Traffic Engineering

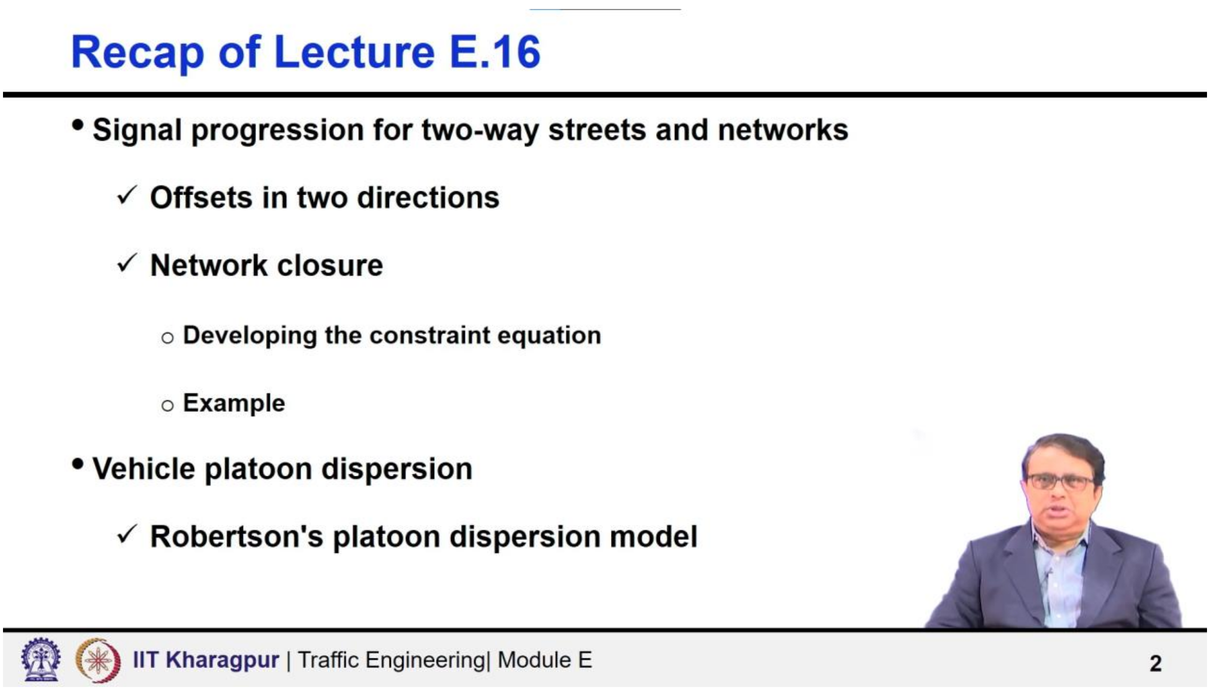
Professor. Bhargab Maitra

Department of Civil Engineering

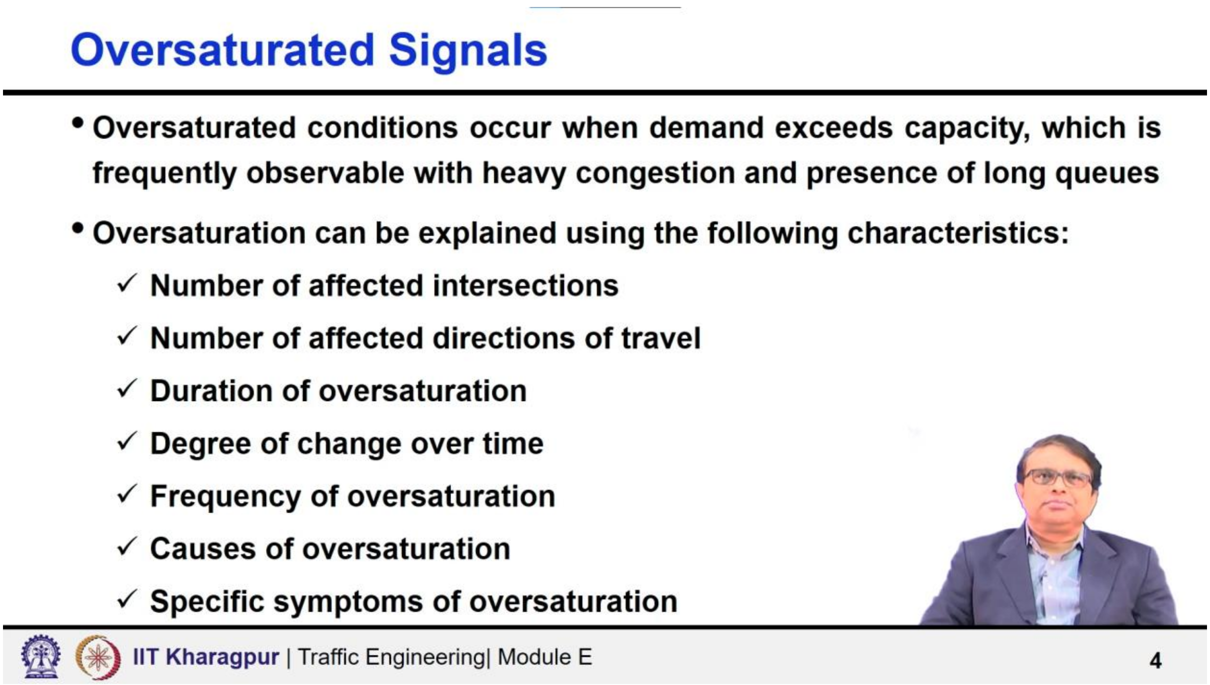
Indian Institute of Technology, Kharagpur

Lecture No. 43

Oversaturated Signals & Mitigation Strategies

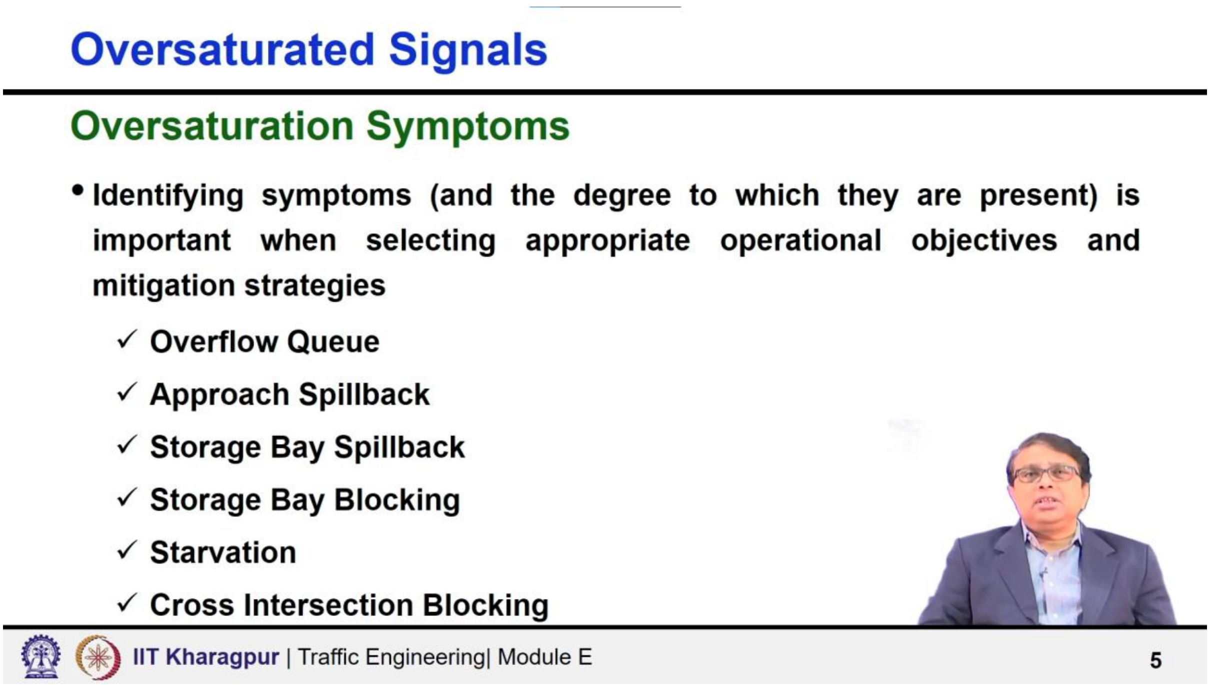


Welcome to module E lecture 17. In this lecture, we shall discuss about over saturated signals and mitigation strategies. In lecture 16, I mentioned to you about signal progression for two way streets and networks, how the offsets in two directions are interdependent and linked with the cycle time, the concepts of network closures, how to develop the constraint equation and took a small example to explain you the interrelations. Then I also mentioned to you about vehicle platoon dispersion and the theoretical models that was proposed by Robertson's, the basic understanding of that platoon dispersion model by Robertson's. Today, let us first discuss about over saturated signals and then we shall discuss about the mitigation strategies. Over saturated conditions occur when the demand exceeds capacity, it is nothing new.

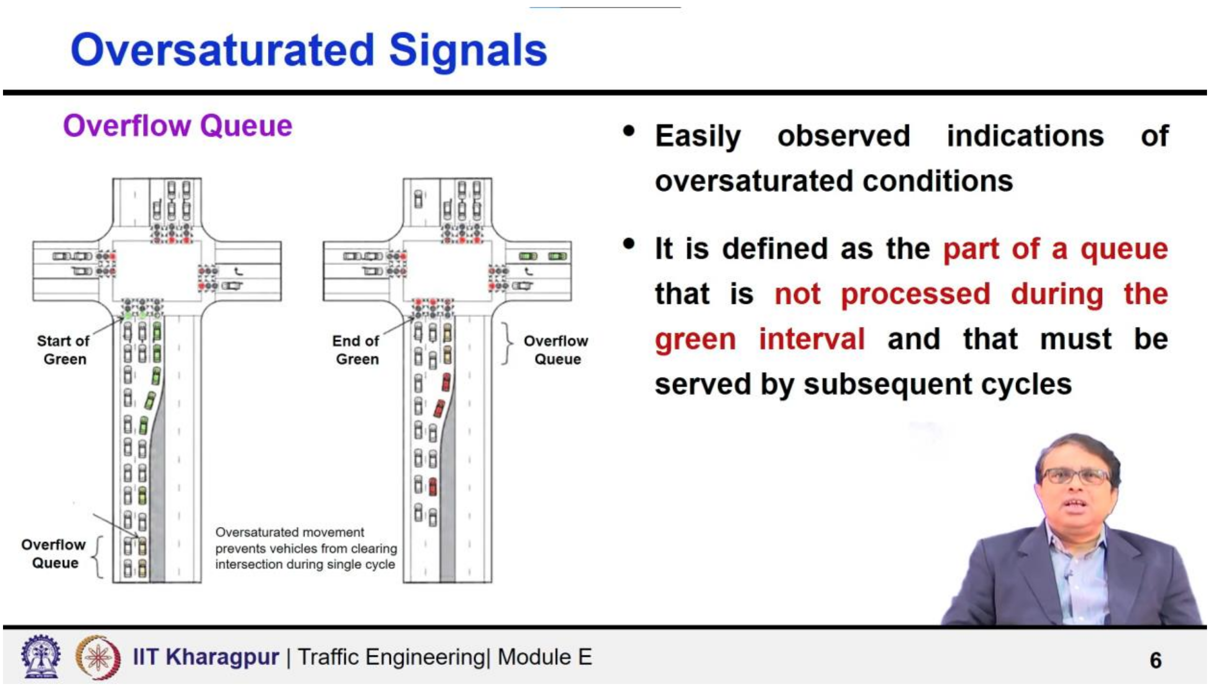


In fact, in most of our urban areas specially in Indian context, the demand supply imbalance is very high and often the demands in the peak hours particularly the morning peak and the evening peak in urban areas, the demands exceed capacity. And because of that we often observe heavy congestion and long queues in the upstream of signalized intersections. Over saturation can be explained, over saturation can be explained using several characteristics. For example, how many numbers or how many intersections are affected with such kind of over saturation, number of affected directions of travel, not that all directions of travel will have over saturations.

Say for example, typically in the morning peak all travels are towards the CBD. So, maybe the through traffic towards the CBD along the major arterial, those directions or that directions or maybe one or two more directions depending on the network geometry may be affected adversely with the over saturation. What is the duration of over saturation? Yes, over saturated, but for how long? What is the degree of change over time? How the over saturation level is changing over time? How frequently such kind of over saturation is happening? What are the different causes accordingly also we can characterize that what is really causing over saturation and the specific symptoms of over saturation that is very important. The symptoms could be many and then what are the specific symptoms of over saturation? Based on the symptoms we can actually do the characterization of based on the symptoms we can do the characterization of over saturations and these symptoms are extremely important in the context of over saturated signals. So, let us discuss little bit in details about these specific symptoms of over saturation.

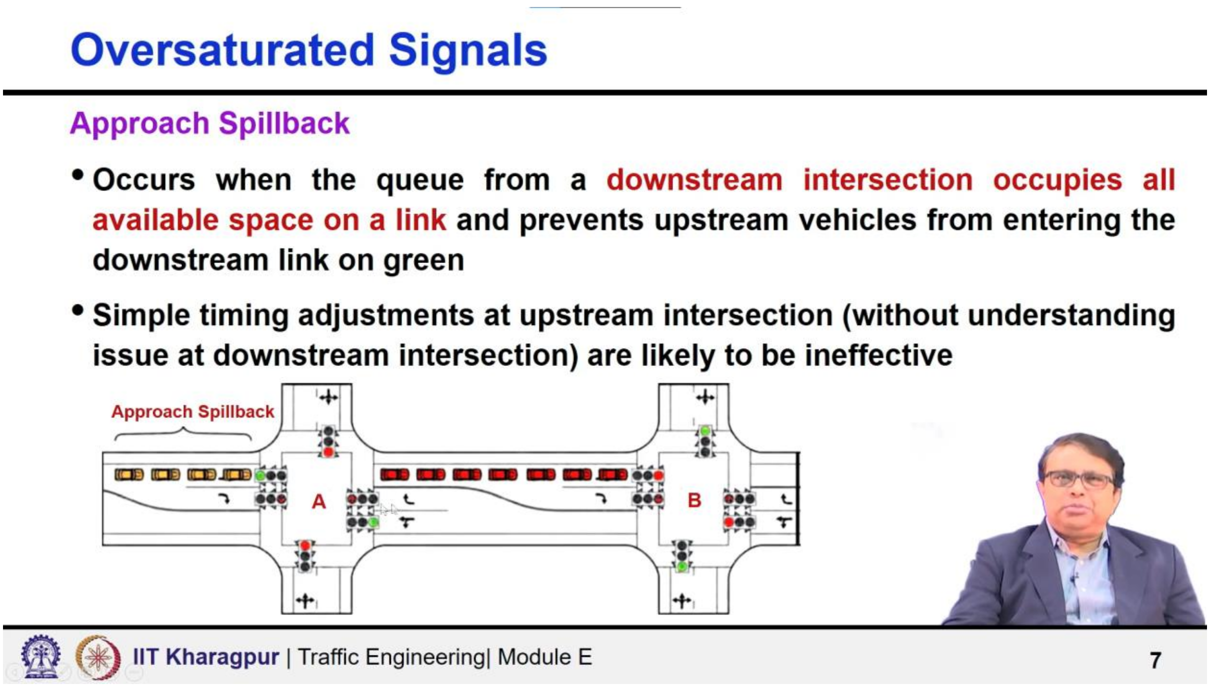


Assigning these symptoms and also the degree to which they are present is important because when we are facing with such kind of over saturation what would be then the specific or appropriate operational objectives and what should be the mitigation strategies that probably should help us to handle the overall network of the intersections either at the corridor level or at network level. Identifying symptoms is important for selecting appropriate operational objectives and mitigation strategies. So, these symptoms are very important and it gives us a clue that what is the real problem and therefore, what should be my operational objectives as well as my mitigation strategies. Here I have listed several symptoms overflow queue, approach spill back, storage bay spill back, storage bay blocking, starvation, cross intersection blocking. Let us discuss each of these.



First overflow queue, overflow queue you often observe in urban area probably you do not need much explanation for that. These are easily observed indications of over saturated conditions and it is defined as the part of a queue that is not processed that is not processed during the green interval and that must be served by subsequent cycles. For example, look at this figure at the start of green you have this much long queue, but actually during the green only queue up to this portion probably is getting cleared. So, the remaining vehicles which were there they are overflow queue they are forming the overflow queue and these vehicles can only be served during the next green. So, by the end of green these vehicles are still there which are from the previous queue original queue and could not be served during the green time.

Of course, there are additional vehicles which have also arrived at the intersection during the green time those also could not be cleared right. So, this is clearly the case of overflow queue. So, basically a part of the queue we are not able to process during the green interval. You had this long queue not all vehicles in the queue could be cleared in the green time. So, a part of the queue remained that is the overflow queue and that is to be cleared during the next green. So, that is the overflow queue.



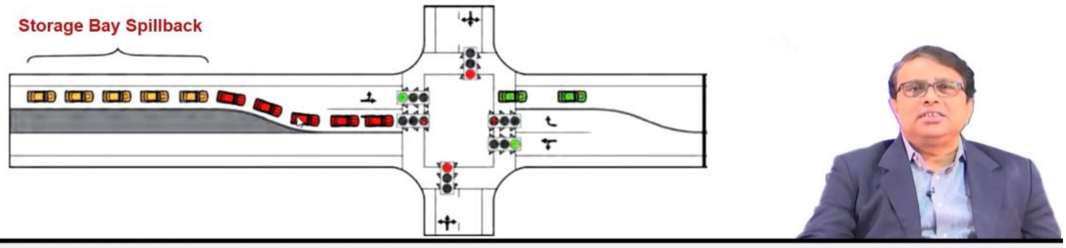
Going to the approach spillback, approach spillback typically occurs when the queue from the downstream intersections. Here I have shown the figure A and B are the two intersection B is the downstream intersection and A is the intersection in the upstream. So, vehicles are getting discharged from A and travelling towards B, but what is then happening approach spillback is happening why because queue from a downstream intersection occupies all available space on the link. You can see here the signal is red and all the space which is available is occupied by queued vehicles and it has gone up to the previous signal almost right the complete length is occupied.

So, what is happening this is now preventing upstream vehicles from A to enter the downstream link on green. So, even if you can see the signal is green here showing the green indication, but these vehicles cannot proceed further cannot enter into this link simply because the whole link is occupied with queued vehicle. So, that is approach spillback. So, approach spillback occurs when the queue from a downstream intersection occupies all available space on a link and therefore, prevent upstream vehicles in this case signal A from entering the downstream link on green time even though signal is green the vehicles cannot enter. Now, obviously, simple timing adjustment at upstream intersection if you think that you will do some timing adjustment at intersection A without understanding the issue at the downstream intersection in this case B you are unlikely to solve a be able to solve the problems. So, you are unlikely to be able to solve the problem effectively. So, that is what is the approach spillback.

Oversaturated Signals

Storage Bay Spillback

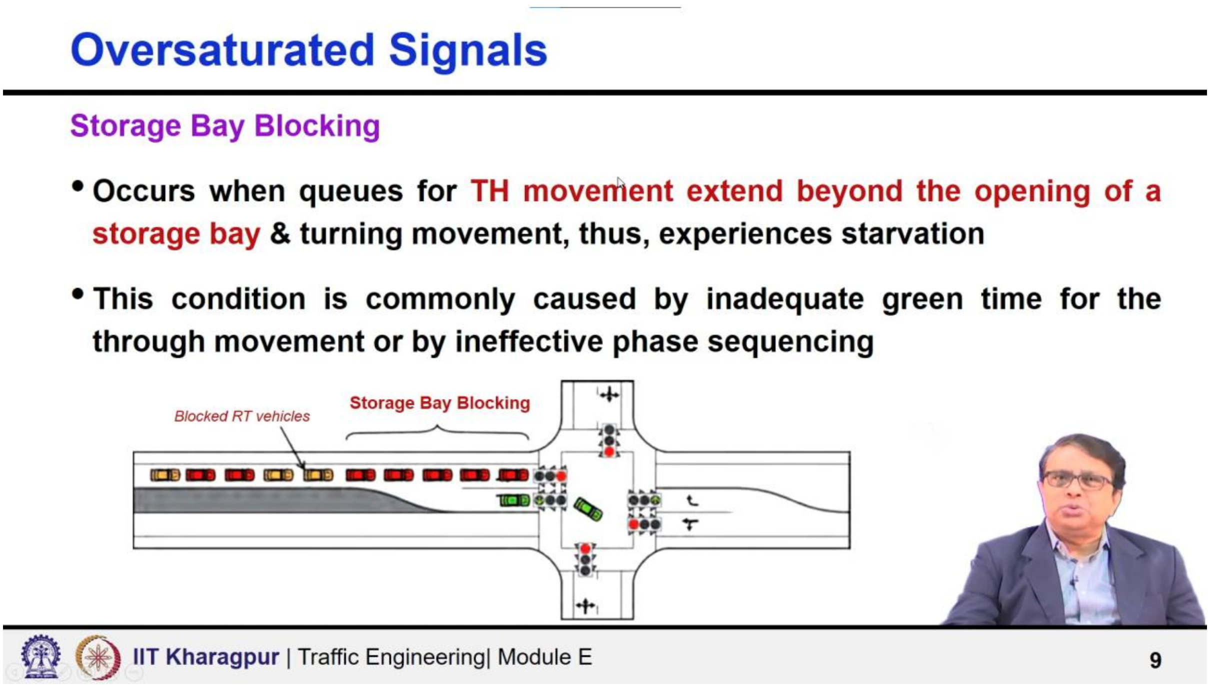
- Occurs when **turning traffic uses up the entire space** of the storage bay and blocks through traffic; thus, blocked TH movement may experience starvation
- Storage bay spillback is commonly caused by inadequate green time for the turning phase or ineffective phase sequencing



IIT Kharagpur | Traffic Engineering| Module E 8

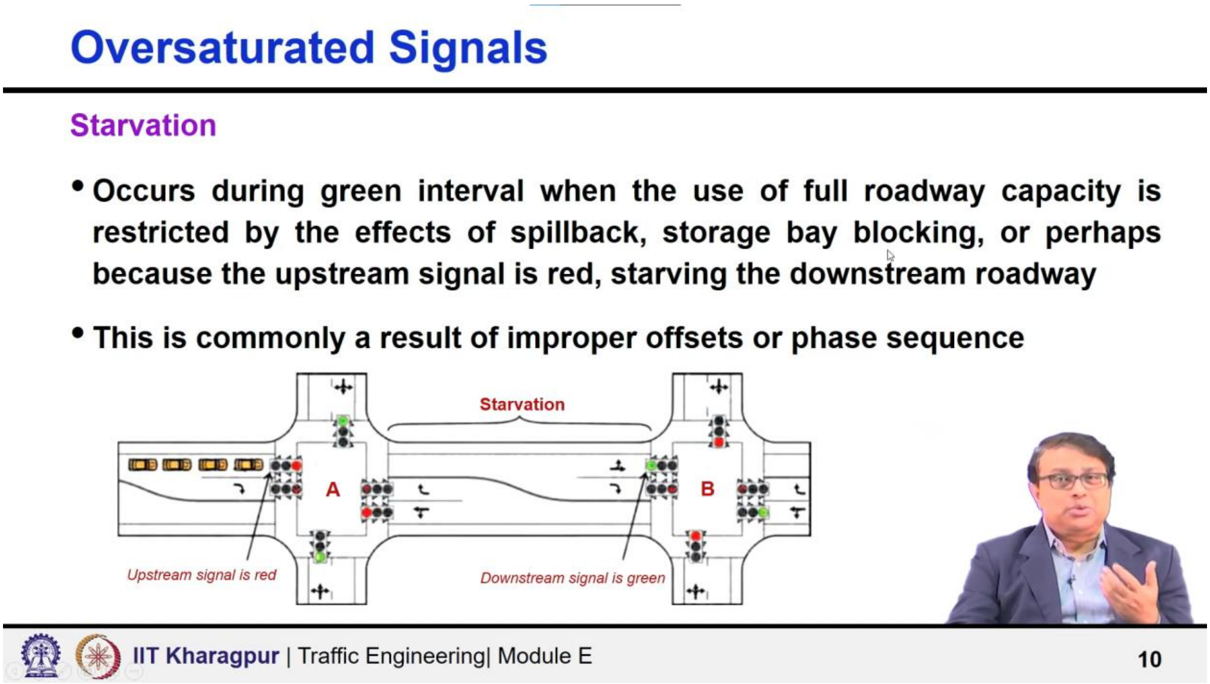
Moving to the next symptom what is storage bay spillback when this kind of symptom we can get such situations occur when turning traffic uses up the entire space of the storage bay and blocks the through traffic therefore, block the through movement may experience starvation. So, what is really happening you can see here there is a right turn storage lane, but whatever number of vehicles it can accommodate you have more number of vehicles are there waiting to enter into the right hand storage lane and to carry out right hand maneuver. So, this queue spill has gone to the mainstream main lane and therefore, these yellow vehicles which are actually they want to move straight, but they are not able to move straight because the red vehicles are actually occupying and overflow has happened to the lane which is primarily to be used by the through lane.

So, even if the signal is green for the straight movement the straight vehicles are not able to actually come up to the stop line. So, they are stopped there. So, this is the storage bay spillback you can say all the yellow vehicles are actually blocked, but these yellow vehicles are actually through vehicles not the right turning vehicle right turning vehicles are the red ones. Storage bay spillback is common because by inadequate green time for the turning phase why this queue length has gone up to this because whatever actually green time is required for the right turning vehicles we have not been able to provide that much green time or the turning phase or ineffective phasing sequence that also could be there the sequence of phasing could be ineffective and this is one possible remedy. So, we can try different phasing to sort out this issue.



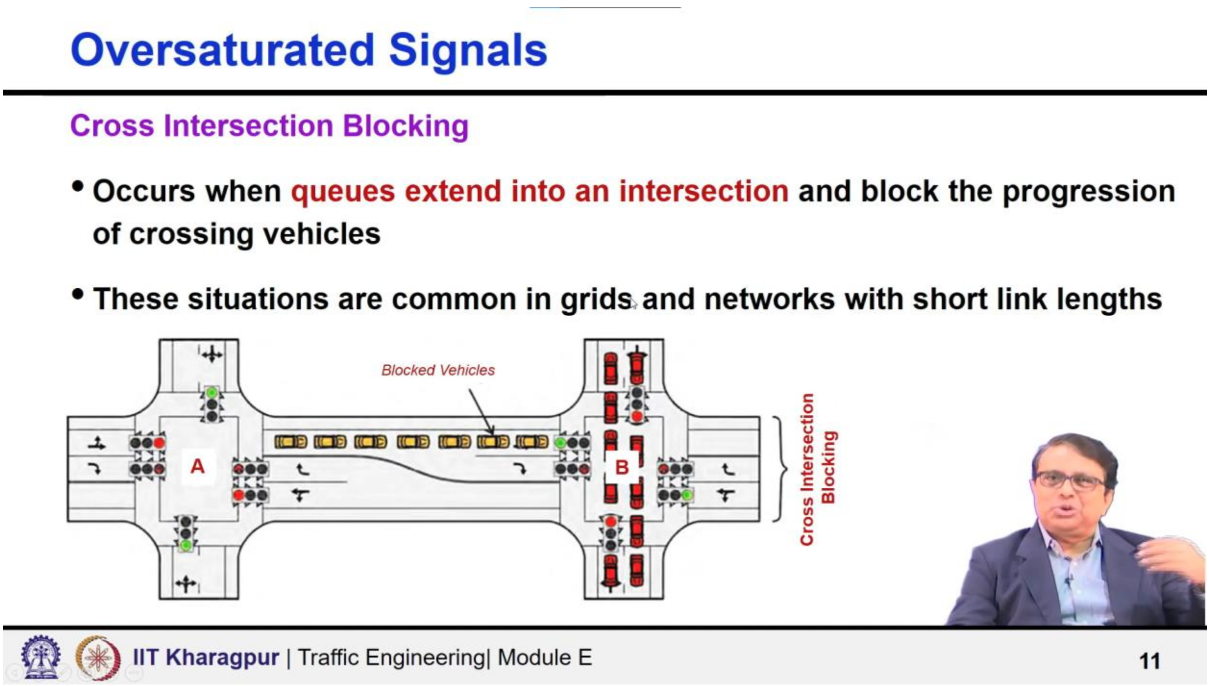
Here storage bay blocking this is something again different this is practically the reverse one what is happening and when it occurs it occurs when queues for through movement extend beyond the opening of a storage bay and turning movement thus experience starvation. What is starvation I shall discuss later starvation is when the signal is green, but no vehicle is actually crossing and entering into the subsequent link. So, the subsequent downstream intersection even though it is green there is no vehicle in the link vehicle could not arrive because of some problem in the upstream. So, storage bay blocking occurs when the queues of through movement extend beyond the opening of a storage bay and turning movement thus experience starvation. Here this turning movement is experiencing starvation of course, the turning vehicles are again entering into another link and eventually we will approach to another downstream signals.

So, this condition is commonly caused by inadequate green time for the through movement or by ineffective phase sequence. Again this ineffective phase sequence could be a reason and could be used therefore, as a probable strategy for sorting out this issue. So, you can see here actually the straight vehicles are blocking. So, here in this case the rate all the red vehicles are through vehicles right and these yellow ones these are actually the right turn vehicles and even though the right turn is green these vehicles are not able to enter into this right turn bay simply because the straight or the through queue is so long that it is blocking the entry the vehicles yellow marked vehicles are not getting an opportunity to use the right turning storage lane to proceed further. So, obviously, it will happen the green is there, but there may not be any vehicle to serve although there is a demand, but vehicles are not able to reach. So, the downstream intersection which is actually serving this right turning vehicles they will experience starvation in this case.



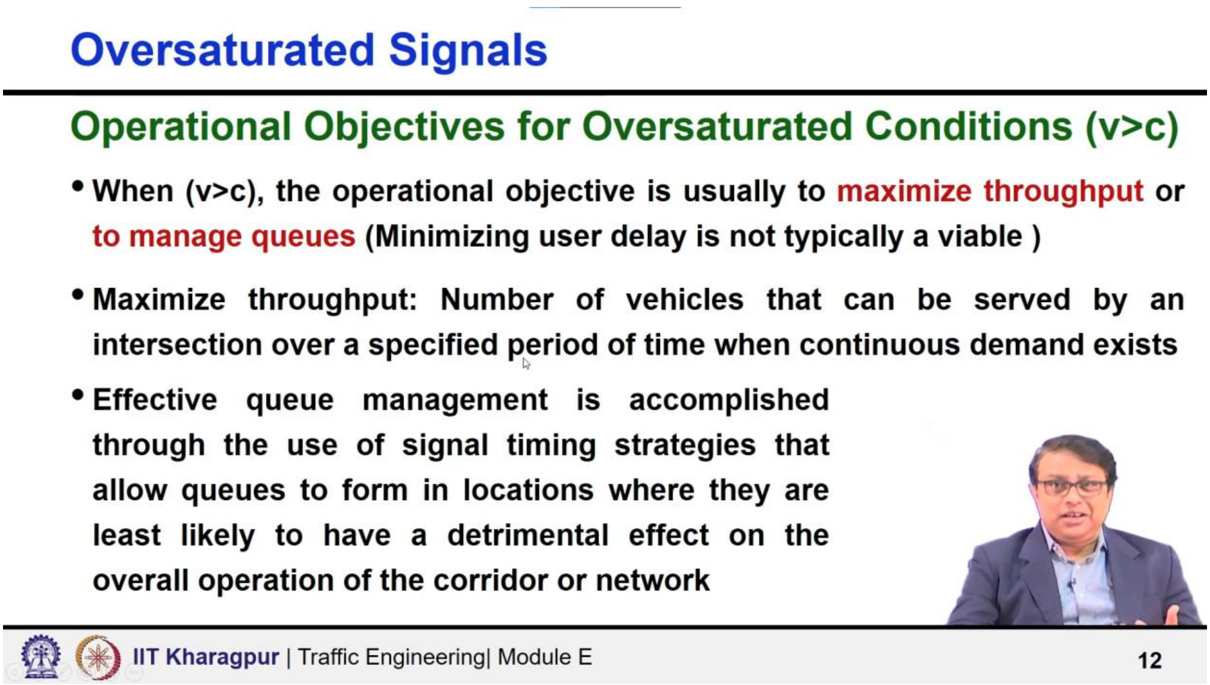
Now, coming to starvation is also another symptom as I said it you know starvation occurs when or during green interval when the use of full roadway capacity is restricted by the effects of spill back storage blocking I have explained what it is or perhaps because of the upstream signal is red starving the downstream roadway. The essence is here you can say the signal is green, but there is no vehicle in this lane does it mean there is no demand no demand is there, but there is some issue upstream as I have explained I have explained earlier that the approach the storage bay spill back might have happened. So, the through vehicles are not able to pass through during the green. So, no vehicle is entering in the subsequent lane.

So, that kind of problem could be there or it could be perhaps because the upstream signal is red. So, when you expect these vehicles to come the signal is not becoming green at that time. So, this kind of situation is happening this is called starvation when the signal is green for a particular approach, but there is no vehicle, but that does not mean that there is no demand there is demand, but the vehicles are not able to reach there due to some problem in the upstream maybe with green timings maybe with spill back or storage bay blocking whatever may be the problem there could be someone or multiple problems which are leading to this effect and this is commonly a result of improper offset or phase sequence.



Now, this is called cross intersection blocking cross intersection blocking is it is now happening along the cross streets what has happened such kind of situation occurs when queues extend into an intersection and block the progression of crossing vehicle you can see here something has gone wrong in this north south corridor. So, the whole intersection is blocked the intersection B is blocked entirely by vehicles which are on this north south corridor.

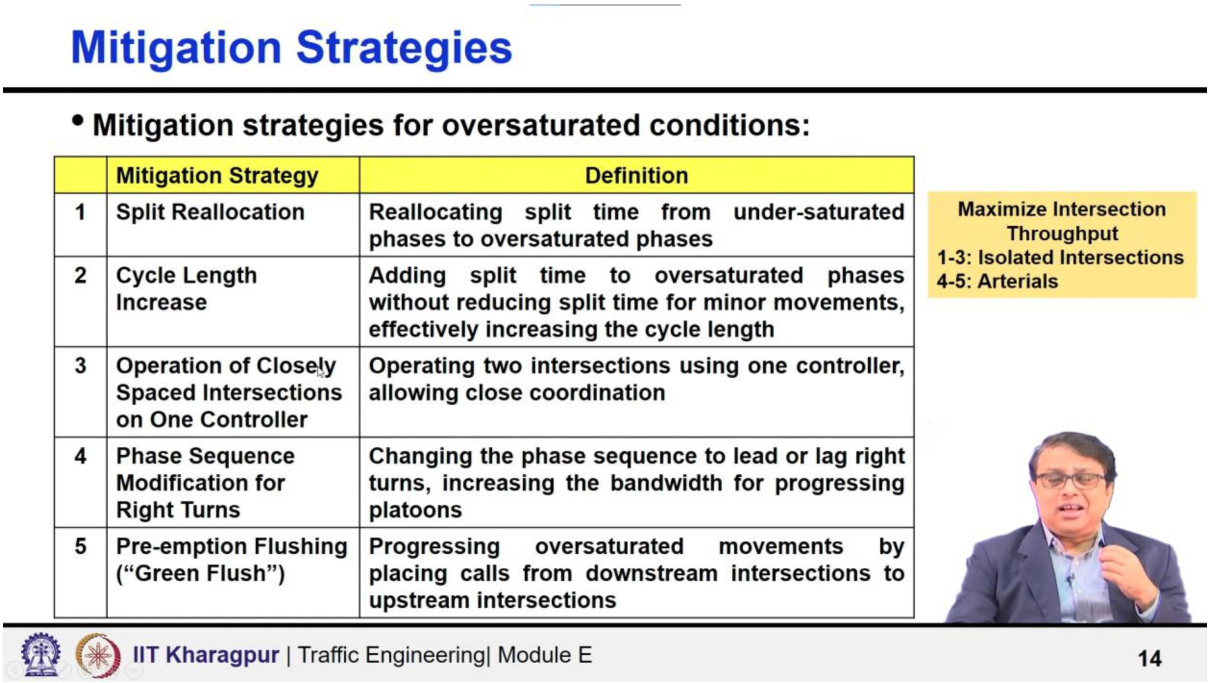
So, the east west movements so many vehicles are waiting they are blocked vehicles the signal is green, but these vehicles cannot move straight because the intersection area is not free it is blocked and blocked by cross vehicles cross moving vehicles. So, cross intersection blocking occurs when queues extend into an intersection and block the progression of crossing vehicle and obviously, these situations are common in grid and network with short link length such kind of things are more likely to happen when the link lengths are short.



Now, going to the next part if such kind of over saturations are there if there are symptoms and you know what kind of problem is happening then what should be our operational objectives. For under saturated condition normally our objective is to minimize the delay user delay, but then when the over saturated conditions occur what would be our operational objective. In this case, the operational objective is usually the operational objective is usually to maximize throughput, how we can pass more number of vehicles or to minimize queue because of the queue so many issues could happen.

So, how do we do better management of vehicle queues to have minimum detrimental effect along the corridor or overall at a network level. So, certainly when there are over saturated conditions minimizing user delay is not typically a viable objective. What I mean by maximize throughput it means that number of vehicles that can be served by an intersection over a specified period of time when continuous demand exists. That means, demand exists continuous demand exists and under such condition what how we can ensure that maximum number of vehicle that can be served by an intersection over a specified period of time that is the throughput. So, we want to increase the throughput as far as possible with our strategies.

Second effective queue management is accomplished through the use of signal timing strategies that allow queues to form in location somewhere the queue will form, but we want the queue to form in locations where there are they are least likely to have a detrimental effect on the overall operation of the corridor or network. So, how in a larger perspective if you are talking about a corridor or overall talking about the network then how and where you know we store the vehicle where we allow the queues to grow queues to form. So, that the overall detrimental effect on the network or the corridor is minimum that is what is the principle for queue management. With this let us go to the last part that is mitigation strategies. We know what is over saturation, we know what are the symptoms, what should be our strategies either increase the throughput how we can increase the throughput or how to do better management of queues under over saturated conditions.



Mitigation Strategies

- Mitigation strategies for oversaturated conditions:

	Mitigation Strategy	Definition
1	Split Reallocation	Reallocating split time from under-saturated phases to oversaturated phases
2	Cycle Length Increase	Adding split time to oversaturated phases without reducing split time for minor movements, effectively increasing the cycle length
3	Operation of Closely Spaced Intersections on One Controller	Operating two intersections using one controller, allowing close coordination
4	Phase Sequence Modification for Right Turns	Changing the phase sequence to lead or lag right turns, increasing the bandwidth for progressing platoons
5	Pre-emption Flushing ("Green Flush")	Progressing oversaturated movements by placing calls from downstream intersections to upstream intersections

Maximize Intersection Throughput
1-3: Isolated Intersections
4-5: Arterials

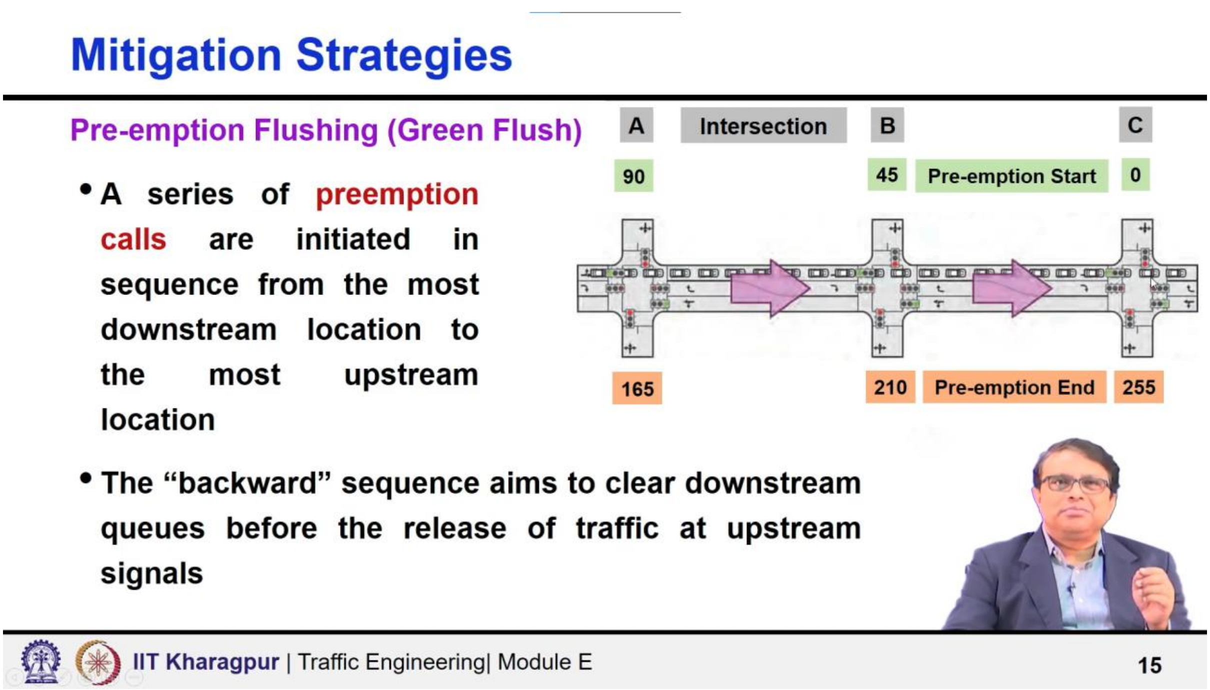
IIT Kharagpur | Traffic Engineering| Module E 14

So, what could be our strategies? There are several strategies I shall discuss very briefly each of these strategies can be discussed in details, but it will take a longer time. So, I want to mention them very briefly so that you understand the concept. You want to know more details about the strategies please refer to signal timings manual. First split reallocation all what we are trying to talk about the strategies under over saturated situations. So, one strategy is split reallocation what we are doing? We are reallocating split time or in general I should say the green times from under saturated phases to over saturated phases not all phases are over saturated.

So, what we know if we find that under such over saturation is the really the key problem that we are trying to handle simply cut the time green time from the under saturated phase give more time to the over saturated phase without changing the cycle time; cycle time remains same simply reduce the green time for the under saturated phase give more time green time for the over saturated phase. Second cycle length increase in this case we keep the green time for all other phases under saturated phases same, but add extra green time for the over saturated phase. So, the overall cycle length will increase that is what I say adding split time or the green time to over saturated phases without reducing split time for minor movements and therefore, effectively increasing the cycle length. Third operation of closely spaced intersection on one controller this I have mentioned when I was talking about various types of progression in my just previous lecture that one strategy is operation of closely spaced signal with one controller. So, that means, when signals are closely spaced we are operating two intersections using one controller.

So, same time the green time is given same time same amount of green time is given to both signals, but this will work only when the signals are very closely spaced. So, operating two intersections using one controller allowing close coordination. Now, this 1 to 3 all the strategies they are used to maximize intersection throughput how we can serve more vehicles and 1 to 3 are also applicable for isolated intersection individual intersections we are talking. Now, strategy 4 and 5 are typically applied for arterials to maximize intersection throughput what are those 4 is phase sequence modification for right turns. You have seen that we have said the through vehicle may block the right turn vehicle right turn vehicle queue may also block the through turn through moving vehicles we have discussed those symptoms earlier.

So, what we are doing here change the phase sequence to lead or lag right either we can start first giving the right turn then straight or first straight and then give the right turn it depends on what is the nature of the problem we are facing and accordingly the phase sequence need to be modified. So, changing the phase sequence to lead or lag right turns increasing the bandwidth for progressing platoons. Fifth pre-emption flushing or called green flush this is again quite effective what we do? Progressing oversaturated movements by placing calls from downstream intersection to upstream intersection starting from downstream intersection and then going towards upstream intersections. What we are doing let me explain you little bit better in the next slide.



In pre-emption flushing or green flush a series of pre-emption calls are initiated in sequence it goes in sequence starting from the most downstream location to the most upstream locations here three intersections I have shown A B and C.

C is the most downstream intersection A is the most upstream intersections B is in between. So, pre-emption starts from the most downstream intersections then the pre-emption happens for intersection B then pre-emption happens for intersection A. So, suppose if it takes 45 seconds to travel from intersection B to C approximately I am saying then if the pre-emption starts at C as 0 means green giving green starts at C equal to 0 then we do the pre-emption of B at 45 seconds. So, the moment these queued up vehicles are cleared immediately you are releasing the vehicle from the immediate upstream intersection. The moment the immediate vehicles are discharged from immediate upstream intersection further upstream intersection pre-emption you are doing.

So, it you are doing it at 90 seconds. So, the pre-emption is done in sequence C then B then A and starting from the most downstream location at 0 in C and then progressing towards the most upstream location. So, then at 45 B and at 90 A now the closing also is basically in the reverse order whatever we have cleared say from 1 up to 165 all those will take up to 210 seconds to clear this part clear intersection B and they will also take up to 255 to clear from intersection C. So, pre-emption ends at C 165 at B 210 at C 255, 255 is typically the maximum limit that is acceptable. Now, the backward queue sequence is aimed to clear the downstream queues here we are doing first pre-emption. So, we are trying to clear this downstream queue or when we are doing the pre-emption here we are trying to clear this downstream before we allow this or when we are doing the pre-emption here we are first clearing this portion.

So, the backward sequence aims to clear the downstream queues before the release of traffic at upstream signals. So, when we are clearing the traffic from upstream signal B we are trying to ensure that the downstream signal queue is cleared when we are releasing from A we are trying to make sure that the downstream intersection at B this all these vehicle queues are cleared. So, the backward sequence aims to clear downstream queues before the release of traffic at upstream signal.

Mitigation Strategies

	Mitigation Strategy	Definition
6	Alternative Timing Plan Flushing	Using a timing plan to increase the cycle length and give the majority of the green time to the oversaturated phases
7	Green Extension	Adding green time to a phase when a detector exceeds a defined threshold of occupancy
8	Phase Re-Service	Serving an oversaturated phase twice during the same cycle
9	Phase Truncation	Termination of a green interval (despite demand) when there is minimal to no flow over a detector
10	Simultaneous Offsets	Setting offset to zero between intersections, so that queues move simultaneously
11	Negative Offsets	Starting the green interval earlier at downstream intersections to allow the downstream queue to dissipate before upstream vehicles arrive

Maximize Intersection Throughput
6: Arterials

Manage Queues
7-9: Isolated Intersections
10-11: Arterials

IIT Kharagpur | Traffic Engineering| Module E 16

Next alternative timing plan flushing it is somewhat similar to 5, but what we are doing here the whole green time is going here along this direction. In this case we are using a timing plan to increase the cycle length and give the majority of the green time to the over saturated phase something very similar, but with a different cycle length we are increasing the cycle lengths and operating we are anyhow giving maximum time to this over saturated phase, but little bit of green time to other phases as well not completely stopping.

So, 6 is typically applied for arterials to maximize the intersection throughput. Now strategy 7 to 9 and also 10 and 11 they are all used for better management of queues 7 to 9 typically is applicable for isolated intersection and 10 and 11 are typically for arterials. Let us go to the seventh one, green extension you are familiar with this concept we are adding green time to a phase when a detector exceeds a defined threshold of occupancy. So, when you know that it is over saturated means it is the detector is indicating that it is exceeding a defined threshold of occupancy. So, detector occupancy is higher than the threshold limit indicating that there is over saturation.

So, what we are doing in that case we are adding green time to a phase or to that particular phase that is green extension. So, we want to reduce the queue. Phase re-service another strategy we are trying to serve an over saturated phase twice during the same cycle because you know that is the particular phase which is over saturated and therefore, you are serving that phase two times within the same cycle. The other phases one time, but here you are serving that phase two times to do better management of queues you do not allow the long queues to grow. So, instead of giving one longer green time you are actually giving two times green time within the same cycle.

Nine phase truncation other way termination of a green interval typically for the minor streets despite demand when there is minimal to no flow over a detector. No flow means almost no flow over a detector. So, that we are doing and where we are you can remember the earlier all discussion when we talked about the coordinated signal systems as well right coordinate signal systems or even the other strategies in this module only. Several lectures were dedicated on many of the discussions related to this that phase truncation. Termination of the green interval despite demand when there is a minimal to no flow over a detector particularly this was discussed when we talked about the actuated signals.

How actuated signals operate what are could be the different strategies recall particularly right. So, that those are getting linked here. So, we are truncating the green interval and where we are we are going back going back and giving green to the over saturated phase. So, basically primarily the through movement. So, add green go back go back to the through movement and give green truncate the minor movement green.

So, 7 to 9 these are all again for isolated intersection. Tenth one is simultaneous offset what is simultaneous offset setting offset to 0 between intersection. So, that queues move simultaneously initiate the green simultaneously setting offset to 0 between intersection. So, that queues move simultaneously you have understood already the progression vehicle progression during coordination and the queued up vehicle already which are present in the upstream signal.

So, you can understand what we are talking here. Last one is negative offset starting the green interval earlier at downstream intersections to allow the downstream queues to dissipate before the upstream vehicles arrive. So, negative offset we are using that means, normally what we do we initiate the green from the upstream and after time t we initiate the green for the downstream intersection right to ensure progression. And then if there are queued up vehicles maybe we will start bit early. So, that all the queued up vehicles are cleared before the platoon of vehicles reach from the upstream intersection, but there are lot of vehicles in the queue. So, you have to start the green so early that the offset becomes negative.

So, the downstream signal becomes green even before the upstream signal becomes green because of the long queue. So, the offset becomes negative. So, we call it as reverse progression.

Mitigation Strategies

	Mitigation Strategy	Definition
12	Offsets to Prevent Queue Spillback	Choosing offsets that allow the downstream queue to clear before the upstream vehicles reach the end of the downstream queue
13	Offsets to Prevent Starvation	Choosing offsets that ensure the first released vehicle at the upstream intersection joins the discharging queue as it begins to move
14	Metering (Gating)	Impeding traffic at appropriate upstream points to prevent traffic flow from reaching critical levels at downstream intersections
15	Adaptive Control	Applying detection data and adaptive signal control algorithms to adjust signal timing
16	Combination of Mitigation Strategies	Combining mitigation strategies and/or using them in sequence throughout the oversaturated period

Manage Queues
12-13: Arterials
14: Networks

Maximize Intersection Throughput and Manage Queues
15-16: All

IIT Kharagpur | Traffic Engineering| Module E 17

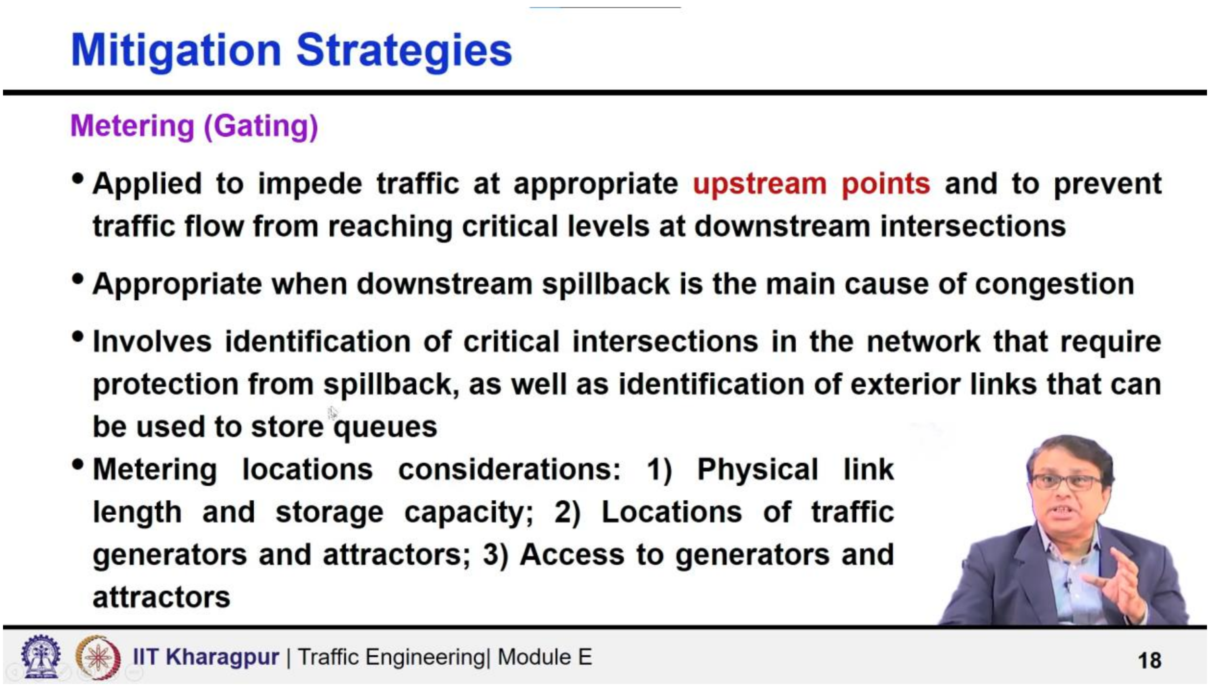
Then offset to prevent queue spillback choosing offset that allow downstream queue to clear before the what I mentioned before the upstream vehicle reach at the end of downstream queue. So, obviously, you know there is better better management will happen.

Offset to prevent starvation choosing offsets that ensure the first release vehicle at the upstream junction joins the discharge queue as it begins to move. So, before it starts beginning starting to move the vehicle from the upstream intersection will reach. So, choosing offset that ensure that the first released vehicles from the upstream joins the queue discharge queue as it begins to move. So, there is no starvation always you have vehicles during the green. Metering again another very effective instrument often done at the network level typically in the CBD and the metering we do for the side road or the minor road.

Controlled way in a controlled way you are allowing the vehicle to enter your through movement is there. So, from other roads in a controlled way metering we are doing we are controlling the rate at which the inflow is happening. So, impeding traffic at appropriate upstream points to prevent traffic flow from reaching critical levels at the downstream intersection. We know that downstream intersection cannot accommodate more than this and over saturated condition will happen and everything will be chaotic. So, to avoid that we are controlling the inflow from the upstream signals at appropriate locations where it is useful or where it can be done effectively there we are doing the metering.

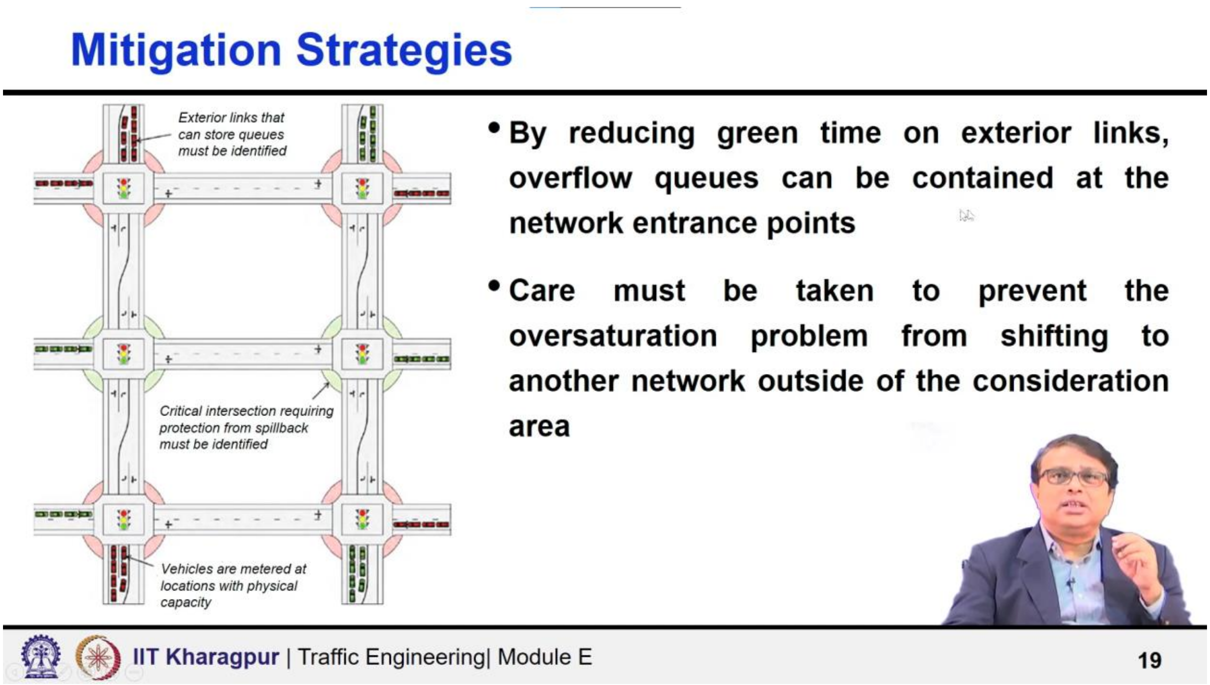
We are controlling the inflow because we know that if we do not control if we allow every vehicle to enter as they want or as they wish then ultimately the downstream intersection will not be able to handle and the over saturation will occur and everything will become chaotic. So, to a trying to do avoid that metering or through metering or getting I will discuss little bit more about that. The other two are the adaptive control particularly is the advanced one it is adaptive system we are talking like applying detection data and adaptive signal control algorithm to adjust signal timings. This I am saying this is the advanced type of coordination also is done you are doing the actuation you are actually detecting the data and controlling everything.

So, the adaptive control is also one strategy. Then combination of mitigation strategies combined mitigation strategies and or using them in sequence throughout the over saturated period.



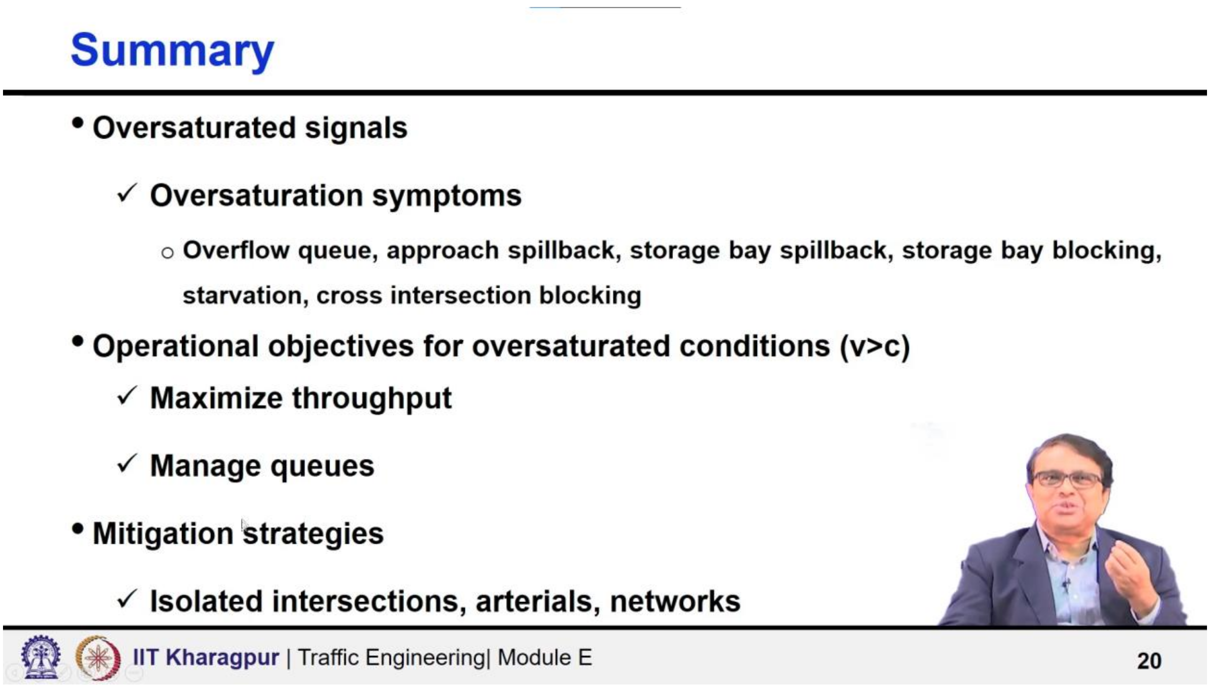
So, what is really metering as I said is applied to impede traffic at appropriate upstream points and to prevent traffic flow from reaching critical level at downstream intersection we know the capacity is limited. So, stop the vehicle well in advance while they are entering through different points and appropriate when downstream spill back is the main cause of congestion and it involves identification of critical intersections in the network that require protection from spillback. So, we know from the past experience that which are the typical intersections where such kind of over saturation and spillback will occur and which need some kind of protection. So, to protect those intersections we will do the metering at upstream intersections.

Also we need to identify of exterior links that can be used to store queues because there we are stopping vehicles. So, there should be have facilities physical facilities should be there to operate such kind of things. So, metering locations we decide considering several things for example, physical link length and storage capacity. For example, the physical link length and storage capacity also the locations of traffic generators and attractors the access to those generators and attractors all these are considered to decide where you want to really do the metering and control.



So, that is what I have shown here. So, if this is the critical intersection requiring protection from spill back that we have identified. So, by reducing green time on exterior links overflow queues can be content at the network entrance point. So, this everything if you are seeing this network is getting fed by external points right. So, exterior links that can be that can store queues must be identified. So, you have identified here you have probably have also identified here and then you are actually controlling the entry from the upstream intersections just to protect this intersection or to avoid the queue spill back over saturated at this intersection.

Now care must be taken to prevent the over saturation problem from shifting to another network outside the consideration area. Maybe I am only looking at this, but there will be an edge effect because I am taking that these are the intersection located in the periphery of my study area, but if they become if I do metering there what will be the impact. So, I should not actually transfer the problem hugely to another network which is not within my consideration. So, I want to avoid problems without causing significant problem to other networks. So, it should not happen that I protect this, this is free, but all these intersections become over saturated and utter chaotic that also we cannot accept right. So, balance we have to maintain.



So, to conclude we discussed today about over saturated signals particularly the symptoms of over saturations and then what could be our operational objectives maximize the throughput and also do better management of queues and then discussed various strategies which could be applied appropriately either at isolated intersections or at arterials or at network level. With this I close this lecture and also close this module. Thank you so much.