

Traffic Engineering
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Lecture 14
Queueing Analysis - I

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**NPTEL Online Certification Course on
Traffic Engineering**

Module C
Shock Wave and Queueing

Week 3: Lecture C.4
Queueing Analysis-I



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Recap of Lecture C.3

- Example Problems on Quantitative Analysis of Shockwaves
- Shockwave Propagation
 - ✓ Small discontinuity in traffic density
 - ✓ Complete stopping situations
 - ✓ Starting situations
- Example Problem on Shockwave Propagation



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Welcome to module C, lecture 4. In this lecture, we shall discuss about queueing analysis. In lecture 3, we took up two example problems to explain you the quantitative analysis of shockwaves. Then also discussed about shockwave propagation, three scenarios, small discontinuity in traffic densities, then complete stopping situations and then starting situations. Then we took an example problem to show you sample calculations, how we can calculate various parameters under these three scenarios.

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Queueing Analysis

Introduction

- One of the greatest concern to traffic engineers is the high congestion on roads and highways, especially during peak hours
- Traffic congestion results in **formation of queues** on on-ramp and off-ramp facilities in expressways, at signalized and unsignalized intersections, arterials, etc.
- Traffic queues in peak periods cause considerable amount of **delay and loss of performance**
- An understanding of the process that leads to occurrence of queues and subsequent delays is essential for the proper analysis of the effect of queueing

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With this background, today, we switch over to the next topic which is queueing analysis. One of the greatest concern to traffic engineer is the high congestion level on roads and highways. Specially we find such high level of congestion during the peak hours or the peak period. And the loss is enormous due to congestion and queueing.

The congestion results in the formation of queues on several facilities such as on-ramp, off-ramp, in the context of expressway or controlled access facilities at signalized and unsignalized intersections, arterials etcetera. And we know that traffic queue and congestion at peak period cause significant delay, loss of performance and overall economic loss due to congestion and queueing is also enormous.

So, an understanding of the process that leads to the occurrence of queues and subsequent delays, loss all other things is essential for the proper analysis of the effect of queueing so that is our interest, while we discuss this topic queueing and analysis of queueing.

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Queueing Analysis

- Traffic demand, observed traffic volume and capacity: **Three key aspects** related to queuing
- **Traffic Demand:** The number of vehicles desires to pass a point in the road in an hour (veh/hr. or persons/hr.)
- **Observed Traffic Volume:** The number of vehicles that actually passes a point on the road in an hour (veh/hr. or persons/hr.)
- **Traffic Capacity:** The maximum volume that a particular point or segment of a facility can accommodate (veh/hr. or persons/hr.)



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When we are talking about the analysis of queueing or even the demand supply part, the imbalance, the congestion, the queueing, the three aspects are very very important. One is what is the traffic demand? What is the observed traffic volume? And then, what is the capacity of the facility? So, one end the capacity another end observed traffic volume and then what is the real traffic demand?

So, let us quickly understand these terminologies more clearly before we proceed further. First traffic demand, traffic demand normally or in a simple way can be defined as the number of vehicle desires to pass a point of the road in an hour. The key word here is desires to pass, the number of vehicle desires to pass a point in the road in an hour and we express it in terms of vehicle per hour or person per hour. What is the observed traffic volume?

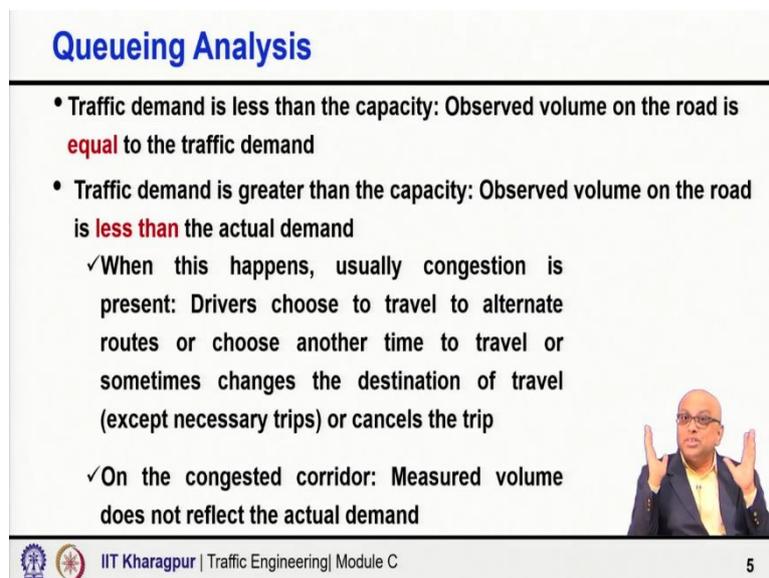
The actual number of vehicles that is passing a point of the road again in an hour and can be expressed in terms of vehicle per hour or even sometimes the observed volume may be also in passengers per hour, overall passenger. I mean when we say traffic volume obviously the measure has to be, measurements have to be in terms of traffic only but similar expression is possible even in terms of number of persons per hour, we can express that also.

So, here the keyword is actually or the portion that is actually passes a point. Desires to pass a point is the demand, actually passes a point is the real observed volumes. What we are observing in the field. Traffic capacity on the other hand is the maximum volume that a particular segment or point on a facility can accommodate. What is the maximum volume?

So, here that is the maximum volume that is very important, the maximum volume that a facility can accommodate. Again, normally when we say traffic or vehicle then obviously vehicle per hour but capacity can also be expressed in terms of number of persons per hour.

So, there are three aspects as I said, one way number of vehicles desires to pass that is the demand. Actually, passing that is the observed traffic volume and what can be the maximum number that is the capacity, physical system road is a physical system so any physical system will have a capacity so a road also has a capacity.

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Queueing Analysis

- Traffic demand is less than the capacity: Observed volume on the road is **equal** to the traffic demand
- Traffic demand is greater than the capacity: Observed volume on the road is **less than** the actual demand
 - ✓ When this happens, usually congestion is present: Drivers choose to travel to alternate routes or choose another time to travel or sometimes changes the destination of travel (except necessary trips) or cancels the trip
 - ✓ On the congested corridor: Measured volume does not reflect the actual demand

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Now when the traffic demand is less than the capacity that means the actual demand is less than the capacity of the road or capacity of the system. In that case, observed volume is equal to the traffic demand, then this two measurements traffic demand and observed volume will be same because there is no capacity constraint. So, the whole demand, the complete demand can pass through the road. So, whatever we will measure on the field, whatever we will measure in the field is actually the demand.

But when traffic demand is greater than the capacity, in that case the observed volume is not the actual demand because observed volume will be in that case is less than the actual demand because the demand is actually greater than capacity and what theoretically maximum can pass through that section is the capacity flow.

When such kind of situation we face, like the demand is greater than the capacity, then usually congestion is present because traffic state will be very different. We have already discussed

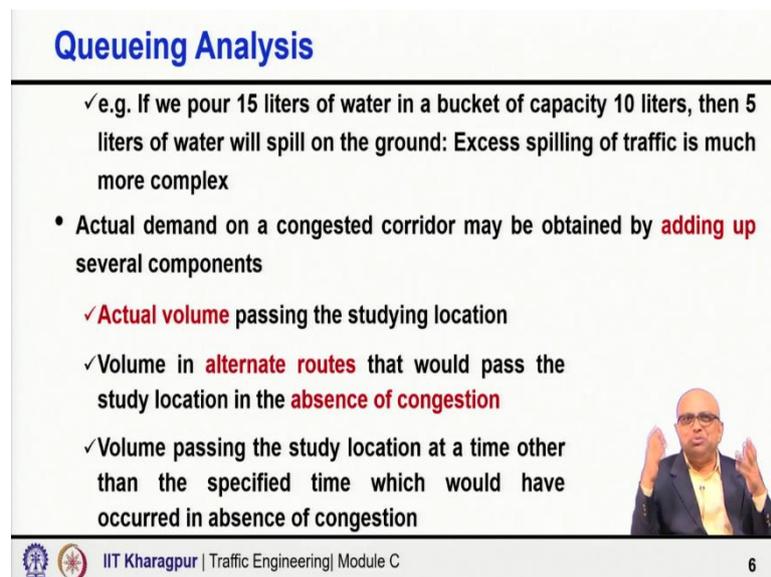
this in module B and also partly in module A, partly in module C itself, in previous lectures. So, you know it.

So, in that case, once the congestion is happening also there will be queueing then drivers choose to travel to alternative route, they may not like to travel on this route because there is no capacity left so they may be forced to travel to some other route or maybe, may choose to travel at some other time or sometimes even change the destination except for necessary trip if it is work trip or education trips you cannot change the destination but if it is a shopping trips, one may choose to go to another shopping destination, if the situation is so.

Or even in worst case, may cancel the trip also. That could be also an extreme situation that wanted to visit a recreational or social trip and that got cancelled as well because of the congestion and because of the traffic, bad traffic situation. So, on congested corridor if we measure the volume and whatever we will be able to measure may not be the actual traffic demand.

Actual traffic demand is something very different and measurements only on that congested corridor where the demand is actually more than the capacity, will not give us the true demand or the actual demand.

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Queueing Analysis

- ✓ e.g. If we pour 15 liters of water in a bucket of capacity 10 liters, then 5 liters of water will spill on the ground: Excess spilling of traffic is much more complex
- Actual demand on a congested corridor may be obtained by **adding up** several components
 - ✓ **Actual volume** passing the studying location
 - ✓ Volume in **alternate routes** that would pass the study location in the **absence of congestion**
 - ✓ Volume passing the study location at a time other than the specified time which would have occurred in absence of congestion

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It is something like very similar that if we have a bucket and the capacity is 10 litre and I want to pour 15 litre of water in that bucket the bucket can only retain 10 litre and the 5 litre will spill over on the ground. But it is similar thing that a system has got a capacity, road also has

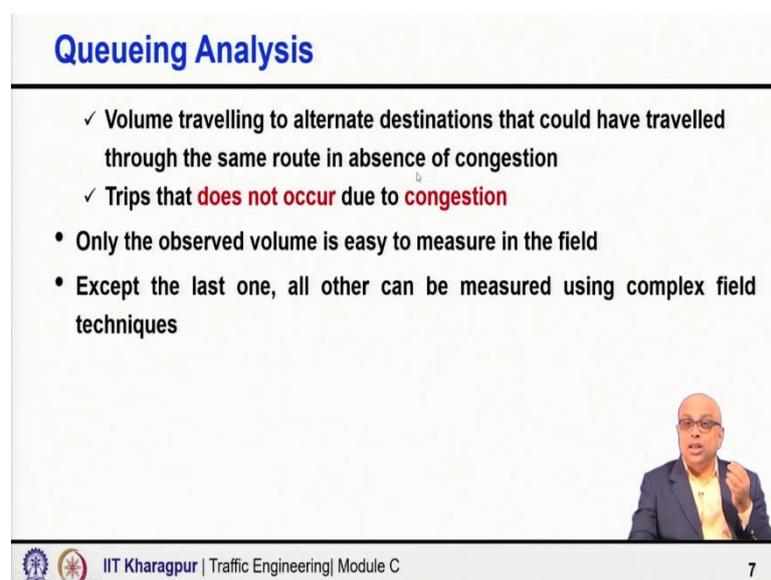
got a capacity like a bucket has got capacity, a road also has got capacity so anything more you try to pass through as we are trying to pour 15 litre waters in a 10-litre bucket.

So, similarly the demand is actually, if it is more only the portion what road can take will get accommodated in the road. And the remaining somewhere or other will be there. Maybe on some other route, some other time, some other destination even cancelled also. All such kind of things will be there.

So, the actual demand on a congested corridor can only be obtained by adding up several components where the demand is more than the capacity. First obviously, a component which is very important and common, is the actual volume passing through the study location or study section because up to capacity in general can be accommodated. So, that is what we can measure.

Then what are the volumes in alternative route that would pass the study section or location in the absence of congestion. So, that is no more here but it is on alternative routes. Similarly, volume passing the study location at a time other than specified time, which would have occurred in the absence of congestion. That means, if the demand is actually more than the capacity at 10 o'clock in the morning, then instead of travelling at 10 o'clock, maybe people will some people will travel at 12 o'clock. So, it will be there at 12 o'clock not at 10 o'clock.

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Queueing Analysis

- ✓ Volume travelling to alternate destinations that could have travelled through the same route in absence of congestion
- ✓ Trips that **does not occur** due to **congestion**
- Only the observed volume is easy to measure in the field
- Except the last one, all other can be measured using complex field techniques

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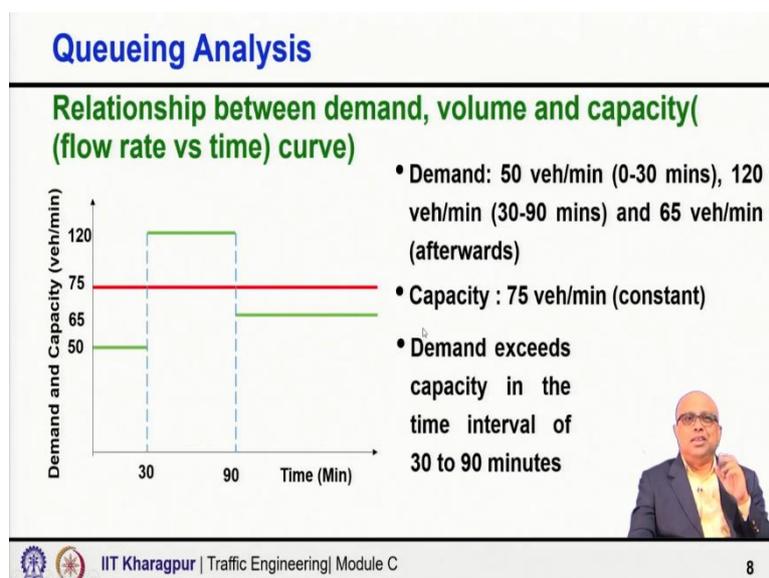
Then volume travelling to alternative destination, as I said, where alternative destination is applicable may not be applicable for shopping, work trip because office location is fixed, you cannot change. School location is fixed you cannot change so educational trips also may not

change. But shopping trips easily can change. Even the recreational trips, destination, alternative destination may be possible.

So, volume travelling to alternative destination not all volumes but that volume which could have travelled through the same route in the absence of congestion. Finally, the last bit, trips that does not or that do not occur due to congestion. Trips that do not occur due to congestion, altogether cancelled. So, if we add up all these components 1, 2, 3, 4, 5 all components if we add, we can then get the actual demand not only by measuring traffic volume on the study location, that is only one component.

Among all these, only the observed volume is easy to measure in the field. What we are observing? It is very easy to measure that even all other components can also be measured somewhere or other through various or well-designed field studies. Except, probably the last one that the trips which do not occur due to congestion.

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Now coming to the relationship between demand volume and capacity. Let us consider, that the travel demand on a given road, actual true demand, on a given road is like this, 50 vehicle per minute for the first 30 minutes, 0 to 30 minutes. Then 120 vehicle per minute for the next 30 to 60 minute, that duration and then comes down to 65 vehicle per minute, afterwards that means beyond 90 minute.

Whereas, the capacity of that section is maybe 75 vehicle per minute and capacity relates to the physical environment, the physical road how much width is available and shoulder is available and all such things will decide what will be the capacity. So, capacity may not change

for a given route over time. Now clearly you can see here the demand exceeds capacity in the time interval of 30 to 90 minute where the demand is actually 120 vehicle and the capacity on the other hand is 75 vehicle per minute.

So, obviously during this period demand exceeds the capacity. See, if you look at the demand first 30 minute this is 50 vehicle, then 30 to 90 minutes 120 vehicle, then comes down to 65 vehicle, all are shown using the green lines and the capacity is constant at 75 vehicle per minute. So, this is the period clearly where the demand is more than the capacity.

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Queueing Analysis

- What is the queue length during the period when demand exceeds capacity? (Area between demand and capacity curve)
 - ✓ (Excess demand- capacity)= $(120-75) \times (90-30) = 2700$ veh
- How long does it take to dissipate the queue after 90 minutes?
 - ✓ (Accumulated queue/ rate of dissipation) = $2700/(75-65) = 270$ min

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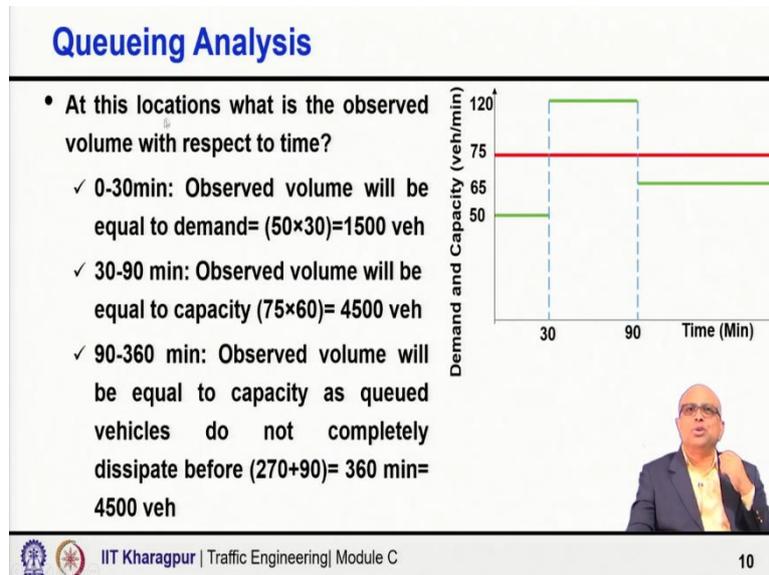
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Now what is the queue length during the period when demand exceeds capacity? It is basically, the area between the demand and the capacity curve. So, that many vehicle, that is basically the excess demand. So, how we can calculate, we can calculate it easily that this is 120, this is 75, so 120 minus 75 and for how much duration, 90 minus 30 so for 60 minute, so we know that excess overall, what is the queue length, how many vehicles will be in the queue, because of this shortfall during this one hour duration 30 minute to 90 minute is 2700 vehicle.

Now, how long it takes to dissipate the queue after 90 minutes? Because after 90 minutes the demand is actually lower than the capacity. So, in general we can assume that the road can discharge at capacity rate at the rate equivalent to capacity and therefore the queue slowly will come down. But how long it will take, this accumulated queue divided by rate of dissipation, what is the rate of dissipation? 75 is the capacity, 65 is the demand so you have 10 excess vehicle can be accommodated every minute from the skewed vehicle, so there are 2700 vehicles so 10 vehicles every minute. So, it will take 270 to clear this queue.

So, beyond 90 minute, what has happened between 30 to 90 minute, it will take 270 minutes to clear that queue or clear that impact.

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Now, at this location, what is the observed volume with respect to time, so demand is something we know clearly, what will happen we know but then with that what is going to be the observed volume? 0 to 30 minute the observed volume will be 1500 vehicles so 50 into 30 minutes so 1500 vehicle.

30 to 90 minute actually we will observe 75 into 90 minus 30 60 so 4500 vehicles and 90 to 360 minute, we say 270 minute it will take to clear that backlog or the queue. So, 90 to 360 minute observed volume will be equal to the capacity as queued vehicles do not completely dissipate before this 270 plus up to this time clock is 90 minute so 270 plus 90 minutes upto 360 minutes.

So, next 270 minute or altogether time clockwise it will go up to 360 minute to clear this backlog vehicles. So, up to that we will also observe that the observed volume will be equal to capacity. So, the observed volume will be equal to capacity from 30 minute to 360 minute. So, now you can compare easily what is the actual demand and what we measured. So, what we measured is not really the actual demand during each of the period.

In the first 30 minutes, it is whatever we observed and whatever we measured these two are equal but beyond that 30 minute up to additional 270, additional 270 plus this one hour that 30 to 90 the demand what you will see observed volume will be equal to capacity but that is not

the true hourly demand, it is happening because of this bottleneck situation, demand supply imbalance and clearing that effect is taking a long time.

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Queueing Analysis

- ✓ Beyond 360 min, observed volume again equals to demand

Formation of Queues and their Impacts

- Queues will form when breakdown conditions occurs (arriving rate exceeds capacity)
- ✓ On ramps
- ✓ Major merge points
- ✓ Intersections

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Obviously, beyond 360-minute time, clockwise observed volume again equals to the demand. Now this formation of queues and how or what will be their impacts. Queues will form when the breakdown condition occurs that means arrival rate exceeds the capacity and this kind of situation is common on ramps, off ramps, major merge point, off ramps it may not be there but more on the on ramps when entering such kind of things are more common. Major merge points and at intersection location.

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Queueing Analysis

Example- Major merge points

- On approach 1 and 2, capacity is more than demand flowrate
 - ✓ Observed volume (V) will be equal to demand
 - ✓ No queue formation
- On downstream the demand rate (d) is = $(3800+3600)=7400$ veh/hr. but capacity (C)=6000 veh/hr.

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Let us take an example of major merge point. Let us consider this two approach, approach 1 and approach 2 are meeting and then this section, the traffic demand is getting served. So, on approach 1 and approach 2, the capacity is more than demand flow rate because here you can see the capacity C is 4000 vehicle per hour. Demand is actually 3800 vehicle per hour which is less than the capacity and therefore the actual observed volume also will be 3800.

But that observed volume will be somewhere upstream, not right at this junction, not at this very near or close to this merging point but somewhere further upstream, the reason I will explain. But in general, we can say if we are taking some distance away from this junction, we can get that observed volume also as 3800 which is actually equal to the demand. So, generally no queue should form if you only consider this demand and this capacity.

Same thing is here in approach 2, your capacity is 4000 vehicle per hour but the demand is 3600 so further upstream somewhere away from this junction, if we measure, we should get the demand and observe volume same. But what is happening? When from both these approaches traffic is trying to enter to this, to this section. So, then the total demand will be 3800 plus 3600 which is 7400 vehicles.

But what is the capacity here, is 6000. So, all those vehicles cannot really enter in this section. So, there will be congestion there will be queue and that queue effect will be there on both approach 1 and approach 2. So, you will not get observed volume as 3800 or on approach to 3600 if you measure it immediately. But beyond certain points away from that junction you will get this volume.

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Queueing Analysis

- Queue will start at merge point and propagates upstream at a rate of $(7400-6000)= 1400$ veh/hr.
- Observed volumes on the downstream will be equal to capacity (6000 veh/hr.)
- Measurements for observed volumes should not be taken within the queue

The diagram illustrates a merge point where two approaches (Approach 1 and Approach 2) meet a main road. Approach 1 has a capacity $C=4000$ veh/hr, demand $d=3800$ veh/hr, and observed volume $V=3800$ veh/hr. Approach 2 has a capacity $C=4000$ veh/hr, demand $d=3600$ veh/hr, and observed volume $V=3600$ veh/hr. The merge point has a capacity $C=6000$ veh/hr, demand $d=7400$ veh/hr, and observed volume $V=6000$ veh/hr. A queuing area is shown upstream of the merge point, where the observed volume is less than the capacity.

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Now, queue will start at merge point and then propagate upstream, what will be the rate? Rate will be 7400 is the demand. Actual capacity is 6000 so shortfall is 1400 vehicle per hour at this rate the queue will start building. Observed volume on the downstream will be equal to 6000 vehicles if somewhere here, if we measure the volume, we will get 6000 because 6000 volume is able to pass through. Measurement for observed volumes should not be taken within the queue because then you will not get here 3800 or on this approach 3600 it has to be away.

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Queueing Analysis

- Observed volume at downstream may not be exactly equal to capacity: Queue discharge rate is slightly less than capacity

Bottlenecks, Hidden Bottlenecks and Demand Starvation

- A section of highway having two on-ramp and two off-ramp

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Now, observed volume at the downstream may not be exactly equal to the capacity because we know I have mentioned this that the queue discharge rate is generally slightly lower than the capacity. Whenever the queue formation will happen, the discharge may not happen exactly at the rate of capacity but it will be slightly lesser than the capacity.

Now let us explain you the concept of bottlenecks, hidden bottlenecks and demand starvation. A section of the highway having two on ramps and two off ramps you can see there these are the two on ramps, these are the two off ramps and these are the section S1, S2. S3, S4.

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Queueing Analysis

- Observed volume in S_1 and S_2 : 2200 veh/hr. and 3000 veh/hr. respectively as demand < capacity
- Observed volume in S_3 : 3400 veh/hr. (Demand is 3700 veh/hr. but capacity is 3400 veh/hr.) demand > capacity
- Observed volume in S_4 : $3400 - [(500/3700) \times 3400] = 2941$ veh/hr. (Distribution of observed vehicles is assumed to be same as distribution of demand)

Sections	S1	S2	S3	S4	S5
Demand (veh/hr.)	2200	3000	3700	3200	2800
Capacity (veh/hr.)	3200	3200	3400	3000	3000



Queueing Analysis

- Observed volume in S_5 : $2941 - [(400/3200) \times 2941] = 2574$ veh/hr.
- The analysis reveals **section 3 as the bottleneck location** (Based on observed volume and capacity)
- Lets increase the capacity of section 3 to 4000 veh/hr. so that it is no longer remains as the bottleneck

Sections	S1	S2	S3	S4	S5
Demand (veh/hr.)	2200	3000	3700	3200	2800
Capacity (veh/hr.)	3200	3200	4000	3000	3000



Queueing Analysis

- Observed volume in S_3 : 3700 veh/hr.
- Observed volume in S_4 : 3000 veh/hr. (Demand is 3200 veh/hr. but capacity is 3000 veh/hr.) \Rightarrow New bottleneck is created
- The potential bottleneck in Section 4 was hidden by the fact that section 3 did not allow the true demand to proceed into Segment 4: **Hidden bottleneck**

Sections	S1	S2	S3	S4	S5
Demand (veh/hr.)	2200	3000	3700	3200	2800
Capacity (veh/hr.)	3200	3200	4000	3000	3000



Now the observed volume on S1 and S2 are 2200 vehicle and 800 anti-throw, S2 also will be 3000 vehicle per hour and observed volume on S3 will be different because here you can see the actual demand on S3 will be 3700 because 2200 plus 800 plus 3000 plus 700, 3700, that is the observed demand but the capacity is 3400. So, what you will observe is actually only 3400, the capacity flow not beyond that.

Similarly, on S4 the actual demand is 3700 minus 500 so 3200, but what is the capacity is 3000 so you will actually observed only lesser than that because the exit ramp will take in proportion so you will have 3400 total minus, then how much will go here? If it would have been 3700 the total one, then 500 would have exited in proportion then 500 by 3700 into 3400.

So, this much less vehicle will be there and this many vehicles will actually take this exit ramp. So, there will be 2941 vehicles so what we are assuming here the distribution of observed vehicles is assumed to be same as distribution of demand. So, if there are 3700 vehicles on S3, if than 500 will go there. So, as it is not 3700 it is 3400 so in proportion the vehicle will exit.

Similarly, observed volume in S5 will be how much? Here you have seen that S5 would have been actually demand wise very different but again due to the same reason the bottleneck situation it will be 2941 minus 3200 is the actual demand. So, if it would have been 3200, then 400 could have exited.

So, now it will be 400 by 3200 into 2941 so 2941 minus this quantity, so 2574. So, this whole analysis then will reveal that section 3, is the bottleneck, if you look at this analysis still this time you will only feel that bottleneck is there on only in section 3 because in all other cases the actual volume what will be observed, the actual volume, I have given here observed volume on S1 is 2, S3, S4 and also in S5.

So, the observed volumes will be lesser than capacity except for S3. So, if we go by measured volume, will feel like the major problem is only in S3 because S3, this section is the bottleneck. So, the general tendency will be what? Let us increase the capacity of the bottleneck so because that is the problematic section, so you increase it.

Now suppose we increase the capacity of section 3 to 4000 vehicle per hour. Then this section is no more the bottleneck. So, now the whole demand 3700 will be able to pass through this section, so with that what will be then S3? S3 is 3700, what will be then S4, S4 will be 3000 vehicles, why? Because demand is actually 3200, because out of 3700, 500 will exit and 3200

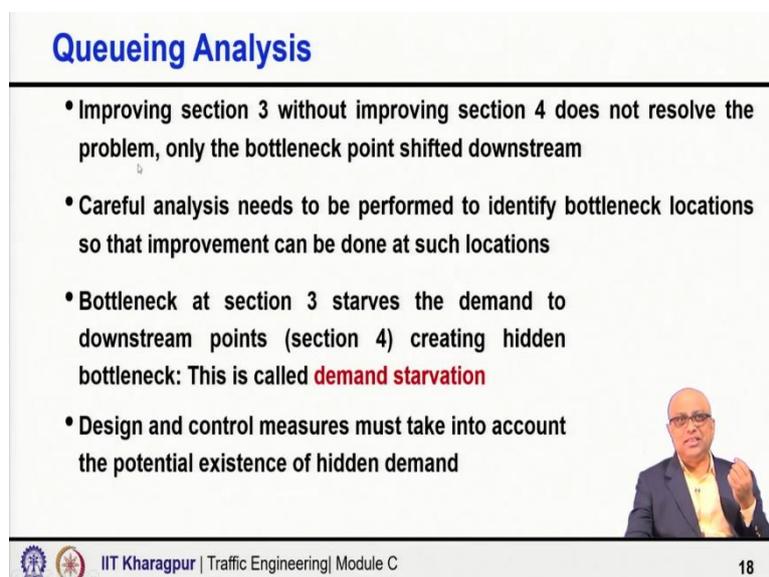
will be there. But then, this capacity is 3000. So, only 3000 vehicles will be able to pass through, not the whole demand. So, now S4 will be our new bottleneck.

Earlier we could not identify S4 as a bottleneck. Earlier analysis because S4, S3 was bottlenecked, the way the demand was happening if by measured volume and the capacity if we compare, we only found that S3 was a problematic location. But now you have removed the bottleneck at S3, so now you realize actually the bottleneck is S4 all again.

So, removing S3 bottleneck does not help completely. You also have to consider that S4 is another bottleneck. But this potential bottleneck in section 4 was hidden by the fact that section 3 did not allow the true demand to proceed to segment 4 because of the bottleneck earlier case the demand which was passing through section 4, passing to section 4 S4 was constant. So, it did not realize that actually there is a capacity constant. So, this is called hidden bottleneck.

So, S4 actually was a hidden bottleneck, which could not be identified based on this analysis. We could only identify S4 when we remove the bottleneck at S3. So, S4 may be considered as hidden bottleneck.

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Queueing Analysis

- Improving section 3 without improving section 4 does not resolve the problem, only the bottleneck point shifted downstream
- Careful analysis needs to be performed to identify bottleneck locations so that improvement can be done at such locations
- Bottleneck at section 3 starves the demand to downstream points (section 4) creating hidden bottleneck: This is called **demand starvation**
- Design and control measures must take into account the potential existence of hidden demand

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So, altogether as I said, improving section 3 without improving section 4 does not resolve the problem completely, it removes the problem partially because now S3 bottleneck is removed and rather what happens, the bottleneck point is shifting. Earlier S3 was bottlenecked and now S4 is bottlenecked. So, the careful analysis needs to be performed to identify bottleneck locations so that improvement can be done at all such location and eventually what happened,

bottleneck at section 3 starves the demand to downstream point section 4 because of its low capacity. The throughput from that section was constrained.

So, it was actually creating hidden bottleneck four and because the whole demand was not reaching to section 4 we can call it as demand starvation. So, not the actual whole demand is able to reach even to that section. So, what is reaching is not actually the true demand, the true demand is something lesser than that is reaching. So, demand starvation is happening. Design and control must take into account the potential existence of this hidden bottleneck.

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Queueing Analysis

Capacity vs. Queue discharge

- Capacity is the maximum flow rate obtained in an hour under stable flow conditions and usually occurs for a short time before a breakdown occurs
- After the breakdown, vehicles are discharged at queue discharged rate
- Queue discharge rates ranges from **capacity to 5 to 10 % lesser** than capacity but are not as stable as capacity
- It is important to understand the queue discharge rate and its **influence on breakdown** and queuing

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Now, let us quickly try to understand capacity versus queue discharge. Now as you know the capacity is the maximum flow rate obtained in an hour under stable flow condition and usually walkers for a short time before a breakdown occurs and after the breakdown vehicles are actually discharge at the queue discharge rate not that capacity and the queue discharge rate is slightly lesser may be 5 to 10 percent lesser than the capacity. It is important to understand that the queue discharged rate and its influence on the breakdown and queuing.

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Queueing Analysis

- Consider a scenario where one truck is stalled at one lane in a three lane highway at 6 am and cleared by 6.30 am
- Demand flowrate is given as 6000 veh/ hr. (6-9 AM), 5000 veh/hr. (9-10 AM) and 4000 veh/hr. (10-11 AM)
- Assuming, capacity and queue discharge rate is equal to 2000 veh/hr. /lane (Scenario-1)
 - ✓ What will be the **size of queue** during different hours?
 - ✓ By what time the queue will be **completely dissipated**?

Demand flowrate-
6-9 AM: 6000 veh/hr.
9-10 AM: 5000 veh/hr.
>10 AM: 4000 veh/hr.



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So, let us take an example problem to explain you that more clearly. Consider a scenario where one truck is stalled at one lane in a three-lane highway, there are three lanes, 1, 2, 3 and one lane is blocked because by of a stalled truck, certain breakdown probably happened and therefore it is occupying that lane and that happened between 6 and 6:30 that means by 6:30 the vehicle is cleared, only for half an hour.

Now, what are the demand flow rates? Demands are between 6 to 9 AM, 6000 vehicle then come down to 5000 during 9 to 10 AM and then further come downs to 4000 vehicle during 10 to 11 AM. If that is the demand, let us assume that the capacity and queue discharge rate is equal initially, equivalent to 2000 vehicle per hour per level standard capacity. Then what we want to find out here, what will be the size of the queue during different hours and by what time the queue will be completely dissipated?

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Queueing Analysis					
Scenario 1:					
Time (AM)	Arrival Rate (veh/hr.)	Arrivals (veh)	Departure Rate (veh/hr./lane)	Departures (veh)	Size of Queue (veh)
06:00-06:30	6000	$=6000 \times (1/2) = 3000$	2000	$=2000 \times (1/2) \times 2 = 2000$	$= 3000 - 2000 = 1000$ (Max)
06:30-07:00	6000	3000	2000	$=2000 \times (1/2) \times 3 = 3000$	$=1000 + (3000 - 3000) = 1000$
07:00-08:00	6000	6000	2000	$= (2000 \times 3) = 6000$	$=1000 + (6000 - 6000) = 1000$
08:00-09:00	6000	6000	2000	6000	$=1000$
09:00-10:00	5000	5000	2000	6000	$=0$

Queue will be completely cleared at 10:00 AM



Let us go through this simple calculation. Time 6 to 6:30, the rate of arrival is 6000 vehicle per hour but so in half an hour how many vehicles will be there, 3000 vehicles because this is per hour and so in half an hour 3000 vehicle. Departure rate is 2000 vehicle per hour but in half an hour actually how many 2000 vehicle into 30-minute 0.5 hour into effective there are two lanes out of three lanes so total 2000 vehicle can be discharged.

So, arrival is 3000, discharge is 2000. So, what will be the size of the queue is the remaining vehicle so 3000 minus 2000 is 1000. Now 6:30 to 7 o'clock again 6000 vehicles again 3000 again departure rate 2000 but now the breakdown vehicle that has been removed. So, you have all three lanes available so 30-minute 2000 per hour per lane so 1000 vehicle in half an hour per lane multiplied by 3 lanes. We are able to discharge 3000 vehicles. So, what will be the size of the queue?

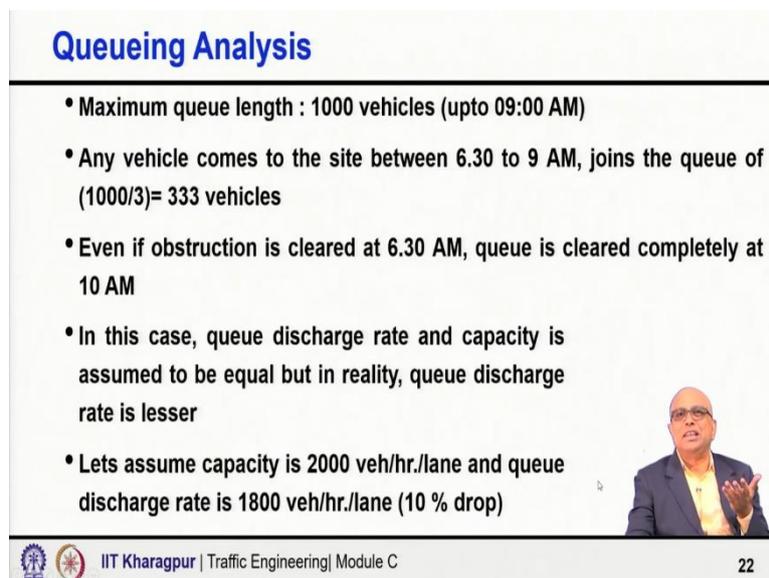
Size of the queue will be this 1000 vehicles which were there already from at 6:30 plus share 3000 vehicle arrival and 3000 vehicle discharge. So, 3000 minus 3000 so it still remains 1000. 7 to 8 again 6000 vehicles in the hour arrival during this whole hour is again 6000 here because we have taken one hour duration here earlier cases it was half an hour, half an hour but one hour, departure rate same so here also 6000 vehicle will get discharged. So, whatever new vehicles are entering that many vehicles are able to get discharged so the queue remains, the queue 1000 vehicles in the queue will still be retained.

Now 8 to 9 o'clock is still same 6000, 6000, 2000, 6000 and 1000 vehicle but then from 9 o'clock as it has been told that 9 to 10 the vehicle is 5000 vehicle per hour. So, 9 to 10 o'clock

the demand is 5000 but vehicle arrival is 5000 and here it is 2000. So, the departure could be 6000 as per capacity. So, 5000 here 6000 here so this 1000 vehicles which were there in the queue are getting discharged.

So, what you are getting actually? 6 to 6:30, the truck was occupying one lane and that lane capacity could not be utilized because of that whatever queue will be formed that impact will be there up to 10 o'clock even though after 6:30 that vehicle is removed, 3 and half hours still that impact will be there.

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Queueing Analysis

- Maximum queue length : 1000 vehicles (upto 09:00 AM)
- Any vehicle comes to the site between 6.30 to 9 AM, joins the queue of $(1000/3) = 333$ vehicles
- Even if obstruction is cleared at 6.30 AM, queue is cleared completely at 10 AM
- In this case, queue discharge rate and capacity is assumed to be equal but in reality, queue discharge rate is lesser
- Lets assume capacity is 2000 veh/hr./lane and queue discharge rate is 1800 veh/hr./lane (10 % drop)

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So, anybody entering will still find there is a queue, although that that truck is no more existing. So, maximum queue length here is 1000 vehicle you have seen here, any vehicle comes to the site between 6:30 to 9 AM, the vehicle truck will not be there but the queue will be there and average queue length per lane will be 333 vehicles because 1000 vehicles. So, three lanes if we assume they will get evenly distributed so they will join a queue of any lane. They will join a queue of 333 vehicles.

Even if obstruction is cleared at 6:30 AM queue is completely cleared only at 10 AM and in this case the queue discharge and capacity we have assumed same. But in reality the queue discharge rate will be lesser. If we assume that that queue discharge is not two thousand but it is 1000, 1800, 90 percent of that 1, 10 percent drop.

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Queueing Analysis					
Scenario 2:					
Time (AM)	Arrival Rate (veh/hr.)	Arrivals (veh)	Departure Rate (veh/hr./lane)	Departures (veh)	Size of Queue (veh)
06:00-06:30	6000	=6000×(1/2) =3000	1800	=1800×(1/2)×2 =1800	=3000-1800=1200
06:30-07:00	6000	3000	1800	=1800×(1/2)×3 =2700	=1200+(3000-2700)=1500
07:00-08:00	6000	6000	1800	=(1800×3)=5400	=1500+600=2100
08:00-09:00	6000	6000	1800	5400	=2700 (Max)
09:00-10:00	5000	5000	1800	5400	=2300
10:00-11:00	4000	4000	1800	5400	=900
11:00-12:00	4000	4000	1800	5400	=-500

Queue will be completely cleared at 11:39 AM [11+(900/1400)]



Then how it will happen? A very similar calculation is shown here and here interestingly we will see that because the capacity or the discharge is lesser, the queue length will go even longer. What you got here as 1000 vehicles maximum not in the queue it is in different lane but total accumulated vehicle in the queue is 1000 but here it is going up to 2700 and it is taking up to 11:39 AM to actually clear this vehicle because we simply the way we were calculating, we calculated here between 11 to 12 o'clock but then the number becomes negative, indicating that it does not require time up to 12 o'clock.

So, we calculated it, that it is 4000 is the arrival and 5400. So, 1400 vehicles, additional vehicles can be cleared in 60 minute and we have only or 1 hour and we have only 900 vehicles. So, how much additional time it will take beyond 11 o'clock is can be calculated very easily and that is 11:39 AM. So, what we observe all together, that maximum queue length is 2700 instead of 1000 vehicle. So, the moment the actual queue discharge rate will be like this lesser than the capacity so, how it impacts the queue length.



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Queueing Analysis

- Maximum queue length : 2700 veh (@ 09:00 AM)
- Any vehicle comes to the site at 8 AM, joins the queue of $(2100/3)=700$ vehicles (Same kind of calculation for different hours)
- Even if obstruction is cleared at 6.30 AM, queue is cleared at 11.39 AM
- By comparing two scenarios it is observed that queue discharge rate clearly affects queuing process



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Any vehicle comes at the site at AM joins a queue of 700 vehicles, take any lane, you have to be at the back of 700 vehicle whether it was 330 vehicles in earlier case. If an observed obstruction is clear even if the obstruction is cleared at 6:30 AM the queue is completely cleared at 11:39, it takes much longer time.

Earlier we could clear it only by 10 o' clock and now we are able to clear it only at 11:39. So, by comparing this two shared, it is also shown that how the queue discharge rate significantly affects the queueing process and the overall gaming process is explained through this example.

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Summary

- Concept of traffic demand, volume and capacity
- Relationship between demand, volume and capacity
- Formation of queue and their impacts
- Bottlenecks, hidden bottlenecks and demand starvation
- Capacity vs queue discharge



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So, altogether we discussed here about the concept of traffic demand volume and capacity. What is the relationship between demand volume and capacity? How the queues are formed because of this imbalance between the demand and the capacity and how the bottlenecks, the concept of bottleneck, hidden bottlenecks and the demand starvation and also took an example to explain you the capacity versus queue discharge, how it changes. With this, I close this lecture. Thank you so much.