

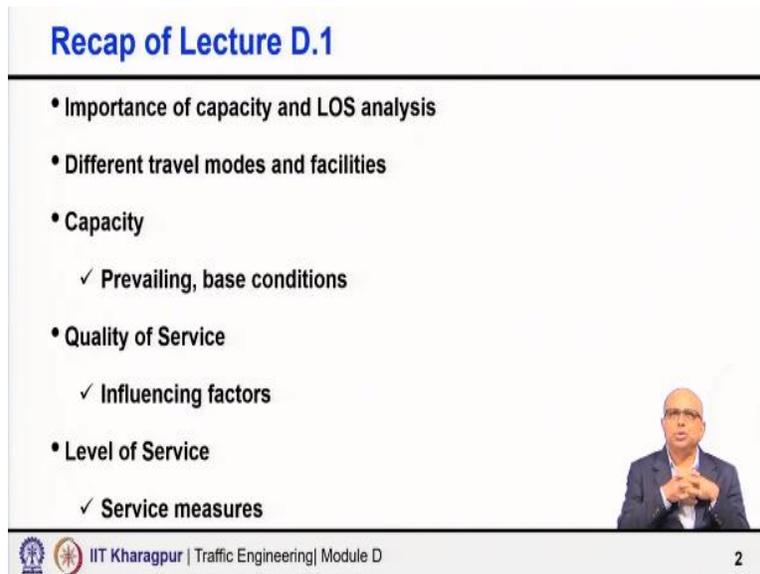
Traffic Engineering
Professor Bhargab Maitra
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture 17

Analysis of Basic Freeway and Multi-Lane Highway Segments (as per HCM, 2016) -I

Welcome to module D lecture 2, in this lecture we shall discuss about analysis of basic freeway and multi-lane highway segments as per highway capacity manual 2016.

(Refer Slide Time: 0:34)



The slide is titled "Recap of Lecture D.1" in blue text. It contains a bulleted list of topics covered in the previous lecture. A small video inset of Professor Bhargab Maitra is visible in the bottom right corner of the slide content area. The footer of the slide includes the IIT Kharagpur logo and the text "IIT Kharagpur | Traffic Engineering | Module D" and the number "2".

- Importance of capacity and LOS analysis
- Different travel modes and facilities
- Capacity
 - ✓ Prevailing, base conditions
- Quality of Service
 - ✓ Influencing factors
- Level of Service
 - ✓ Service measures

In lecture 1 I mentioned to you about why we need to carry out capacity analysis, what answers we can get, why we need to carry out level of service analysis, then different modes and different travel facilities, the LOS may vary, also mentioning to you the concept of capacity, the concept of base conditions, how the prevailing conditions things are different from base conditions, then the various factors which may influence the quality of service and then mention to you about six levels of service and different service measures.

With this background today we are going to discuss about basic freeway and multi-lane highway segments, how to carry out capacity and level of service analysis as per highway capacity manual 2016.

(Refer Slide Time: 1:44)

Introduction

- Basic freeway and multilane highway segments are analyzed as **uninterrupted flow facilities**
 - ✓ **Basic freeways** are **access-controlled** facilities: Grade-separated cross streets and ramp movements to access the facility 
 - ✓ **Multilane highways**: Uninterrupted flow exists when there are **no traffic control devices** that interrupt traffic and where **no platoons** are formed by upstream traffic signals 



IIT Kharagpur | Traffic Engineering | Module D 4

Basic freeway and multilane highway segments are analyzed for this purpose as uninterrupted flow facilities, they are uninterrupted flow facilities, basic freeways are access controlled therefore, grid separated cross streets and ramp movements are there to access the facilities, there is no traffic signal, no uncontrolled access.

So, obviously these facilities are uninterrupted flow facilities, multilane highways can also be considered, at least those segments can be considered as uninterrupted flow facilities where there are no traffic control devices that interrupt traffic externally and where no platoons are formed by the upstream traffic signals.

So, basically long mid block sections of multilane highways which are away from intersections or signalized intersections which occasionally may come on multilane highways and these sections or segments are not within the influence area of traffic signals and these are the sections which do not have influence of any external factors such as traffic signals or traffic signs, stop controlled intersection or yield control intersections that kind of traffic sign influence.

So, these sections can also be considered as uninterrupted flow facilities, so our analysis for basic freeway and multilane highway segments are considering the segments logically as uninterrupted flow facilities.

(Refer Slide Time: 3:55)

Introduction

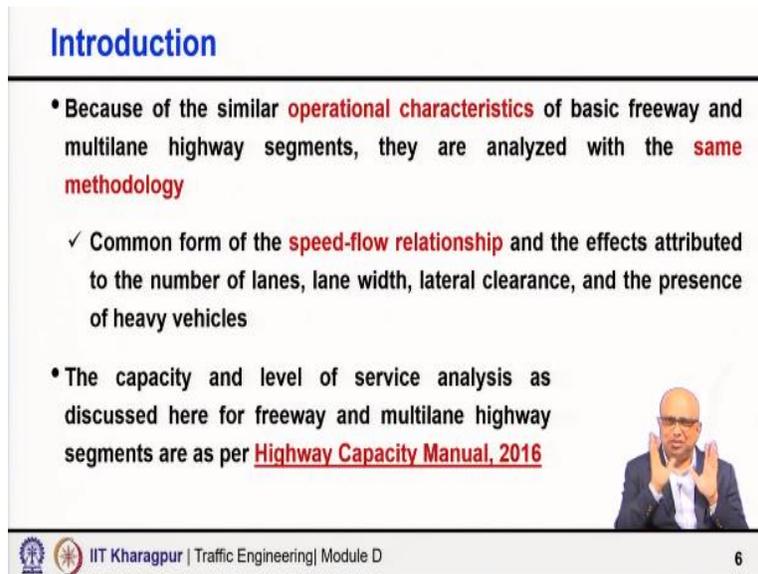
- Segments included for **Capacity and level of service (LOS)** analysis
 - ✓ Outside the **influence** of merging, diverging, and weaving manoeuvres
 - ✓ Outside the influence of **signalized intersections (for Multilane highways)**
- All analyses are applied to segments with **uniform characteristics**
 - ✓ Same geometric and traffic characteristics
 - ✓ Constant demand flow rate



Second, we are analyzing those segments for capacity and level of service which are outside the influence of merging, diverging and weaving maneuvers, because the impact and interactions will be somewhat different in those sections which are in close proximity of merging, diverging or weaving sections and also as I have said earlier, I am repeating it again particularly for multilane highways that these segments are outside the influence of signalized intersections.

All analysis are applied to segments of freeways and multilane highways which are with uniform characteristics, that means when we are saying that we are analyzing it for this segment, then this segment has same geometric and traffic characteristics within it and also the constant demand flow rate, those are some kind of basic assumptions.

(Refer Slide Time: 5:14)



Introduction

- Because of the similar **operational characteristics** of basic freeway and multilane highway segments, they are analyzed with the **same methodology**
- ✓ Common form of the **speed-flow relationship** and the effects attributed to the number of lanes, lane width, lateral clearance, and the presence of heavy vehicles
- The capacity and level of service analysis as discussed here for freeway and multilane highway segments are as per **Highway Capacity Manual, 2016**

IIT Kharagpur | Traffic Engineering | Module D

6

Because of the similar operational characteristics of basic freeway and multilane highway segments, yes, they are different facilities but they have similar operational characteristics and therefore, the same methodology is applied for capacity and analysis of levels of service.

Methodology and approach is same, when I say similar operational characteristics means common form of speed flow relationship, exactly speed flow relationship is not same, obviously that will vary, even one freeway to another freeway or one multilane highway to another multilane and highway the exact relationship may vary but the form of relationship is same and the effects attributed to factors, such as number of plane, what is the lane width and the effect of lateral clearance, presence of heavy vehicles they are common in both sections or both types of facility.

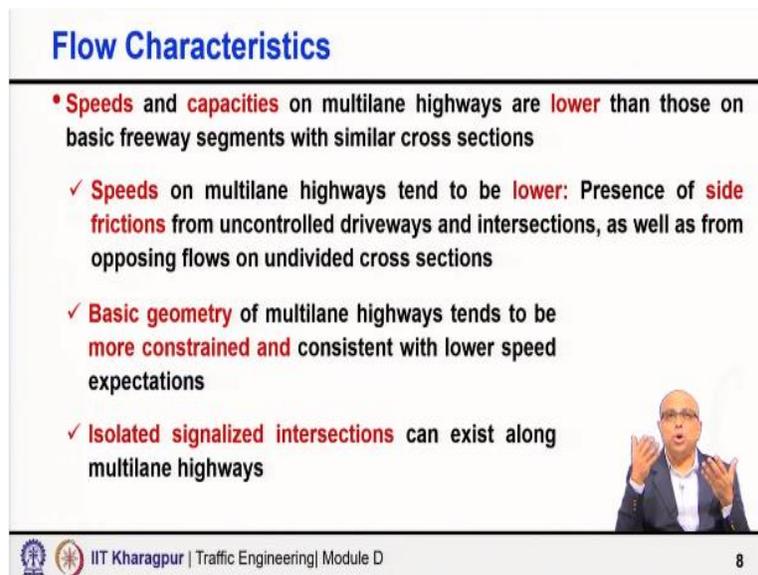
Once again to tell you very clearly that whatever we are going to discuss today and the next two lectures, today is part one of this freeway and multilane segments analysis for capacity and level of service. The analysis what we are going to discuss, the steps, the further assumptions, equations, table, values whatever we are going to say are going to discuss they are all as per highway capacity manual 2016.

I may mention it in other context, I may not mention it every time but right in the beginning let me remind you that the capacity and level of service analysis as discussed here in this lecture and the next two lectures or even subsequent lectures also for other types of facilities like two lane roads, urban roads this all procedure what we are going to discuss these are as per highway capacity manual 2016.

There are different manuals or guidelines, US highway capacity manual is globally well recognized, well known, so that is the procedure what I am going to explain. There are many things which are there in highway capacity manuals, many types of facilities are there, there various types of analysis are presented and its very exhaustive, it is not possible to teach you everything whatever is there in highway capacity manual, maybe I will teach you one, two percent or five percent of it, not even that.

But some very common segments like freeway and multilane highways, two lane roads, urban segments these are the three components, some basic analysis for this segments I am going to discuss under this module. Then we shall also spend little bit of time to discuss about Indian highway capacity manual in though HCM, some of the provisions and some of the approaches very briefly I am going to discuss towards the end of this module.

(Refer Slide Time: 9:22)



Flow Characteristics

- **Speeds and capacities** on multilane highways are **lower** than those on basic freeway segments with similar cross sections
- ✓ **Speeds** on multilane highways tend to be **lower**: Presence of **side frictions** from uncontrolled driveways and intersections, as well as from opposing flows on undivided cross sections
- ✓ **Basic geometry** of multilane highways tends to be **more constrained and** consistent with lower speed expectations
- ✓ **Isolated signalized intersections** can exist along multilane highways

IIT Kharagpur | Traffic Engineering | Module D

8

Coming back to this freeway and multilane highway segments, the first thing let us try to understand the flow characteristics. Speed and capacities on multilane highways are lower than those on basic freeway segments with similar cross section. I said many things are similar that is why the similar approach is followed but there are differences as well, this is one of the differences in that way, like the speed and capacities of multilane highways are lower. Why?

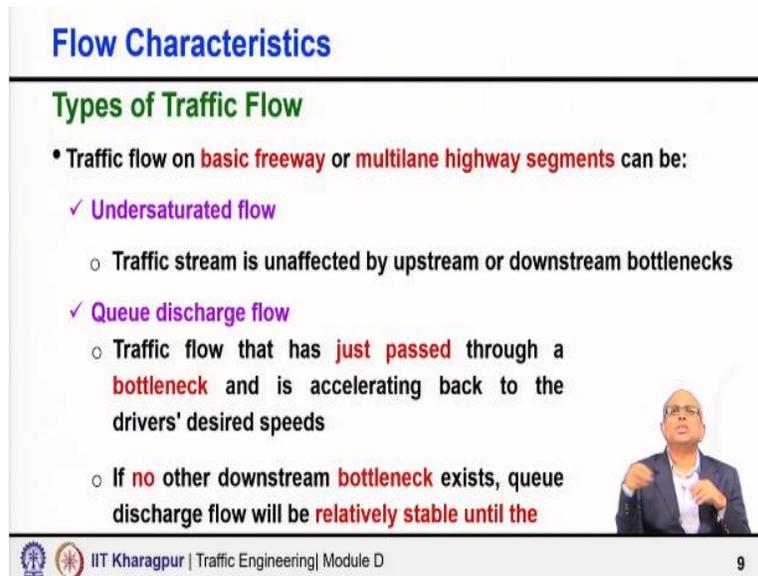
Because speed on multilane highways tend to be lower because of the presence of site friction from uncontrolled drivers and intersections, multilane highways are not access controlled completely, so

there are side frictions, reasonable amount of side friction is present from the uncontrolled drivers and intersection, also from opposing flow especially on undivided cross sections.

The basic geometry of multilane highways tend to be more constrained because you have to understand that and accept that freeways are the highest level of facilities. So obviously, multilane highway is not at the same level, so the basic geometry of multilane highways tend to be more constrained and therefore, also consistent with lower speed expectation, that is why the speeds are lower.

Third, isolated signalized intersections can exist along multilane highways, although we do not expect it to be at the rate as it is normally expected on an urban arterial or urban roads but isolated signalized intersection can exist, may not be at frequent interval but sometimes it can exist, so the speed environment also is not going to be as high as it is expected on freeway segments because freeways are completely access controlled.

(Refer Slide Time: 11:42)



Flow Characteristics

Types of Traffic Flow

- Traffic flow on **basic freeway** or **multilane highway segments** can be:
 - ✓ **Undersaturated flow**
 - Traffic stream is unaffected by upstream or downstream bottlenecks
 - ✓ **Queue discharge flow**
 - Traffic flow that has **just passed** through a **bottleneck** and is accelerating back to the drivers' desired speeds
 - If **no other downstream bottleneck** exists, queue discharge flow will be **relatively stable until the**

IIT Kharagpur | Traffic Engineering | Module D 9

Let us look at the type of flows that we find on freeways, basic freeway and multilane segments. Three types of flow are possible, one is under saturated flow. What is under saturated flow? We are calling by name under saturated, so traffic stream is basically unaffected by upstream or downstream bottleneck. So, whatever we are getting for a segment that flow is unaffected by upstream or downstream bottleneck, so it is under saturated condition.

Second, queue discharge flow, traffic flow that has just passed through a bottleneck and is accelerating back to drivers desired speed that flow state we will call it as queue discharge and when there is no other downstream bottleneck this is a phenomena bottleneck is actually in the upstream but when there is no downstream bottleneck as well then the queue discharge flow will be relatively stable until the queue is fully discharged.

Now, this again I have discussed it on earlier occasions. Say, you have a three lane road and then you have a two lane road, now if the demand which is coming from the three lane road if it is more than the two lane road capacity then not all the flow can pass through this two lane section, so there will be bottleneck which will start at the junction of this two lane and three lane at that boundary and that accumulation of flow will occur and proceed towards upstream.

So this queue will be there at that time, there will be queue in section a and starting from the junction of section a and section b, section b is now the two lane road and it will proceed towards upstream of section a. Under that situation whatever discharge will get through section b it is called queue discharge flow.

I will mention it again in the next slide, also I have indicated to you earlier that this queue discharge rate is generally slightly lower than the capacity, because it is getting discharged from the queue or forced flow condition, the rate is normally slightly lesser than the capacity. So, the traffic flow that has just passed through bottleneck and is accelerating back to drivers desired speed think of section b there you will get the queue discharge.

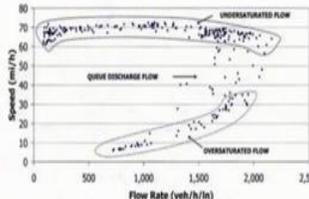
Next point what I am saying if there is further a bottleneck in the downstream, then further such kind of queue may form downstream and that may affect this discharge flow rate what we were getting. So, what I am saying there is no other downstream bottleneck and if so queue discharge flow will be relatively stable till the time the demand, original demand which is approaching through section a is lower than the capacity of this section b and till the time the whole accumulated vehicles are discharged and this the force flow condition actually is vanished completely, till that time you will get a relatively stable discharge.

(Refer Slide Time: 16:14)

Flow Characteristics

queue is fully discharged

- ✓ Oversaturated flow
- Conditions within a queue that has backed up from a downstream bottleneck
- Reflects consequences of a downstream problem and not prevailing conditions of the segment



Source: HCM, 2016

IIT Kharagpur | Traffic Engineering | Module D

10

Third, over saturated flow, when the forced flow condition exists what I just described before the bottleneck section, upstream, immediately upstream of the bottleneck section as more than two lane demand is approaching, the queue is getting formed and within that queue what will be the flow state it will be actually forced flow condition, so the discharge will be over saturated flow, that flow we can call over saturated flow.

So, conditions within a queue just immediately upstream of b that has backed up from a downstream bottleneck, it is increasing as long as the inflow is higher than the capacity of this bottleneck, so conditions within a queue that has backed up from a downstream bottleneck and interestingly this is very important an interesting point, it reflects consequences of a downstream problem and not prevailing condition of the segment.

Although there the traffic is actually in forced flow condition and the flow is over saturated flow, but there is no problem in that section, that section is having three lane capacity and the further upstream also three lane capacity, further upstream there is no issue traffic is flowing smoothly but whatever you are getting upstream of immediately upstream of section b it is because of the capacity problem in section b, but the condition is going to over saturated flow you are getting or forced flow you are getting in section a which is immediately upstream of this bottleneck.

So, it reflects consequences of a downstream problem in section b at the beginning of section b and junction of section b and section a and not prevailing condition of the segment, that means not a problem of actually section a.

(Refer Slide Time: 18:35)

Flow Characteristics

- **Important terms** related to freeway capacity: Freeway Breakdown, Recovery, Prebreakdown Flow Rate and Postbreakdown Flow Rate

Freeway Breakdown

- Describes **transition** from uncongested to congested conditions
- Formation of queues upstream of the bottleneck and the **reduced prevailing speeds** make the breakdown evident
- Breakdown event on a freeway bottleneck is defined as **sudden drop in speed** of at least 25% below free flow speed (FFS) for sustained period of at least 15 min that results in queuing upstream of bottleneck (**HCM 2016**)



IIT Kharagpur | Traffic Engineering | Module D 11

Flow Characteristics

Recovery

- Recovery from breakdown event and resulting oversaturated conditions happens when the **average speeds** (or occupancies) **reach** prebreakdown conditions for a **minimum duration of 15 min**
- Recovery is the **inverse** of breakdown
- Breakdown recovery on a freeway bottleneck is return of the prevailing speed to **within 10% of FFS** for a sustained period of **at least 15 min**, without the presence of queuing upstream of bottleneck (**HCM 2016**)



IIT Kharagpur | Traffic Engineering | Module D 12

Important terms, there are several important terms related to freeway capacity, let us try to understand those. For example, freeway breakdown, recovery, pre breakdown flow rate and post breakdown flow rate. Let us try to understand this four terminologies because they are important and in the context of our discussion about capacity.

What is freeway breakdown? It describes transition from uncongested to congested condition, the traffic flow is increasing, say from early morning, at certain point the operation is bottleneck starts forming and the operation is actually changing from steady state to force flow or unstable condition.

So, it describes that when the transition is happening from this uncongested to congested condition or to force flow condition that transition is happening flow state is changing that is then we call that there is a freeway breakdown, so it will be evident how we can recognize that a freeway breakdown has occurred because we can see there will be formation of queues upstream of that bottleneck queue start forming.

The moment queue start forming at this take the same example of section a and section b, section a three lane capacity, section b two lane capacity and let us consider the demand is increasing slowly right from the morning and at some point it is two lane and then it is going higher than that, the moment it is going higher than two lane the freeway breakdown is happening because you start getting queue.

So you can see that formation of queue is happening at the upstream of the bottleneck and the reduced prevailing speed, with reduced prevailing speed, speed will come down that make the breakdown evident.

As per highway capacity manual, please note this point carefully, breakdown event on a freeway bottleneck is defined when we say specifically breakdown has happened conceptually this is correct, but when we say as per highway capacity manual breakdown has happened as sudden drop in speed at least 25 percent below free flow speed whatever is the free flow speed, the speed has now gone or dropped, get dropped at least 25 percent below free flow speed for sustained period, not that suddenly it has gone and then come back, no.

We say freeway breakdown only when there is a sudden drop in speed of at least 25 percent below speed free flow speed for a sustained period of at least 15 minute, that results in queuing upstream of bottleneck, very clear, so at least 25 percent drop in the speed below the free flow level, sudden drop and that drop remains for at least 15 minutes.

Recovery, if there is a breakdown there will be also a recovery because when the demand flow is slowly going down and some point it will also go down and will be less than the capacity of this two lane road or whatever is the queue discharge below that level even. So, that is where the recovery will start slowly, so recovery from breakdown event and resulting over saturated condition when the breakdown has happened, the operation has gone to over saturated condition, so the flow whatever you get is the over saturated flow.

Now, the recovery from breakdown even and resulting over saturated condition happens when the average speed of course, also the occupancies reach pre breakdown condition it has gone back for a minimum duration of again 15 minutes. So, recovery is in that way the inverse of breakdown and as per highway capacity manual when we say the breakdown has occurred, breakdown recovery on a highway bottleneck is return of the prevailing speed which has gone below 25 percent.

At least below 25 percent drop in speed, of at least 25 percent below free flow speed that has now come up and is returned to the prevailing speed to within 10 percent of the free flow speed again same for a sustained period of at least 15 minutes, without the presence of queuing upstream of bottleneck.

So, it went to break down when queue started forming up and operation went to congested condition or force flow condition and was sustained for 15 minute with a speed drop of at least 25 percent below the free flow speed and now when it comes back within 10 percent prevailing speed to within 10 percent of FFS and sustained period of 15 minute and without the presence of queuing upstream or bottleneck then we call recovery has happened.

(Refer Slide Time: 25:05)

Flow Characteristics

Prebreakdown Flow Rate

- Flow rate that **immediately precedes** the occurrence of a **breakdown event**
- Expressed in units of **passenger cars per hour per lane (pc/h/ln)** by converting trucks and other heavy vehicles into an equivalent passenger car traffic stream
- Prebreakdown flow rate is the 15-min average flow rate immediately before breakdown event (**HCM 2016**). May be called as the **capacity**



IIT Kharagpur | Traffic Engineering | Module D 13

Flow Characteristics

Postbreakdown Flow Rate

- **Queue discharge flow rate or average discharge flow rate**
- Usually **lower than** prebreakdown flow rate, resulting in **significant loss of** freeway throughput during **congestion**
- Average flow rate during **oversaturated conditions** (i.e., during the time interval after breakdown and before recovery) (**HCM, 2016**)



IIT Kharagpur | Traffic Engineering | Module D 14

Now, the pre breakdown flow rate, before it breaks down what is the flow rate, flow rate that immediately precedes, carefully note it, the flow is going up, the demand is going up and there is a bottleneck. So, before it goes to breakdown state, freeway breakdown state the free flow rate immediately precedes the occurrence of breakdown event.

It is expressed as usual in units of passenger car, so passenger car hour, per hour per lane not that the actual stream will have only car, there may be effect of truck, heavy vehicle so you convert them using appropriate equivalency value and express every traffic in terms of passenger car and totally in terms of passenger car per hour per lane.

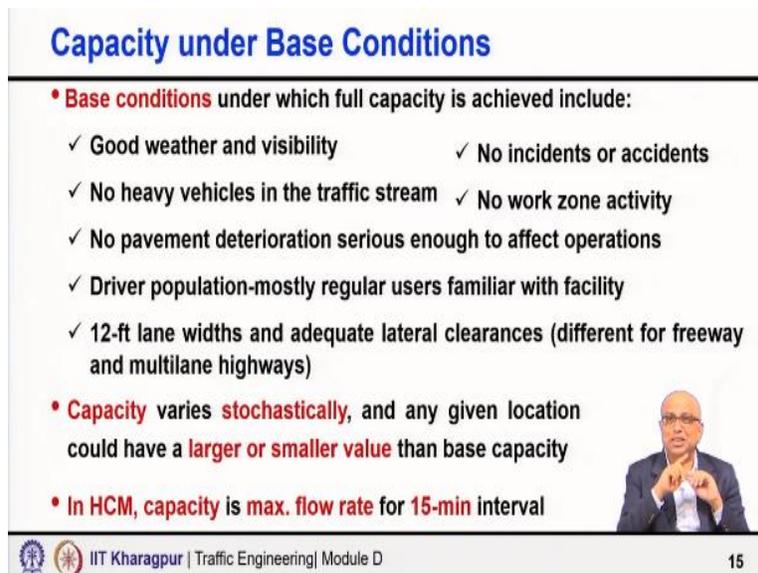
Now, obviously pre breakdown flow rate is basically the 15 minute average flow immediately before the breakdown event, you may call it as the capacity that is the time you will get the capacity but immediately then break down.

Post breakdown flow rate, queue discharge flow rate or average queue discharge flow rate, this is when the queue has been formed and whatever we are getting now in section b, the two lane capacity section queue has been formed in the three lane section because of the excess demand, excess to two lane capacity and whatever then when the queue is there whatever the flow we are getting through section b that is actually queue discharge flow rate or average discharge flow rate.

And this is definitely going to be somewhat lower than what you got in the pre breakdown flow rate, that is called the queue discharge flow rate and usually lower than the pre breakdown flow rate, resulting in significant loss of freeway throughput during congestion.

Average flow rate during over saturated condition we are taking that is during the time interval after breakdown and before recovery, what is the average flow rate that we consider as post breakdown flow rate.

(Refer Slide Time: 27:52)



Capacity under Base Conditions

- **Base conditions** under which full capacity is achieved include:
 - ✓ Good weather and visibility
 - ✓ No incidents or accidents
 - ✓ No heavy vehicles in the traffic stream
 - ✓ No work zone activity
 - ✓ No pavement deterioration serious enough to affect operations
 - ✓ Driver population-mostly regular users familiar with facility
 - ✓ 12-ft lane widths and adequate lateral clearances (different for freeway and multilane highways)
- Capacity varies **stochastically**, and any given location could have a **larger or smaller value** than base capacity
- In HCM, capacity is **max. flow rate** for 15-min interval

IIT Kharagpur | Traffic Engineering | Module D

15

Now, capacity as I have indicated in lecture one is defined for certain base condition, almost like idealized condition, here for freeway and multilane highway segments the base condition is again defined based on number of things, say good weather and visibility, no incidence or accidents, no heavy vehicle in the traffic stream, all are car, no work zone activity, you have not blocked a part

of the road and doing the maintenance work, no pavement deterioration serious enough to affect operation, pavement condition is generally good.

Driver population they are regular users and therefore, familiar with the facility, the driver population is again homogeneous in that sense and highway capacity manual as they use the unit 12 feet lane widths and adequate lateral clearance, I have not mentioned here because lateral clearance is slightly different for base condition in for freeway segments and multilane highway segments but all these are there, that defines my base condition or almost like ideal environment.

Now, as capacity varies stochastically, yes, you get the discharge but it is not exactly one value, there are variations, even for the same road section and similar type of event every date sometime it is happen you are getting somewhere but it may not get, you may not get exactly the same discharge, capacity very stochastically and any given location therefore, could have a larger or smaller value than the base capacity, not that always prevailing you will get lower some points, you may get a few points on certain occasion may get marginally even higher but that is not a contradiction.

I have said it earlier also the reasonability, when we defined what is capacity which you can observe repeatedly that steady flow we are talking about, it is not the ever highest flow which may be observed, so it is within the capacity definition, within that premises.

In highway capacity manual whenever we are expressing maximum flow rate or capacity, we are expressing, it considering 15 minute interval this has again meaning because if you take instead of 15 minute if you take 5 minute your maximum flow rate may be different.

(Refer Slide Time: 30:51)

Capacity under Base Conditions

- **Capacities** represent an average flow rate across **all lanes**. Individual lanes could have higher stable flows

Table 4.1: Base Capacity Values for Basic Freeway Segments & Multilane Highway Segments

FFS (mi/h)	Capacity of Basic Freeway Segments (pc/h/ln)	Capacity of Multilane Highway Segments (pc/h/ln)
75	2400	NA
70	2400	2300*
65	2350	2300*
60	2300	2200
55	2250	2100
50	NA	2000
45	NA	1900

Notes: 1. NA = Not available
2. *Capacities for multilane highways with 65 & 70 mi/h FFS are extrapolated and not based on base data



IIT Kharagpur | Traffic Engineering | Module D 16

So, capacities represents an average flow rate across all lanes, sometimes lane wise also it may vary but what we are representing is the average flow rate across all lanes, individual lanes could have higher stable flow depending on the condition or operation and as given in highway capacity manual, I have reproduced this table to give you a feel about how the capacity changes.

Capacity depends on the free flow speed, so these are the values of free flow speed in miles per hour and depending on that what would be then the capacity of basic freeway segment in passenger car per hour per lane and the right most column indicates what would be the capacity for multilane highway segment, passenger car per hour per lane.

Now, you can generally see for the similar free flow speed because of the explanations given earlier, the capacity of basic freeway segments will be higher as compared to the capacity of multilane highway segments, the reasons I have said so you can see that suppose 2250-2100, 2300-2200 and these two values are actually extrapolated and not based on the actual data. So, similarly it is a free flow state speed on basic freeway less than 50 or even 45 mile per hour could not be observed, so these data are not available.

(Refer Slide Time: 32:33)

Speed-Flow Relationship

- **Characteristics** such as lane width, lateral clearance, median type, and (for multilane highways) access point density will affect **FFS** of the facility
- Under **base conditions**, **speed-flow curves** for uninterrupted flow on **basic freeway** and **multilane highway segments** follow a **common form**:
 - ✓ **Constant speed range**: Speed remains constant over a range of flow rates from **zero** to a **breakpoint value BP**. Over this range, the speed is equal to **FFS**
 - ✓ **Decreasing speed range**: From **BP** to capacity, speed decreases from **FFS** in a generally parabolic relationship



IIT Kharagpur | Traffic Engineering | Module D 17

Now, continuing the discussion to speed flow relationship. Characteristics such as lane width, lateral clearance, lateral clearance median time and for multilane highway access point density, this access point density will not come into picture for freeway because there is no uncontrolled access, so it will be there only for the multilane highway, all this will affect the free flow speed of the facility. So, under base condition speed flow curves for uninterrupted flow on basic freeway and multiple or multilane highway segments follow a common form.

Three segments we get, I discussed this somewhat earlier also in another module, module B probably when we talked B or C want to mention to you once again. One, is a constant speed range where the speed remains constant over a range of flow rate from zero to a break point value, it does not start dropping immediately, zero this one and as it increases little bit flow the speed is dropping that does not happen, it remains more or less same free flow speed is maintained up to certain break point value, beyond this break point it is something like parabolic, that is the decreasing speed range from BP, break point to capacity speed decreases from free flow speed in a generally parabolic relationship.

(Refer Slide Time: 34:23)

Speed-Flow Relationship

✓ **Capacity:** In all cases, capacity occurs when the traffic stream density **D is 45 pc/mi/ln**

Source: HCM, 2016

General form of speed-flow curves on basic freeway and multilane highway segments

IIT Kharagpur | Traffic Engineering | Module D 18

Speed-Flow Relationship

- **Characteristics** such as lane width, lateral clearance, median type, and (for multilane highways) access point density will affect **FFS** of the facility
- Under **base conditions**, **speed-flow curves** for uninterrupted flow on **basic freeway** and **multilane highway segments** follow a **common form**:
 - ✓ **Constant speed range:** Speed remains constant over a range of flow rates from **zero** to a **breakpoint value BP**. Over this range, the speed is equal to **FFS**
 - ✓ **Decreasing speed range:** From **BP** to capacity, speed decreases from **FFS** in a generally parabolic relationship

IIT Kharagpur | Traffic Engineering | Module D 17

Then the third here important point is capacity in all cases occur when the traffic density is 45 passenger curve per hour per lane, so you can see that three segment, one is this straight one, although the flow is increasing speed does not increase up to this break point, so zero to break point flow rate speed is free flow speed, no drop practically, beyond the earlier assumption was from here itself would start following some kind of parabolic relationship, speed drop happens but no here up to breakpoint that is one segment, that is called constant speed range.

Then as I have said decreasing speed range, it is this segment is the decreasing speed range and then the capacity occurs when the density is 45 passenger car per hour, speed and flow is known so the density can also be plotted.

(Refer Slide Time: 35:27)

Speed-Flow Relationship

- The general analytic form of the speed-flow relationship is given by HCM (2016)
 - $S = FFS_{adj}$ for $v_p \leq BP$ 4.1 (a)
 - $S = \frac{FFS_{adj} - (FFS_{adj} - \frac{c_{adj}}{D_c})(v_p - BP)^a}{(c_{adj} - BP)^a}$ for $BP < v_p < c$ 4.1 (b)

Where S = mean speed of traffic stream under base conditions (mi/h)

v_p = adjusted demand flow rate (pc/hr/ln)

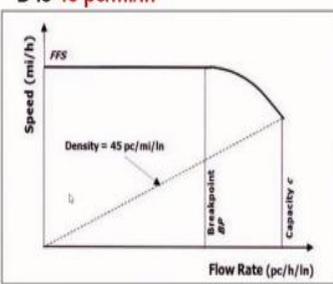
Other variables are as given below



 IIT Kharagpur | Traffic Engineering| Module D 19

Speed-Flow Relationship

✓ **Capacity:** In all cases, capacity occurs when the traffic stream density D is 45 pc/mi/ln



Source: HCM, 2016

General form of speed-flow curves on basic freeway and multilane highway segments



 IIT Kharagpur | Traffic Engineering| Module D 18

Then the generalized analytic form of the speed flow relationship is given by highway capacity manual, it gives it how you express the speed in this range up to break point same a constant value, that is what is there it is free flow speed adjusted when the flow is less than the break point flow and beyond break point up to capacity it is some kind of parabolic relationship, this part and the

equation is given here and what all terminology we are using like v_p is the adjusted demand flow rate and all other variables are described here.

(Refer Slide Time: 36:07)

Speed-Flow Relationship

Table 4.2: Speed-Flow Curve Parameters as per HCM (2016)

Parameter	Definition and Units	Basic Freeway Segments	Multi-lane Highway Segments
FFS	Base segment free-flow speed (mi/h)	Measured or predicted	Measured or predicted
FFS_{adj}	Adjusted free-flow speed (mi/h)	$FFS_{adj} = FFS \times SAF$	No adjustments
SAF	Speed adjustment factor	Locally calibrated/estimated SAF = 1.00 for base conditions	1.00
c	Base segment capacity (pc/h/ln)	$c = 2200 + 10(FFS - 50)$ $c \leq 2400$ $55 \leq FFS \leq 75$	$c = 1900 + 20(FFS - 45)$ $c \leq 2300$ $45 \leq FFS \leq 70$
c_{adj}	Adjusted segment capacity (pc/h/ln)	$c_{adj} = c \times CAF$	No adjustments



IIT Kharagpur | Traffic Engineering | Module D 20

For example, free flow speed can be measured or predicted for both freeway segment and multilane highway segment. Adjustment is done actually for freeway segment using this SAF speed adjustment factor and this could be locally calibrated and C is the base segment capacity how we can express it a formula is given, so you know $2200 + 10 \times (FFS - 50)$, so higher the free flow speed you will get higher capacity both cases but here the limiting value is 2400, here C has to be less than 2300, speed ranges are given and how further the capacity can be adjusted for the basic freeway segment using capacity adjustment factor.

(Refer Slide Time: 37:03)

Speed-Flow Relationship

Parameter	Definition and Units	Basic Freeway Segments	Multi-lane Highway Segments
CAF	Capacity adjustment factor (decimal)	Locally calibrated/estimated CAF = 1.00 for base conditions	1.00
D_c	Density at capacity (pc/mi/ln)	45	45
BP	Break point (pc/h/ln)	$BP_{adj} = [1000 + 40 \times (75 - FFS_{adj})] \times CAF^2$	1400
a	Exponential calibration parameter (decimal)	2.00	1.31

- **CAF and SAF** are calibration parameters to adjust for local conditions. They are provided only for basic freeway segments, since **no empirical research** exists for equivalent capacity-reducing effects on **multilane highways**




IIT Kharagpur | Traffic Engineering | Module D
21

Speed-Flow Relationship

- The general analytic form of the speed-flow relationship is given by HCM (2016)

$$S = FFS_{adj} \text{ for } v_p \leq BP \quad \dots\dots\dots 4.1 (a)$$

$$S = \frac{FFS_{adj} - (FFS_{adj} - \frac{c_{adj}}{D_c})(v_p - BP)^a}{(c_{adj} - BP)^a} \text{ for } BP < v_p < c \quad \dots\dots 4.1 (b)$$

Where S = mean speed of traffic stream under base conditions (mi/h)

v_p = adjusted demand flow rate (pc/hr/ln)

Other variables are as given below




IIT Kharagpur | Traffic Engineering | Module D
19

This capacity adjustment factor how you can calibrate the capacity for local condition, density at capacity is D_c which is 45 passenger car per lane, same for the freeway and multilane highway, the same value, then the break point how you can calculate for multilane highway it is always 1400 and for freeway you can calculate using a free flow speed value so and the exponent the b this equation, sorry, a in this equation that what would be the value of a, that is given here the exponential calibration parameter it is 2 for basic freeway segment and multilane highway is taken as 1.31, these are all matter of calibration.

One thing is interesting the CAF the capacity adjustment factor and SAF which is speed adjustment factor these are calibration parameter to adjust for local condition and they are provided only for basic freeway segment since no empirical research for equivalent capacity reduction effects on multilane highways is available.

(Refer Slide Time: 38:25)

Speed-Flow Relationship

Basic Freeway Segments

Multilane Highway Segments

Source: HCM, 2016

- Curves developed for **FFS values** between **55 & 75 mi/h** for freeways, between **45 & 70 mi/h** for multilane highways
- For **freeways**, BP varies with FFS: as **BP ↑ FFS ↓**
- For **multilane highways**, BP is a constant: **1,400 pc/h/ln**

IIT Kharagpur | Traffic Engineering | Module D

22

Speed-Flow Relationship

Parameter	Definition and Units	Basic Freeway Segments	Multi-lane Highway Segments
CAF	Capacity adjustment factor (decimal)	Locally calibrated/estimated CAF = 1.00 for base conditions	1.00
D_c	Density at capacity (pc/mi/ln)	45	45
BP	Break point (pc/h/ln)	$BP_{adj} = [1000 + 40 \times (75 - FFS_{adj})] \times CAF^2$	1400
a	Exponential calibration parameter (decimal)	2.00	1.31

- **CAF** and **SAF** are calibration parameters to adjust for local conditions. They are provided only for basic freeway segments, since **no empirical research** exists for equivalent capacity-reducing effects on **multilane highways**

IIT Kharagpur | Traffic Engineering | Module D

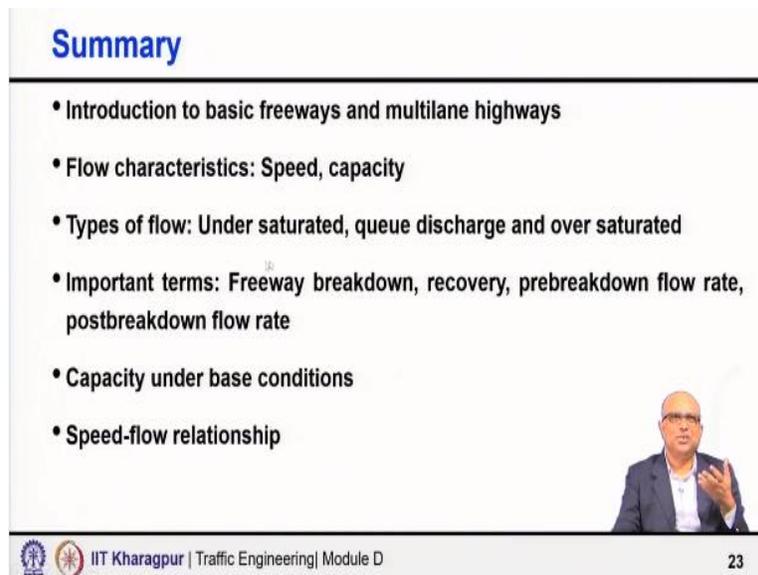
21

The other thing I have shown in here how the speed and flow changes, you can see here for basic freeway segment and multiple highway segment and this is the line which is 45 pcu/ln (passenger car per lane), that is as it is given here, passenger car, sorry, per mile per lane, so that is given here, the one interesting thing is that the cars developed for free flow speed values between 55 and 75

mile per hour for freeways and between 40 to 70 mile per hour for multilane highways as because you know the multilane highway speed is lesser so what is the actual range, observed range or expected range that is used for multi lane highways and for freeways obviously that range is higher.

One thing is very interesting that for freeways segments the lesser the speed the higher is the break point, you can see that for a longer period or for higher flow rate the speed does not change, so lower the speed, free flow speed longer will be the lane of flow up to the BP and for multilane highways this is not, no such change is observed and it is BP is constant at 1400 passenger car per hour per lane.

(Refer Slide Time: 40:04)



Summary

- Introduction to basic freeways and multilane highways
- Flow characteristics: Speed, capacity
- Types of flow: Under saturated, queue discharge and over saturated
- Important terms: Freeway breakdown, recovery, prebreakdown flow rate, postbreakdown flow rate
- Capacity under base conditions
- Speed-flow relationship

IIT Kharagpur | Traffic Engineering | Module D

23

So, what we discussed here is we introduced to you the basic freeway and multilane highway segments, the characteristics, the assumptions, the flow characteristics, the speed and capacity also, the type of flow I indicated as under saturated, queue discharge and over saturated and some of the important terms like freeway, breakdown, recovery, pre breakdown flow rate, what is post breakdown flow rate and so on.

Then what are the capacities under base conditions for freeway segments and multilane highway segments and how the speed flow relationship is there, the constant and then you know changing following a parabolic relationship and then 45 passenger car per lane and per mile, per mile per lane. So here I stop, I shall continue in the next class, go further about the actual how further analysis can be done, thank you so much.