumes and Time Headways

Welcome to Module B, Lecture 2. In this lecture we shall discuss about Traffic Volumes and Time Headways.

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Recap of Lecture B.1

- Individual **drivers** and **vehicles** interact with each other in unique ways and with **roadway environment** in the **traffic stream**
- Traffic facilities are of two types: **Uninterrupted** and **interrupted**
- Broadly, traffic stream parameters are classified as **macroscopic** and **microscopic**

✓ **Macroscopic** and **microscopic** **speed** characteristics



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In lecture 1 we discussed about traffic streams where individual vehicles and drivers they interact with each other in unique ways with roadway environment and traffic streams. Then I mentioned to you about two types of traffic facilities, uninterrupted flow facilities and interrupted flow facilities. And then I mentioned to you about the macroscopic and microscopic parameters of traffic streams.

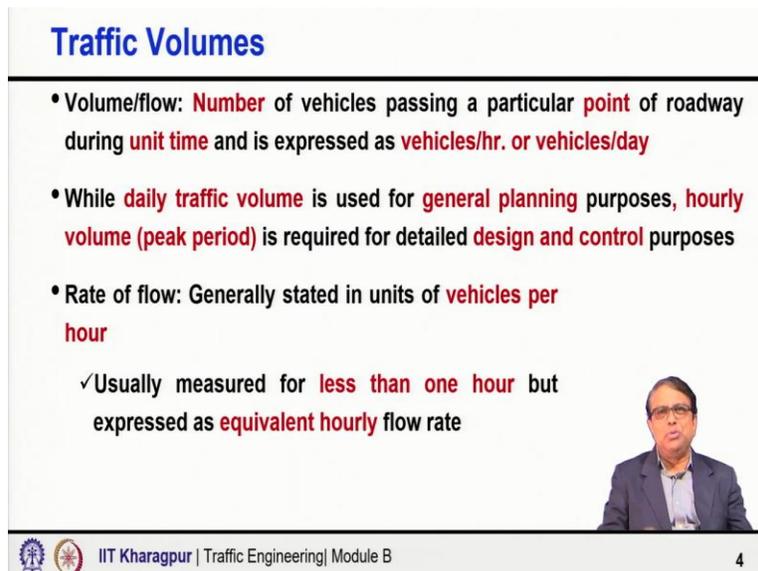
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With this background, today, let us focus on traffic volumes.

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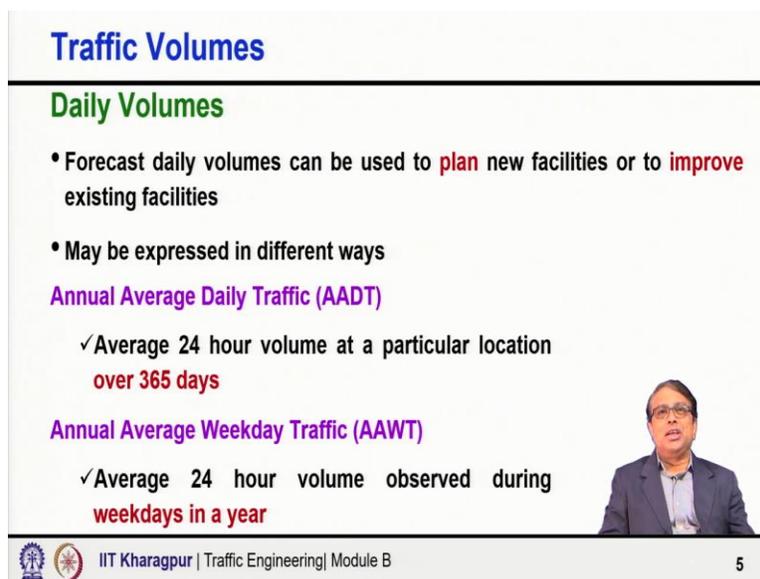
- Volume/flow: **Number** of vehicles passing a particular **point** of roadway during **unit time** and is expressed as **vehicles/hr. or vehicles/day**
- While **daily traffic volume** is used for **general planning** purposes, **hourly volume (peak period)** is required for detailed **design and control** purposes
- Rate of flow: Generally stated in units of **vehicles per hour**
 - ✓ Usually measured for **less than one hour** but expressed as **equivalent hourly** flow rate

Traffic volumes is normally expressed as the number of vehicles passing a particular point of road during unit time and is expressed as either vehicle per hour or vehicles per day. So, we are talking about traffic measurements at a point. When vehicles are crossing we are counting the vehicles. During unit time. that unit time sometimes could be hour, sometimes could be day, and therefore, we express the volume as number of vehicles per hour or per day.

Daily traffic volumes is used for general planning purposes. You want to upgrade road infrastructure. We want to develop a new road, a new connectivity. We estimate the traffic volume which is mostly the daily volumes. But hourly volume is also required sometimes for detailed design, maybe you want to understand the capacity, you will eventually try to see that what will be the design hourly volume and accordingly matching the level of service what you actually want. You would then say that how much capacity will be required or how many lanes will be required.

Volumes often is expressed in terms of rate of flow that means vehicle per hour, but although the rate of flow is expressed in terms of vehicle per hour, but usually we measure the traffic volume for less than 1 hour, typically, for say 15-minute count we can do, but then express it as an equivalent hourly flow rate. That means I may take actually 15-minute count and whatever number of vehicles I am getting, I can express them in equivalent hourly flow rate multiply by four, because 15 minutes, so 60 minute in an hour, so 4 times interval, so multiply it by four times. So, that is the way we normally express the rate of flow. Although the rate of flow does not mean the actual measurement is for 1 hour, it may be for shorter than 1-hour duration, but expressed in terms of equivalent flow rate.

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Traffic Volumes

Daily Volumes

- Forecast daily volumes can be used to **plan** new facilities or to **improve** existing facilities
- May be expressed in different ways

Annual Average Daily Traffic (AADT)

- ✓ Average 24 hour volume at a particular location **over 365 days**

Annual Average Weekday Traffic (AAWT)

- ✓ Average 24 hour volume observed during **weekdays in a year**

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5

As I said, traffic volume can be expressed in so many ways, maybe expressed in terms of daily volumes, hourly volumes, sub-hourly volumes. So, let us see what are the different ways the daily volumes can be expressed and why we need such kind of expression for daily traffic volumes.

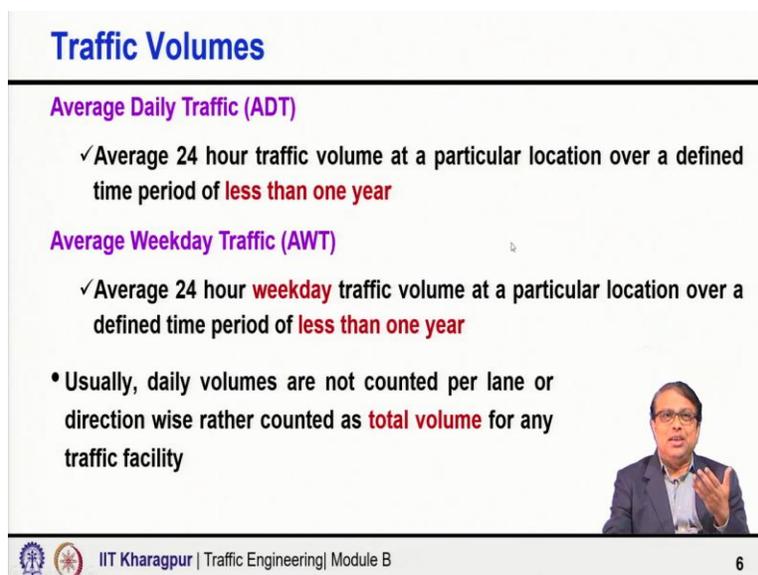
Forecast daily volumes typically are used to plan new facilities or to improve the existing facilities and maybe expressed in different ways.

First, Annual Average Daily Traffic, AADT, Annual Average Daily Traffic. It is annual average. So, that means, theoretically, we are making account for 365 days in a year and taking the average of that. So, what it will include? It will include all seasonal variations that usually happen on non-urban roads, some cases some special other roads also.

So, that seasonal variations will get captured. Somewhere maybe winter traffic is less, but summer traffic is more. So, if we are taking 365 days count, all seasons, all days we are covering and taking the average. So, that is actually true representation of annual average, because we can simply multiply it by 365 to get that exact yearly traffic volume that the road has to handle.

Then next is annual average weekday traffic. This is also annual average. So, ideally one year, but one more word has gone inside, not daily traffic but annual average weekday traffic. So, the weekday traffic, annual average weekday traffic. So, that means during the year what measurements we have taken on all the weekdays it is the average of that daily traffic. So, that is what is annual average weekday traffic. So, if typically weekend traffic is less, typically, then you will get annual average weekday traffic higher than the annual average daily traffic.

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Traffic Volumes

- ✓ Average Daily Traffic (ADT)
 - ✓ Average 24 hour traffic volume at a particular location over a defined time period of **less than one year**
- ✓ Average Weekday Traffic (AWT)
 - ✓ Average 24 hour **weekday** traffic volume at a particular location over a defined time period of **less than one year**
- Usually, daily volumes are not counted per lane or direction wise rather counted as **total volume** for any traffic facility

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6

Most cases, we cannot directly measure the traffic throughout the year, because if you have a highway project typically you will have 2 to 3 months, maximum 4 months time you can get, not more than that in any case to do the traffic part or the traffic forecasting part. So, what we can measure is not for 365 days real measurements. So, there what we do, we measure typically for more than a day, but not for 365 days.

So, if we are taking the average of traffic count more than a day but less than 365 days theoretically, then that average 24-hour volume whatever we will calculate we will call it as average daily traffic. The word which we are omitting here is annual, because it is not yearly average. It is something less than 365 days. And as per current practice for all the highway projects we typically take 7-day traffic count, one-week, complete week we take an average of that to calculate the average daily traffic.

Obviously, average daily traffic and annual average daily traffic will not be same, because the seasonal variations will be different, effect of seasonal variations will be different. Here in ADT if we are doing it during winter time, we will get only winter traffic average, the daily volume will get. On the contrary, if we are taking the annual average, then all seasons will be considered in that measurement.

So, always for traffic estimation purpose when we do the highway projects, and we need to actually calculate the traffic volume, give the projection, we measure that ADT and then use some other secondary data available from toll booth or maybe fuel sales data or some other secondary, logical secondary data to understand or captured that seasonal pattern and then convert ADT to AADT. I am not going details into detailed discussion about that. I am not going into detailed discussion about that.

Then average weekday traffic. This is similar to ADT, but we are restricting the count on weekdays only, not the weekend. And therefore, whatever average we are getting that is the average weekday traffic. In a particular season we are doing it maybe 4 or 5 days, whatever it is the number, but not on weekends or holidays. So, that is why the measurements will be, when we take the average, we call it as average weekday traffic.

Usually, daily volumes are not counted per lane or direction wise, rather counted as total volume for any traffic facilities. I would like to little bit clarify here not counted means actually we may

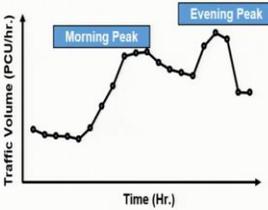
count it direction wise, but we rather express it as total volume. So, we may count it separately, but we express this as total volumes.

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Traffic Volumes

Hourly Volumes

- Important because of **morning and evening rush** of traffic (Demand may exceed capacity)
- **Highest hourly volume** is called as the peak hour traffic volume which usually occurs either in morning or evening rush hours
- Peak hour traffic is expressed as **directional volume**: Direction of travel is **opposite** in morning and evening
- **Both sides** of a facility must be designed to accommodate **peak directional** traffic flow



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7

Then next what we express traffic volume is in terms of hourly volumes. Why hourly volumes? This is important because of morning and evening rush of traffic. Typically, if you see the corridors which are interurban corridors or within urban areas, some kind of commuting trips are there, there you will typically find the peak like this as I have shown in the figure, typically a morning peak and an evening peak. Urban traffic this is very, very predominant.

In most cases, unless the city is really congested and overloaded and peak has spread substantially over a longer period there also we will get peak but the peak may not be so distinct because off peak also may be still very significant, especially during the daytime, morning maybe 8 o'clock to evening 8 o'clock, no where you will find traffic is dropping drastically.

So, how much peak will, you will get that depends on the city that depends on the activities that are happening in the city and so many other factors. But typically, you will have morning and evening rush hour the traffic volume will be high. And the road capacity is expressed generally in terms of hourly volume, how much traffic, how many vehicles we can pass through a given section in an hour. We may relate it to the daily volume that is a different thing.

End of the day you may say what is the ADT and how much is the number of lanes that is required to serve the traffic volume with a desired level of service that is a different thing. We may still eventually connect it to AADT or ADT. But generally, the capacity is for hourly traffic. So, the necessity is there to establish or express traffic in terms of hourly volume.

We want to identify highest hourly volume and which we often call as the peak hour traffic and that usually occurs either in the morning or in the evening. So, we identify the morning peak and evening peak separately and may take the one which is higher, which is more predominant. Sometimes the evening and morning peak may not be exactly same. So, which one is more predominant, which one is higher value that we should take as the peak hour traffic for the subsequent work.

Peak hour traffic is expressed as directional volume, because here the direction is important. Because often where there is such kind of peaking characteristics of traffic, you will see the morning travel maybe is towards the CBD or towards the city area and evening traffic is away from the city area and maybe if the road is a divided road or even otherwise, we need adequate capacity to support the directional volume. So, both sides of the facility, up and down, morning maybe towards the CBD, evening way from the CBD, so both sides of the facility and if it is a divided road must be designed to accommodate peak directional traffic flow.

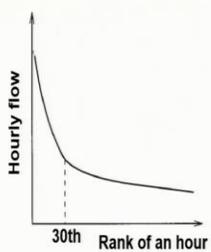
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Traffic Volumes

- In design, usually AADT is used to calculate peak hourly volume: AADT is more stable than hourly volumes
- **Directional design hourly volume (DDHV)** is used for design

$DDHV = AADT \times D \times K$

D=Directional factor
 K=Proportion of daily traffic during peak
- For design purposes, K represents the **proportion of AADT occurring during the 30th peak hour of the year**


- ✓ 30th peak hourly volume represents **hourly traffic that will exceed only 29 times in a year**




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8

In design usually AADT is used to calculate peak hourly volume in a way what I try to mean that we express the peak or the design hourly volume relating it to the AADT. Why AADT, because AADT is more stable than hourly volume. You are expressing as annual average daily traffic. So, it is more stable as compared to the hourly volumes. But then, as I said, that connection is required. We eventually need the hourly volume. So, hourly volume is expressed as a function of AADT, Annual Average Daily Traffic.

Here I have shown if it is directional, then directional design hourly volume how we can calculate, AADT into D into K. What is the D? D is the directional factor, how much split of this AADT is in the direction of peak travel. And K is what? K is the proportion of daily traffic during design or during the peak for the design purpose, how much percentage of AADT is occurring actually during the peak hour or how much we take for the purpose of design.

Now, here it is not directional then K may be omitted also in that case, sorry, D may be omitted in that case. The directional factor will not be there. So, it will be simply design hourly traffic how much we take. Most cases it will be directional as well. So, we take that. And how we then express, what will be the typical K value, how we design it. K represents the proportion of AADT occurring and this is taken as the 30th highest hourly volume considering the yearly traffic. That means, if I have 365 days into 24 hours, that many hours are available to us.

And if we are trying to see what is the 30th highest hourly volume, that means we are taking that as our design, for our design purpose, that means we are accepting 29 times in a year the actual traffic volume could be even higher than our design volume what we are taking and we are ready to accept 29 hours in a year that too in the forecast here it will happen or is the year it will happen. That 29 times in a year 29 hours in a year maybe the condition will be higher that is accepted or the condition will be higher than what we expect what is our design level of surface.

Why? If we take the highest ever hourly volume, the design may not be economical. So, we have to strike a balance, we have to balance, we have to strike a balance between the efficiency and the economy. So, that is why we take the 30th highest hourly volume.

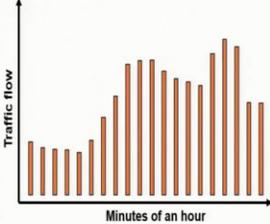
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Traffic Volumes

- ✓ The **design volume** corresponding to such a design hour is generally between **8 % to 10 % of AADT**

Sub Hourly Volumes

- Generally, peak hourly volume is used for most of the design and analysis of traffic facilities but sometimes volume within the peak hour also becomes important
- ✓ Traffic facilities may be adequate for the peak hour but it may not be adequate in shorter interval because **volume within the peak hour varies widely**



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30th highest hourly volume usually is found in the range of 8 percent to 10 percent of the AADT. For some of the roads what traffic engineers have observed generally this is in the range of 8 percent to 10 percent of the AADT. So, we calculate the daily volume, ADT, convert it to AADT and then 8 percent to 10 percent of the AADT is taken as the design hourly volume. And accordingly, I am trying to see how much infrastructure is required or how many lanes are required to ensure the target level of service.

Sometimes even the hourly volume is not sufficient for analysis and we need even sub hourly volumes. If you typically consider say design of signals, signal design if you are doing, we need peak 15-minute traffic flow that is required. That is why I will talk now about the peak hour factor. So, traffic facilities may be adequate for the peak hour, but it may not be adequate in shorter interval, because volume within the peak hour varies widely, not that what you are getting in 60 minute, four 15 minute interval is not same. There is again substantial variation. So, we need to care for the sub-hourly volume also.

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Traffic Volumes

- Design should be based on a period of (say 5 minute, 15 minutes) maximum rate of flow observed within peak hour
 - ✓ For most of the practical cases **15 minute period** is used because flow during this period is considered to be **stable**
- The relationship between **hourly volume** and **maximum rate of flow** within the peak hour is defined by peak hour factor (PHF)

$$PHF = \frac{\text{Hourly Volume}}{\text{Peak rate of flow within the hour}}$$
- Theoretical range of PHF (0.25-1.00)
 - ✓ **Lowest value** is when **entire hourly volume** occurs in a **single 15 minute interval**



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Now, design should be based on a period say 5-minute, 15-minute, maximum flow, rate of flow observed within the peak hour. So, for most cases, practical purpose we take 15-minute period, because flow during this period is considered to be stable. Even 10-minute flow also could be stable, 5 minutes, but not less than 5 minutes.

So, that means if we take the hourly or every minute if you take the flow it will be tremendous fluctuation. Some cases you get a flow rate. If you convert the flow rate, it may be very high which is practically not possible as a steady flow. You may get it in 1 minute or 2 minute, because maybe before or after that there was no traffic. So, somehow it could pass. But steady state you cannot get.

So, we take the duration. The stability is very important. Is it stable, is it, can the road repeatedly can take over a period of time that much traffic that is very, very important. So, the duration cannot be too short. Normally we take 15 minutes. Now, as I said, because the signal design purpose we need the peak 15-minute flow rate, so the relationship between hourly volume and maximum rate of flow within the peak hour is defined by the peak hour factor. What is peak hour factor? It is the hourly volume divided by peak rate of flow within the hour. Typically, 15 minute if we take that means is hourly volume divided by four times peak 15 minute volume that is the peak hour factor.

Theoretically, peak hour factor could be 0.25 to 1. Lowest value when we get, when the entire volume occurs in a single 15-minute interval. The whole 60-minute whatever traffic is passing or

whatever is the demand, actually in a 15 minute this is the same demand. And therefore, remaining three 15-minute interval there is 0 traffic. So, in that case theoretically. So, we are getting in that case the lowest value 0.25.

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Traffic Volumes

✓ **Maximum when there is no variation in the flow within the hour**

- **Practical range of PHF (0.70-0.98)**

Example-1: Calculate PHF from the following data of an intersection survey

Time interval	04:00-04:15	04:15-04:30	04:30-04:45	04:45-05:00	05:00-05:15	05:15-05:30	05:30-05:45
Vehicles	430	446	519	398	513	481	411

Solution:

Volume counts:- 04:00-05:00=1793, 04:15-05:15=1876
 04:30-05:30=**1911**, 04:45-05:45=1803

Maximum 15minute volume= 519

PHF= 1911/(4×519)=0.92




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11

And we get the maximum value that is 1 when there is no variation in the flow within an hour. All four 15-minute period, traffic volume is exactly same. So, whether you take one particular 15 minute multiplied by 4 or whether you take the whole 60 minutes, you get the same number. In that case, the value will be 1. But practical range it is 0.7 to 0.98. I have taken a small example here. Different time interval, 15-minute traffic volume I have given, and I want you to identify the peak hour and the peak hour factor.

So, what we can do? 15 minutes means I can add it up. I can calculate 4 to 5 o'clock, adding four 15-minute volume, 4:15 to 5:15, 4:30 to 5:30, 4:45 to 5:45. So, if you calculate, then you get 4 to 5 is 1793, 4:15 to 5:15, 1876, 4:30 to 5:30, 1911, and 4:45 to 5:45, 1803. So, obviously, the maximum is 1911. So, the peak hour is 4:30 to 5:30. And maximum 15-minute flow within 4:30 to 5:30, these four columns, so maximum here is 519. So, what is then the peak hour factor, peak hour factor is 1911 divided by 4 into 519. So, that is 0.92.

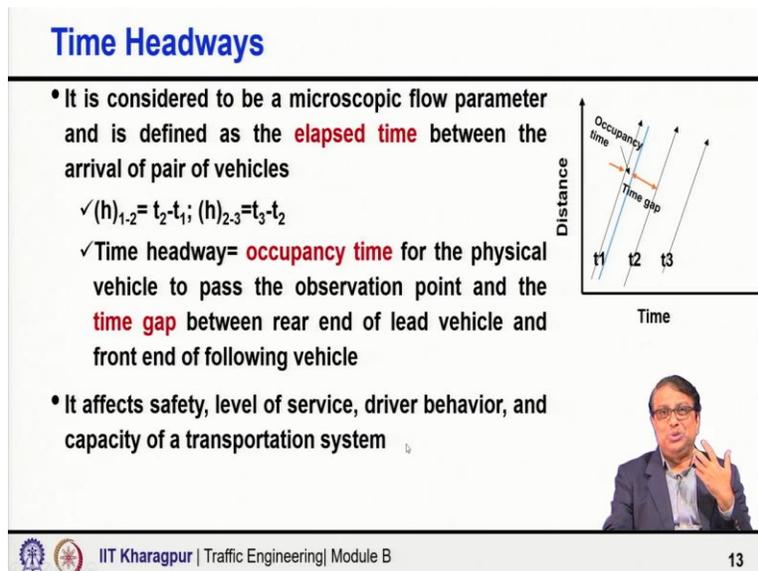
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Now, we go to the next topic, next parameter that is called time headway.

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The slide is titled "Time Headways" in blue. It contains a list of bullet points and a diagram. The diagram shows a graph with "Distance" on the vertical axis and "Time" on the horizontal axis. Two parallel lines represent the paths of two vehicles. The time interval between the arrival of the front of the lead vehicle and the front of the following vehicle is labeled "Time gap". The time interval between the arrival of the rear of the lead vehicle and the front of the following vehicle is labeled "Occupancy time".

- It is considered to be a microscopic flow parameter and is defined as the **elapsed time** between the arrival of pair of vehicles
 - ✓ $(h)_{1-2} = t_2 - t_1$; $(h)_{2-3} = t_3 - t_2$
 - ✓ Time headway = **occupancy time** for the physical vehicle to pass the observation point and the **time gap** between rear end of lead vehicle and front end of following vehicle
- It affects safety, level of service, driver behavior, and capacity of a transportation system

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What is time headway? It is considered to be microscopic flow parameter. Volume is macroscopic, but headway is microscopic. I have mentioned this in my first lecture also in this module. So, it is considered to be a microscopic flow parameter and is defined as the elapsed time between the arrival of pair of vehicles may be front to front.

It need not be always front to front any parts to any part you can take, you will get the same time headway, but normally it is taken front to front, because if you are putting a detector, detector detects the front of the vehicle. So, the front of the vehicle it is passing and next vehicle front is touching again. So, the time gap between the passage of the front of the first vehicle to the front of the next vehicle is called the time headway.

As I have shown here, this is one line, this is another t_2 , t_3 is another line, but I have also shown one more line in a different color using the blue color. So, this, this, these three lines are black, and this line is shown as blue. So, the time headway actually if you see it includes two components. One is the occupancy time and another is the time gap. Occupancy time is for what. It is for the physical vehicle to pass the observation point. That means front touches, but the whole vehicle will pass. So, passage of that vehicle how much time it takes that is the occupancy time. Detector is occupied with vehicles during that time.

And then time gap between the rear end of the lead vehicle that has crossed and the front end of the following vehicle. So, time gap plus occupancy. It affects safety headway. Time headway is very important from the perspective of safety. Also influence the level of service. It influence the driver behavior, how people are going to, drivers are going to react, and also the overall capacity of the transportation system.

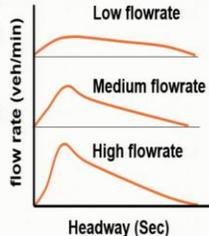
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Time Headways

- Distribution of time headways determines the requirement and opportunity for passing, merging and crossing
- Capacity of system depends on **minimum time headway** and **headway distribution**

Classification of Time Headway Distributions

- **Shape** of headway distribution varies as **traffic flow** changes: Increasing interaction between vehicles as flow increases
- ✓ Low flow conditions: Very little interaction between vehicles - **random time headway** state






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14

Distribution of time headways determines the requirement and opportunity for passing, merging and crossing. I have mentioned this also. The time headway is very important. Doing the maneuver, people look at the time headway. So, the capacity of the system depends on the minimum time headway and the headway distribution. Headway is microscopic parameter. So, every pair of vehicle the headway may be same, may be different. So, it follows the distribution or there is an element of variability in this microscopic measurement.

Therefore, the next topic classification of time headway distributions. Time headway certainly follows certain distribution, because sometimes vehicles may follow the same headway when they are moving in a platoon. They may clearly following a lane discipline, similar kind of vehicle, homogeneous traffic stream they will follow a fixed headway, but most cases it will be a variation of headway, and therefore, the classification of time headway distribution is important.

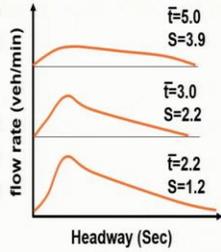
Shape of headway distribution varies as traffic flow changes. I have shown here typically three cars, low flow rate. The traffic volume is actually changing. Here it is low flow rate. So, maybe you can imagine that as you are coming down, your traffic volume is increasing. And here I am showing the headway. So, the bars, the graphs are showing the distribution. As you can see that what we are seeing the, what will be the shape of the distribution that depends on what is the general flow level. So, three flow level we are considering here, generally speaking, low, medium and high. High means near capacity. Low is you know generally lower traffic volume. And one is in between mid range, medium level of flows.

So, you can see the headway distributions do not look same. In low flow condition actually, there is very little interaction between vehicles. So, vehicles are passing through hardly there is any interaction or even if it is there, but the level of interaction is very low. So, the headway looks random. So, you get a traffic headway state what you can call is random time headway state, disperse and more or less going like this, not having any peak, not having very high frequency at one particular headway.

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Time Headways

- ✓ Traffic flow near capacity: Almost all vehicles interact and follow each other- **constant time headway state**
- ✓ In between two boundary conditions: Some vehicles are independent to each other while others are interacting- **intermediate time headway state**
- Intermediate time headway state is **most often encountered** in real world but **difficult to analyze**



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15

But then extreme, if we consider, traffic flow near capacity, then nearly all the vehicles will move in a platoon. So, what will happen? When they will move in a platoon higher number of vehicles, higher percentage of vehicles will actually try to maintain the same headway. Theoretically, in a perfectly platoon moment, the headway will be same.

But in reality, it will not be same, because of vehicle to vehicle variation, because platooning may not be there at all the time, generally although it is a platoon movement, but platooning may not be there all the time, but platooning effect will be there. So as the platoon starts building and vehicle moves in a platoon you will get such kind of peaking nature will happen indicating that higher percentage of vehicle are actually moving, higher percentage of vehicle is moving with a particular frequency and around that also the percentage of vehicles will be higher.

But as you deviate from that rarely very little vehicle are passing. It may not be 0, it will not be 0, because the platooning all 100 percent vehicle moving in platoon may not occur, but larger share of vehicles are actually moving in platoon. So, as the platoon starts building at the volume, overall volume is higher and platoon behavior starts developing, the peaking will take up as you can see. And in between two boundaries, some of the vehicles will move independent to each other and some of the vehicles may move in the platoon. So, it is a mix of both.

So, you get here, it is, if I consider this, I should not say flat, but still I am using the term to just explain you the things, that it is somewhat flat and then meet somewhat peak, near capacity high

flow peaking, more peak, more prominent, more distinct peak you can get. So, the distributions are also unlikely to be same at all the flow level. Typically, I have shown a value where you can see the average t bar, average headway and what is the standard deviation. You can see as the peaking characteristics happen, standard division will be lesser. Here 5, 3.9, 3, 2.2, 2.2, 1.2.

Now, intermediate traffic state, intermediate volume that is quite a significant range actually and that is what we mostly encounter in reality, but that is most difficult thing to analyze, because neither all vehicle will be following behavior like this random, nor it is a completely or largely platoon movement.

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Time Headways

Random Headway State Distribution

- Gap or headway distribution function can be derived from **Poisson distribution** (Counting of vehicle arrivals)

$$P(r) = \frac{(\lambda t)^r e^{-\lambda t}}{r!}$$

Where, $P(r)$ = Probability of arrival of r vehicles in any interval of t sec, λ = Average rate of arrival, t = Time interval

- ✓ If there are **no vehicles arriving** in a time interval of t seconds, then **$r=0$**
- ✓ Hence, **$P(0)$ is the probability of a gap/ headway (h) equal to or greater than t seconds**

$$P(h \geq t) = P(0) = e^{-\lambda t}$$


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Time Headways

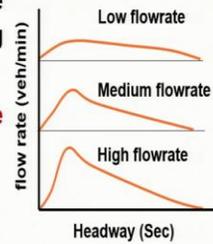
- Distribution of time headways determines the requirement and opportunity for passing, merging and crossing

- Capacity of system depends on **minimum time headway** and **headway distribution**

Classification of Time Headway Distributions

- **Shape** of headway distribution varies as **traffic flow** changes: Increasing interaction between vehicles as flow increases

- ✓ Low flow conditions: Very little interaction between vehicles - **random time headway state**



Now, little bit discussion about each of these three states. First is the random headway state distribution. When random headway state distribution will happen, I have said, when it is low flow condition. I am not defining exactly what volume or what range, but generally I am telling as a traffic engineer. You can sense that it is a low, medium, high. So, when there is low flow, then the random headway state distribution you expect. In this case, the gap or the headway distribution function can be derived, carefully observed, I am not saying it is that Poisson distribution, it can be derived from Poisson distribution.

Poisson distribution essentially is a distribution which representing counting of vehicle arrivals, during an arrival how many vehicles are arriving. So, the Poisson distribution, that counting distribution can be used to get the headway distribution under random headway state. What is the expression, as given here. This is for the Poisson distribution, P_r equal to λt to the power r

e to the power minus λt by factorial r . So, I have given that.
$$P(r) = \frac{(\lambda t)^r e^{-\lambda t}}{r!}$$

And when no vehicle arriving in a time interval in t seconds, r equal to 0, because P_r is the probability of vehicle arrival of r vehicles in any interval t seconds and λ is the average rate of arrival, it is the rate of arrival, and t is the time interval. So, hence, P equal to 0 is the probability when no vehicle is, what is the probability that there will be no vehicle during a time period t .

That means in a way probability of getting 0 vehicle in an interval is equivalent to probability of a headway greater than equal to t seconds so that we can get. So, probability of h greater than equal

to t equal to probability of getting 0 vehicle and that is equal to, you can use this expression e to the power lambda.

(Refer Slide Time: 35:08)

Time Headways

Probability of **headway** being **less than t**, is given by

$$P(h < t) = 1 - e^{-\lambda t}$$

This formulation is called **negative exponential distribution** of headways

✓ Probability of a time headway between t_1 and t_2 can be estimated,
 $P(t_2 \leq h < t_1) = P(h \geq t_2) - P(h \geq t_1)$ if $t_1 > t_2$

Example-2: An observation on an Expressway yielded a count of 200 vehicles of half an hour. Calculate the number of headways in this count: (i) greater than 4.5 seconds and (ii) less than 18 seconds

Solution: We know, $P(h \geq t) = e^{-\lambda t} = \frac{200}{30 \times 60} = 0.11$
 $P(h \geq 4.5) = e^{-0.11 \times 4.5} = 0.6065$





Probability of headway then e to the power lambda t. So, then this formulation for headway distribution is called negative exponential distribution of headways or generally we call it as exponential distribution. So, negative exponential distribution or generally we call it as exponential distribution also. The negative word we may not attach every time. So, what is then the probability of a time headway between t_1 and t_2 that can, so what is the probability that headway will be greater than t_2 and less than t_1 . Let us take an example.

An observation on an expressway yielded a count of 200 vehicles of half an hour. Calculate the number of headways in this count; greater than 4.5 seconds and less than 18 seconds, separate. So, here we know probability of headway greater than t is e to the power minus lambda t. So, lambda is 200 divided by 200 vehicles half an hour, so 30 into 60, so 0.11. So, what is the probability that headway is greater than 4.5 seconds, it is e to the power lambda 0.11 minus lambda into t, t is here 4.5 seconds, so you get it 0.6065.

(Refer Slide Time: 36:49)

Time Headways

(i) No. of headways greater than 4.5 seconds = $199 \times 0.6065 = 120$
 $P(h < t) = 1 - e^{-\lambda t}$
 $P(h < 18) = 1 - e^{-0.11 \times 18} = 0.8647$

(ii) No. of headways less than 18 seconds = $199 \times 0.8647 = 172$

Illustration

- To determine the strength and weakness of this random headway state, the negative exponential distribution is applied to the measured time headways



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So, then I have 200 vehicles, so 199 headways, so number of headways greater than 4.5 second is simply 199 multiplied by 0.6065. Similarly, the headways less than equal to t seconds, 18 seconds, same way you can calculate, 1 minus e to the power minus lambda t. Here you can get, here it is 0.8647. So, again number of headways less than 18 second is 199 into 0.8647 that is 172. Now, to determine the strength and weakness of this random headway state, the negative exponential distribution we are trying to apply to the measured time headways.

(Refer Slide Time: 37:35)

Time Headways

- For low levels of flow, the calculation is given below considering mean headway=5 [$\lambda=(1/5)=0.2$ and $N=1320$]

t_i	$P(h \geq t_i) = e^{-\lambda t_i}$	$P(t_{i-1} \leq h < t_i) = P(h \geq t_{i-1}) - P(h \geq t_i)$	$F(t_{i-1} \leq h < t_i) = N \times P(t_{i-1} \leq h < t_i)$
0.0	$= e^{-(0.2 \times 0)} = 1$		
0.5	$= e^{-(0.2 \times 0.5)} = 0.905$	$= 1 - 0.905 = 0.095$	$= 0.095 \times 1320 = 125$
1.0	0.819	0.086	114
1.5	0.741	0.078	103
2.0	0.670	0.071	94
2.5	0.607	0.063	83
3.0	0.549	0.058	77
3.5	0.497	0.052	69
4.0	0.449	0.048	63
4.5	0.407	0.042	55

- $F(t_{i-1} \leq h < t_i)$ indicates frequency of time headways for each time headway group
- N = Total number of observed headways



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All the data everything I am not getting, giving you here, but just trying to show you some calculation for the low levels of flow. And considering the mean headway of 5 that means λ is 1 by 5 that is 0.2 and our number of observations is 1320. So, here I am showing t_i , 0, 0.5 seconds, 1 second, 1.5, 2, like that up to 4.5.

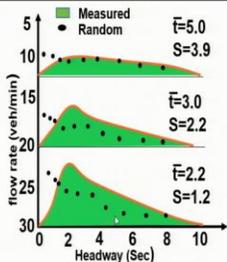
So, what is the probability that headway will be greater than this t seconds. It is $e^{-\lambda t}$ to the power minus λt . You can calculate it. I have shown you two calculations. And the remaining values are also calculated in the same manner. I am calculating i as this one and $i - 1$ as this one. So, 0.5 is i , 0 is $i - 1$. What is the probability that headway will be 0 to 0.5 in that range.

So, greater than, and then this is the, then what would be the frequency. Because our total number 1320, so whatever is the probability multiplied by the frequency. So, you can, overall total number, then you get the frequency. So, probability multiplied by the number 1320, you get the frequency. Like that for every duration, every t_i value we calculate the probability of headway greater than t_i and then what is the possibility that headway will be in between and what is the respective frequency.

(Refer Slide Time: 39:24)

Time Headways

- The observations are
 - ✓ This distribution has inherent characteristics that the **smallest headways are most likely to occur**
 - ✓ As **time headway increases**, probability consistently **decreases**
 - ✓ The comparison between distributions is **best** under **lowest flow level** and **worst** for **highest flow level**
 - ✓ Even in the **lowest flow level**, the distributions are quite different for **time headway of less than 1 second**






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20

Time Headways

- For low levels of flow, the calculation is given below considering mean headway=5 [$\lambda=(1/5)=0.2$ and $N=1320$]

t_i	$P(h \geq t_i) = e^{-\lambda t_i}$	$P(t_{i-1} \leq h < t_i) = P(h \geq t_{i-1}) - P(h \geq t_i)$	$F(t_{i-1} \leq h < t_i) = N \times P(t_{i-1} \leq h < t_i)$
0.0	$= e^{-(0.2 \times 0)} = 1$		
0.5	$= e^{-(0.2 \times 0.5)} = 0.905$	$= 1 - 0.905 = 0.095$	$= 0.095 \times 1320 = 125$
1.0	0.819	0.086	114
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3.5	0.497	0.052	69
4.0	0.449	0.048	63
4.5	0.407	0.042	55

- $F(t_{i-1} \leq h < t_i)$ indicates frequency of time headways for each time headway group
- N = Total number of observed headways



Similarly, for three different flow conditions we did or in this example it was done. Then it is plotted. Now, I want you to show some observations here. So, the green represents actually measured what is in the field and these points, black dots indicate as we have assumed it to follow negative exponential distribution, then how the points will be there or likely to be there. Details of not, are not shown for mid range flow and heavy flow. So, what observations we derive here.

That the distribution has inherent characteristics that the smallest headway are most likely to occur. You can always see the smallest headway, higher frequency. So, you can see it here also, 125, 114, 103, 94. So, that means smaller headway higher will be the f value, frequency. As time headway increases, probability consistently decreases, be getting lower. The comparison between the distribution is best under lowest flow level and worse for the highest flow level.

If you compare this thing, if I have to compare how it is measured and the distribution these two are matching, it is somewhat better for the lower flow. But S square going to mid range flow or higher flow level the fit is even becoming very, very weak. So, the best one is for the lowest flow level and the worse one is the highest flow level.

Even at the lowest flow level the distribution are quite different for time headway of less than 1 second. If you consider less than 1 second headway, then actually the dots and where the green portion is shown they are distinctly different. Here in this range onwards the match is definitely better. So, what it shows that negative exponential distribution, it actually failed when the volume is high and failed miserably when we are applying it to, for the high-volume scenario.

(Refer Slide Time: 41:54)

Time Headways

Constant Headway State Distribution

- **Normal distribution** can be used when either **headways are all constant** or when there is **slight variation in headways** due to **driver error**
 - ✓ First case, mean headway, $\bar{t} = \frac{1}{\lambda}$ and standard deviation (S) is zero
 - ✓ Second case, standard deviation is more than zero and $\alpha = \bar{t} - 2S$
Where, α =Minimum expected time headway

Illustration

- To determine the strength and weakness of this constant headway state, the normal distribution is applied to the measured time headways
- Similar procedure as described earlier is followed

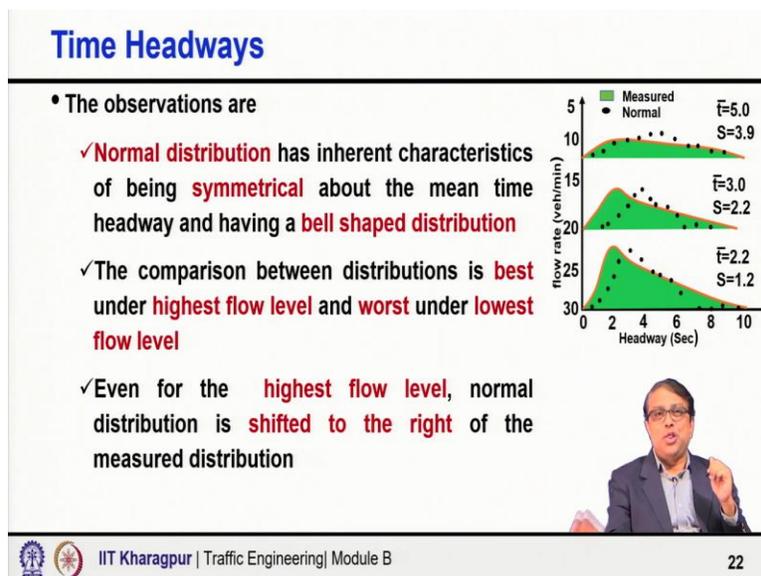


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So, now, we go for the next part, constant headway state distribution. We know that for constant headway state, that means high flow condition, the negative exponential is not going to work. So, here we apply normal distribution when either headways are all constant, if all are constant then that is the first case that means mean will be $1/\lambda$ and standard deviation will be 0 or when there is slight variation in headways due to driver error, driver will not exactly follow the same headway.

So, there will be some variation, not very significant, but there will be some variation, so variation is not 0, not constant headway, in that case, the standard deviation is more than 0 and alpha, which is the minimum expected time headway is $\bar{t} - 2S$. Now, again we try to apply this to some given data to tell you some facts and some insights following the similar procedure as I have described earlier and here are the results.

(Refer Slide Time: 43:03)



Here you can see the normal distribution has inherent characteristics of being symmetrical, you see a distribution, you see a distribution, inherent characteristics of being symmetrical, symmetrical with a bell shaped, having a bell-shaped distribution. But actually, actual field observation measured one does not show symmetrically.

The comparison between the distribution is best so far, even though not exactly very good, but in comparison, when I compare three different traffic states, I find it normal distribution is giving somewhat better or best possible match for the highest flow level and it becomes worst for the lowest flow level.

So, indicating that as the negative exponential distribution made other way at the low flow level it was somewhat better as compared to, and as the flow was increasing it become worse. So, same way the reverse manner the normal distribution fitted better comparatively for the high flow level and as the flow is reduced, low flow, as we are moving towards low flow level, the fit becomes even worse.

Even for the highest flow level, the normal distribution is shifted to right of the measured distribution. So, if you see the actual peak and where the normal distribution is showing the peak, the normal distribution is shifted towards right, actual one is happening towards the left. So, that, these are the observations.

(Refer Slide Time: 44:54)

Time Headways

Intermediate Headway State Distribution

- **Pearson type III distribution** can be used and probability density function is given as

$$f(t) = \frac{\lambda}{\Gamma(k)} [\lambda(t - \alpha)]^{k-1} e^{-\lambda(t-\alpha)}$$

Where, λ = Parameter which is a function of mean time headway and two user specified parameters, K and α

K = User selected parameter that affects the **shape of the distribution**

A = User selected parameter greater than or equal to zero that affects the shift of the distribution

$\Gamma(K)$ = Gamma function



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So, what we do? The next what is remaining is intermediate headway state distribution. That is the more challenging. So, here researchers have applied Pearson type 3 distribution. As I said, this is not a course on statistics, but I will briefly mention the things and you have to study on your own if you are interested to really learn more. Pearson 3 type distribution can be used and probability density function is given as given in this formula. $f(t) = \frac{\lambda}{\Gamma(k)} [\lambda(t - \alpha)]^{k-1} e^{-\lambda(t-\alpha)}$

So, here two things are very important, K, which is a parameter which is a function of the mean time headway and two user specified parameter K and alpha. And K is basically popularly known as shape parameter, because it is selected that affects the shape of the distribution. And A is the user selected parameter greater than equal to 0 and TK is the gamma function.

(Refer Slide Time: 45:51)

Time Headways

- Depending on the value of K and α , person type III distribution can be converted to simpler distribution models
 - ✓ If $\alpha=0$ and K takes any positive value, then Pearson type III distribution become **Gamma distribution**
 - ✓ If $\alpha=0$ and K takes only positive integer value, then Pearson type III distribution become **Erlang distribution**

$$f(t) = \frac{(\lambda t)^{K-1}}{(K-1)!} \lambda e^{-\lambda t}$$

$$f(t) = \frac{(\lambda t)^{K-1}}{(K-1)!} \lambda e^{-\lambda t}$$




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 24

Time Headways

Intermediate Headway State Distribution

- Pearson type III distribution** can be used and probability density function is given as

$$f(t) = \frac{\lambda}{T(k)} [\lambda(t - \alpha)]^{k-1} e^{-\lambda(t-\alpha)}$$

Where, λ = Parameter which is a function of mean time headway and two user specified parameters, K and α

K = User selected parameter that affects the **shape of the distribution**

A = User selected parameter greater than or equal to zero that affects the shift of the distribution

$T(K)$ = Gamma function




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 23

So, depending on what value of K and what value of α , again I am saying K is the shape distribution and α is basically as I said that, user specified is a parameter which is a function of the mean headway and two user specified parameters. So, depending on the value of K and α , Pearson type 3 distribution can be converted to simpler distribution models. It could be gamma distribution, Erlang distribution, even negative exponential distribution could be a very special case of this generalized Pearson type 3 distribution with some specific, for some specific combination of K and α .

So, the shape parameter and the shift parameter you can say. So, when alpha equal to 0 and K takes any positive value, the Pearson type 3 distribution becoming gamma distribution. When alpha is 0 and K takes only positive integer value, then Pearson 3 distribution become Erlang distribution.

(Refer Slide Time: 46:58)

Time Headways

- ✓ If $\alpha=0$ and $K=1$, then Pearson type III distribution become **negative exponential distribution**

$$f(t) = \lambda e^{-\lambda t} \Rightarrow P(h \geq t) = e^{-\lambda t}$$
- ✓ If $\alpha>0$ and $K=1$, then Pearson type III distribution become **shifted negative exponential distribution**

$$f(t) = \lambda e^{-\lambda(t-\alpha)} \Rightarrow P(h \geq t) = e^{-\lambda(t-\alpha)}$$

- To determine the strength and weakness of this constant headway state, Pearson type III distribution is applied to measured time headways
- Similar procedure as described earlier is followed



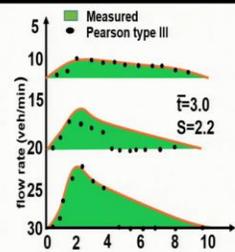

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25

And even you can say when alpha equal to 0 and K equal to 1 then Pearson type 3 distribution become negative exponential. And alpha greater than 0 and K equal to 1 it may become shifted negative exponential distribution. Here you can say here e to the power minus lambda t, here e to the power minus lambda t minus alpha. So, that is what is the shifted negative exponential distribution. Now, as I have done in the two previous cases here also, trying to show that if it is applied, when it was applied to some given data what kind of findings came out.

(Refer Slide Time: 47:33)

Time Headways

- The observations are
 - ✓ Comparison between Pearson type III distribution and measured time distribution for all flow levels indicates that qualitatively both are same
 - ✓ The probabilities of theoretical distributions are almost always less than the corresponding measured distributions for headway groups less than 1 sec and greater than 4 sec
 - ✓ Only a single Pearson type III distribution is investigated for each traffic flow level, and the K and α values are only approximate estimates of “best” Pearson type III parameters



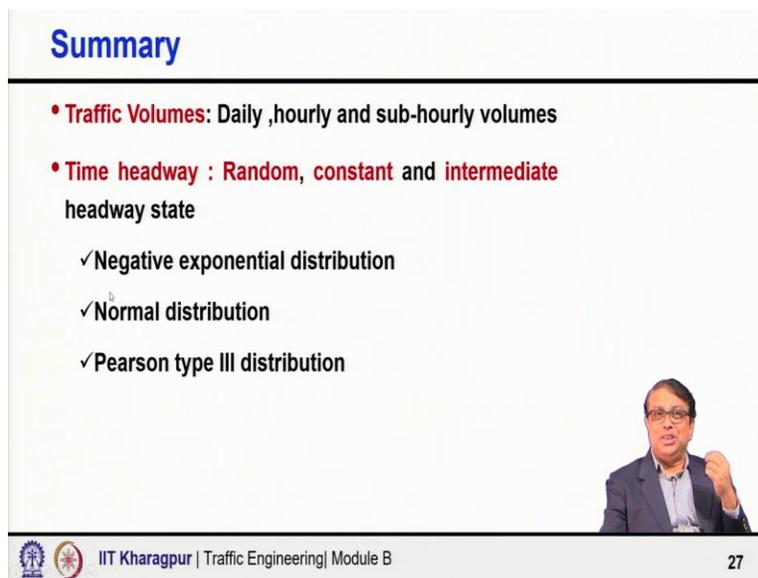
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26

Now, here, again low, medium, high, but remember that only a single Pearson type distribution was investigated in this case for each traffic flow level and therefore the K and alpha values are only approximate estimates of the best Pearson type 3 parameters. You will need to do a sensitivity to find out the best. Our objective was, the objective is not so. So, here only we try to show you that when, generally I am saying Pearson type 3 distribution when they were applied individually to each case how they look like.

Now, here the comparison, the probabilities of theoretical distribution are almost always less than the corresponding measured distribution for headway groups less than 1 second and greater than 4 second. And in general, I should say the comparison between this and measured distribution, Pearson type 3 distribution and measured distribution for all flow level indicates qualitatively both are same, somewhat better. So, people are using Pearson type 3 distributions and more advanced distribution to capture the headway distribution as it is observed from the field. Field measured distribution to better fit distribution to that observed data.

(Refer Slide Time: 49:04)



Summary

- **Traffic Volumes:** Daily ,hourly and sub-hourly volumes
- **Time headway :** Random, constant and intermediate headway state
 - ✓ Negative exponential distribution
 - ✓ Normal distribution
 - ✓ Pearson type III distribution



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So, with this I close it. So, we discussed here about the traffic volumes, different expression, daily, hourly, sub-hourly volume, time headway, mention to you about the random, constant and intermediate highway state and specifically told you the experience with negative exponential distribution of headways, normal distribution and application of Pearson type 3 distribution. With this, I close this lecture. Thank you so much.