Traffic Engineering
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Lecture 39
Actuated Signals

Welcome to Module E lecture 13. In this lecture, we shall discuss little bit more about actuated signals.

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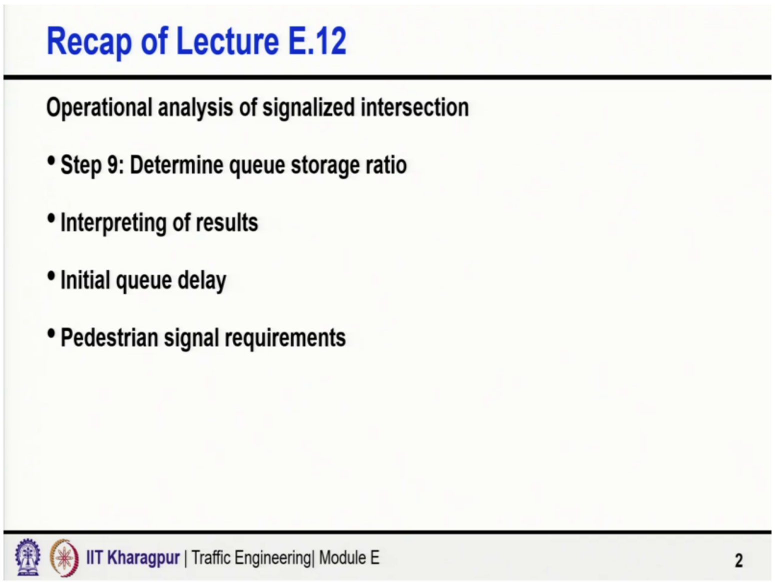

In lecture 12, we discussed about step 9 or practically the last step related to operational analysis of signalized intersection and we focused on step 9 that is determination of queue storage ratio. Then we also discussed about how to interpret the results a little bit more understanding about initial queue delay, estimation and also the requirement of pedestrian signal.

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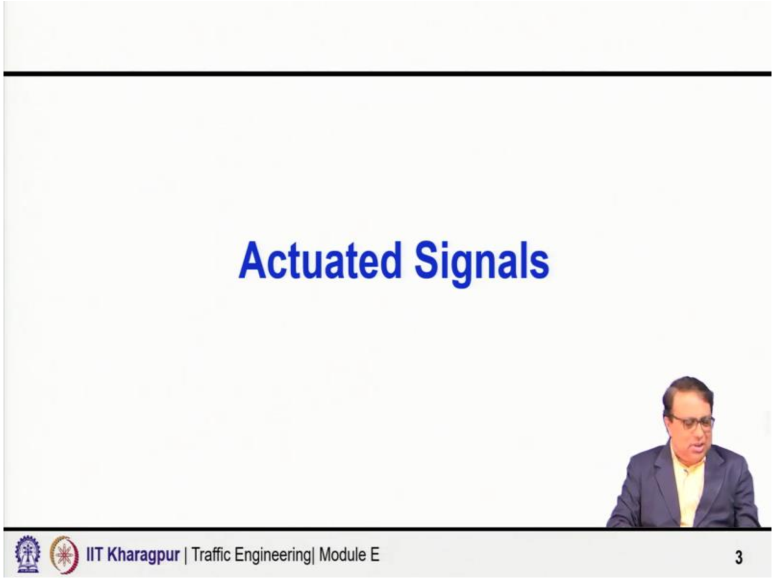

Now, today, we are focusing a little bit more discussion on actuated signal. Today, we are focusing more on actuated signals.

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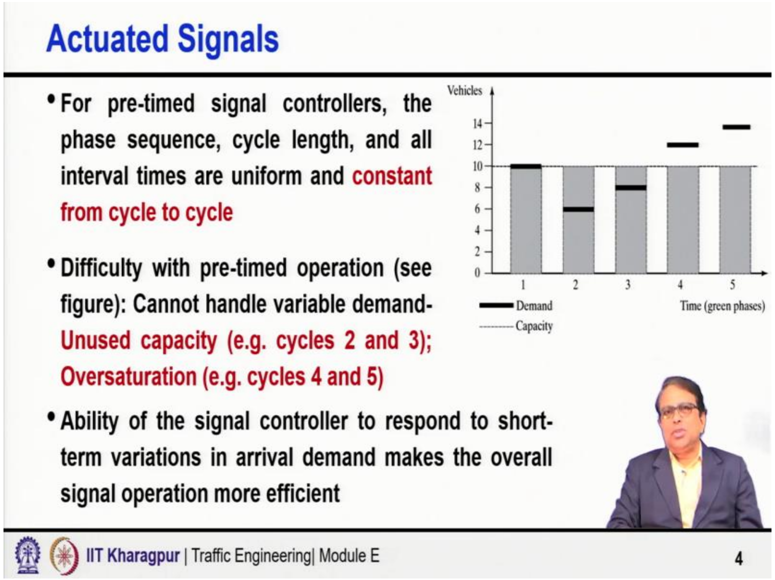

As you know, for pre-timed signal controller, the phase sequence, the cycle length and all interval times are uniform and constant from cycle to cycle, that means, we take let us say, evening peak or morning peak during that period for that entire period, we design the signal and we keep everything constant, cycle length constant, phase sequence constant, interval times constant everything is same. It does not change from cycle to cycle during that period.

Now, this has really got a disadvantage or difficulties that such kind of signals setting or controller cannot handle variable demand. As you know, because of the stochasticity every 15 minute during even the 2-hour, 3-hour or 4-hour period of analysis. The traffic is not exactly same in every cycle. So, sometimes as you can see in some cycle exactly, it may be what we expected and based on which the design has been done. So, I can generally say that capacity and demand are very well balanced same or you can even say we have designed it for a target volume to capacity ratio. So, in that sense also whatever we wanted and whatever demand we wanted to serve through this designed exactly the demand is same.

But in some cycles, it may be demand may be lower as compared to whatever way we have designed. Some cycles, the demand will also be higher. So, fixed time or pre-timed signal has the difficulty that it cannot handle variable demand. So, there could be sometimes unused capacity and sometimes there could be oversaturation as well. Because these are all cycle to cycle fluctuations we are talking. We are not talking about morning peak and off peak or evening peak and off peak, no, within the period for which we have designed the signal within that period also cycle to cycle the demand is varying.

Now, if we can do something to bring the ability or to impart the ability within the signal controller to respond to short term variation, as I have shown here, cycle to cycle variation, then short term variation in arrival demand, then the overall signal operation will be much more efficient. That is what we are trying to do when we are talking about actuated signal.

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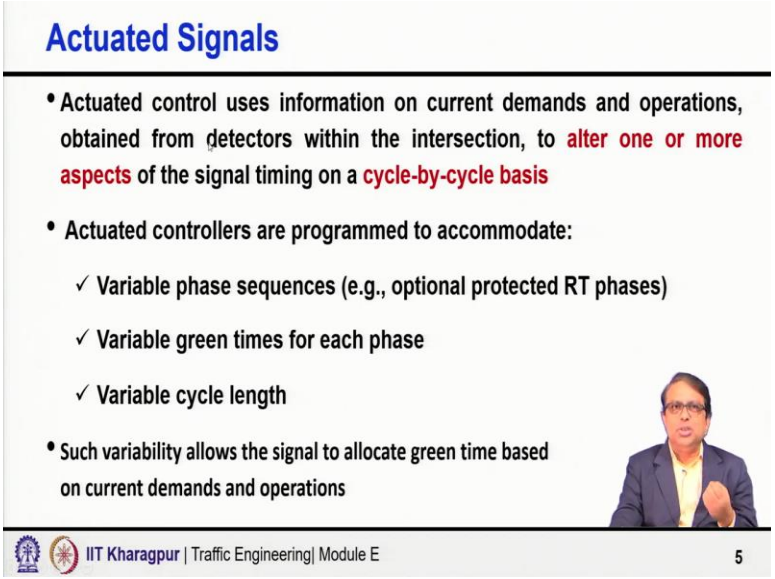

So, actuated controller uses information on current demand and operations obtained through the detectors. So, there are detectors placed detectors may be placed on one approach may be placed on all approaches it depends. But either fully or partially, we are using on some approaches on some approach or all the approaches, we are using detectors and then getting the information on current demands and operations.

And then accordingly, we are then altering one or more aspects of the overall signal design on a cycle to cycle basis. That means, practically, we are sensing we are trying to understand through detector what is the current demand and what is the current operation and then as per the requirement or as per predetermined rule also, we are altering one or more aspects of the overall signal timings on a cycle to cycle basis.

So, actuated controllers are programmed to accommodate several things. First say variable phase sequence, the phase sequence also need not be fixed and sometimes it may be optional protected right turn phase, not always we give when there are the volumes of right turning vehicle and opposing through volume all those conditions are there in that cycle maybe you use a protected right turn phase.

In other situations, you may use as a permitted right turn. It may we may use variable green time for each phase not that green time is fixed, the phase may be same, but the green time is not same in cycle to cycle. Even as per the requirement, the cycle length also vary. So, everything may vary one or more things may vary cycle length may vary, phase sequence may vary, green time for each phase may vary. As per the current demand and operations which are information which are obtained through the detectors.

Now, such variability allows the signal to allocate green time based on the current demands and operations. So, therefore, it will be more efficient and the kind of problems what I explained here that sometimes the demand may be even higher, unused capacity maybe there, somewhere worse saturation could be there, that kind of problem can be avoided to make the overall operations of traffic more efficient through this actuated signal controller.

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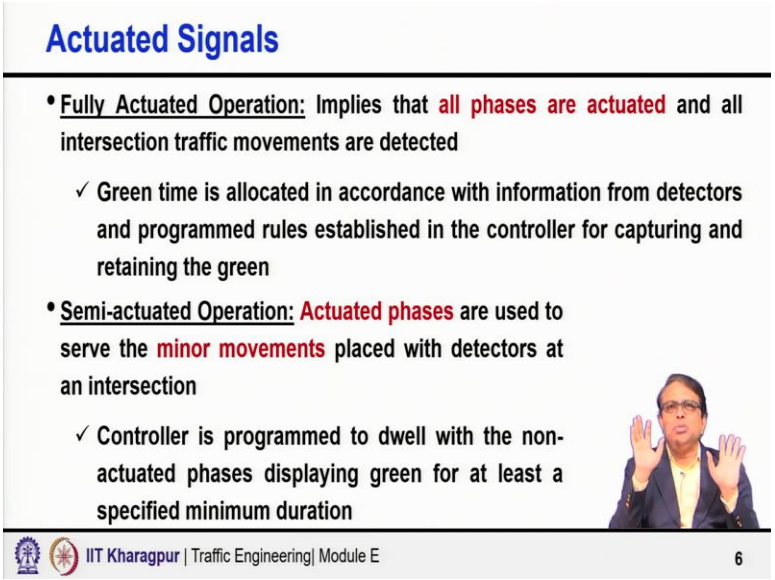

Now, actuated signals could be fully actuated operation or could be again semi actuated operations, what is fully actuated operation? Where all phases are actuated, all approaches, all movements we are getting information through detectors and all intersection traffic moments therefore, are detected.

Now, here the green time is allocated in accordance with the information from detectors and also programmed rule established in the controller for capturing and retaining the green. So, one is how volume level information we are getting, volume related information we are getting from detectors and then what program rule we have established in the controller, regarding, capturing and retaining the green accordingly the whole operation will happen.

So, fundamental thing is all phases are actuated. Semi actuated operation on the other hand are used in this case, where we are using semi actuated operations actuated phases are used to serve the minor movement placed with detectors at an intersection. So, semi actuated is always when one road or one movement corridor has got distinctly higher priority than the other road. So, one major road another is a minor road and, in all cases, by default we would like to give green to the main movement and therefore, the actuation may be required only for the minor movement, minor approach that will be actuated.

So, actuated phases are used to serve only the minor movement placed with detector at an intersection. And in this case as I said, the controller is programmed to dwell with the non-actuated phases displaying green for at least a specified minimum duration. So, not that always the moment a vehicle is you know sensed that the vehicle is approaching from the minor approach, it is not that immediately will give green, there are the main movement once it is giving green once I have given green to the main movement, at least I would like to keep that green for some minimum duration before it is changed or the before the change of phase.

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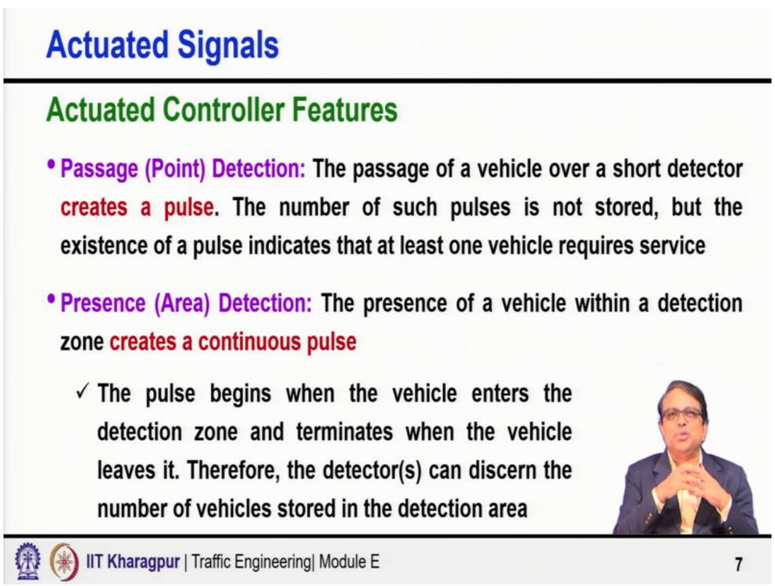

So, now let us look at some of the also understand some of the actuated controller feature. The detection is very important in the overall actuated signal control. The detection could be point detection or area detection. Point detection also can be called as passage detection, I am detecting the passage of vehicle at a point. So, it is at a point detecting vehicle at a point and detecting the passage of vehicle a vehicle has crossed that point that is getting detected.

So, the passage of vehicle over a short detector creates a pulse the number of such pulses is not stored, but the existent of a pulse indicates that at least one vehicle request service. Suppose maybe when the vehicle is crossing during its length also multiple times the pulse is coming and one vehicle has crossed another vehicle is also crossing again multiple times the pulse may come but we are not worried how many pulses are coming that we are not really noting. Because even if there is a pulse only one pulse or more than one pulse, it is sure that at least one vehicle is waiting and for the service.

So, that information is there, yes, there is a vehicle. So, as per programed rules you need to give green and this information is sent that there is a vehicle one or more vehicle waiting for the service. The area detection is basically the presence detection it is not at a point, it is for a in a particular area. So, detection is done over an area. So, the presence of vehicle within a detection zone the area of what I said is basically the detection zone. So, the presence of a vehicle within a detection zone creates a continuous pulse. So, that means whatever is my detection zone as long as vehicle or vehicles are there, continuous pulse will get generated.

So, as long as the pulse is coming, I know that there is a vehicle at least one vehicle is waiting. So, the pulse begins when the vehicle enters the detection zone and terminates when the complete vehicle leaves it, even a part of vehicle is in the detection zone still that pulse will come because the vehicle is present within that area. That is the difference between the point detection and area detection.

Point detection just passage of vehicle it is set a point and the area detection or the presence detection is as long as even a part of the vehicle is present within that detection zone. The pulse will keep generating, generation of pulse will continue as long as the will part of the vehicle is there within the detection zone the generation of pulse will continue. So, the pulse begins when the vehicle enters the detection zone and terminates when the vehicle leaves it and leaves it completely. Therefore, the detector can discern the number of vehicles stored in the detection area that is also possible.

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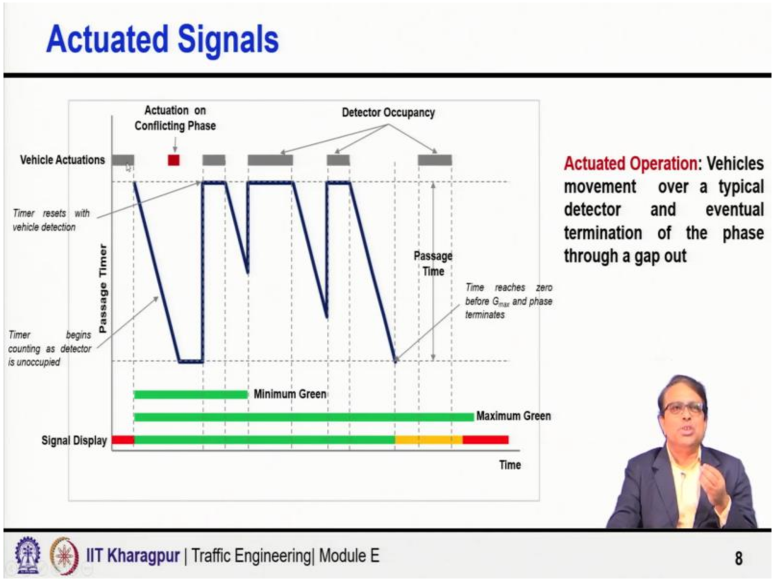

Now, this is an interesting representation many things we are showing here, let us look at this actuated operation, how this actuated operation takes place. Here it is the signal display red, then the green, then again amber followed by green red again. So, and then along with it you can say two green bars, one is showing minimum green as I said that, the minimum green is always provided.

Once you give a green, you want to continue that green for some certain minimum time. So, that is the minimum time. So, this is the lower limit of green and there is also a higher limit which is called as maximum green. So, once the green is given and maybe one after vehicle, another vehicle is one after another vehicle is approaching one after another.

So, we keep on extending, but shall we keep on extending for any time. No, there is also an upper limit that is the maximum green. So, the green actual green will be provided in between minimum green and maximum green it should not be lower than minimum green it should not be hard that maximum green. Here I am showing vehicle actuations. So, the grey portion indicates that vehicle is present.

So, wherever you can see grey these all indicate that a vehicle is present there and the blank portion indicates no vehicle is present. So, whenever a vehicle is present detector is occupied, you can see that is shown as grey. The red share this small box shows actuation on conflicting phase, it is an indication that in a conflicting phase a vehicle has arrived and waiting that information is coming.

Now, what happens signal changes from red to green, so, the vehicle which was waiting and the detector was occupied, it is cleared then there is no vehicle. So, the here we are saying passage time bar and there is something called passage time as well. So, passage timer starts working the moment the detector is free of vehicle the counter starts 1, 2, 3, 4, it starts.

And there is a maximum time given which is called the passage time that means, once the detector is free, then up to that given passage time within that time, if another vehicle is reaching, then the green will be extended. So, if within the passage time and another vehicle is also reaching then or arriving then green will be extended to give green to that vehicle also we just arrived just now.

So, here you can see here that passage timer is on and this dotted line shows the limit for the passage time. So, passage timer says that the given passage time is over, but then it should change it should go to the next phase making it red with of course amber but we cannot do that, why? Because it is still lower than the minimum green.

So, we have to give up to minimum green. So, even if the passage time is over, passage timer indicates that but still the green will not be terminated because the minimum green time has not been given. So, it continues and then detector is again occupied. So, another vehicle has come. So, it goes back once that vehicle is cleared again the detectors sense that there is no vehicle so the passage timer starts working.

But now before it reaches to the limiting value of the passage time another vehicle is detected. So, it continues. Again, it comes back comes down passage timer starts working, but before it touches the base that the maximum passage time or passage time whatever we have given again vehicle detector is occupied. So, it goes back.

Now, here in this position you can see, it comes down to this touches, this dotted line, which is this time duration, this time duration between this dotted line horizontal and this dotted line, this is actually the passage time what we have set. So, within the passage time now, no more vehicle and we have already given green more than the minimum green. So, now, and there is also actuation on conflicting phase, so, you terminate this green. So, you give amber followed by red, that is the whole operation.

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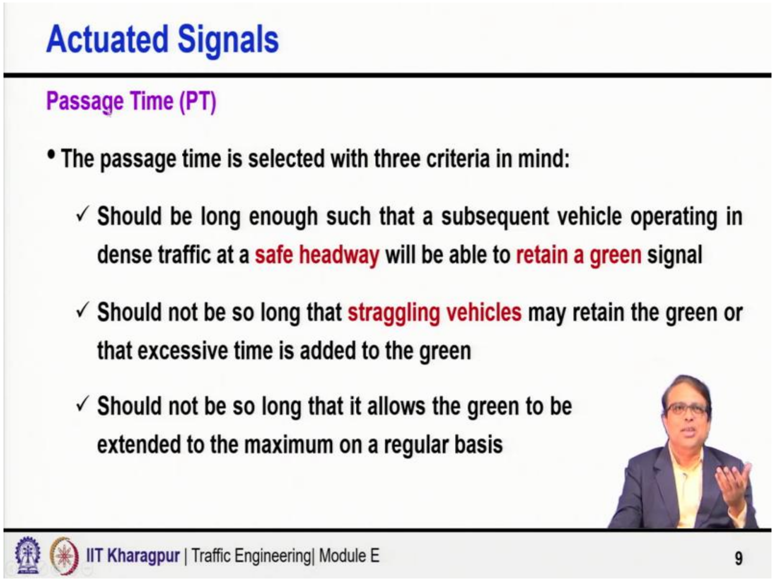

So, what is the passage time? I have explained. The passage time system is selected with three criteria in mind. First, it should be long enough such that the subsequent vehicle operating in a dense traffic at a safe headway will be able to return a green signal. So, if I give it too short and it is so, short. So, less that even when vehicles are operating in a dense traffic flow and maintaining a safe headway, still one vehicle to another vehicle discontinuation will happen that we do not want. We do not want it to be so short.

So, it should at least it should be long enough such that subsequent vehicle operating in dense traffic at a safe headway will be able to return the green, that much long it has to be. But it should not be so, long that straggling vehicles may retain the green or that excessive time is added to the green that kind of, yes, minimum it has to satisfy the first point, but it should not be so, long that straggling vehicles may return the green or the excessive time is added to the green.

Third it also should not be so, long that it allows the green to be extended to the maximum on a regular basis. That means, you have given the passage time so, high value that nearly every time you are actually using the maximum green on a regular basis. That means, if you are most of the cases you are actually your green time is going up to maximum green then this is that indication that your passage time is actually high. It should bring down or lower passage time is desirable.

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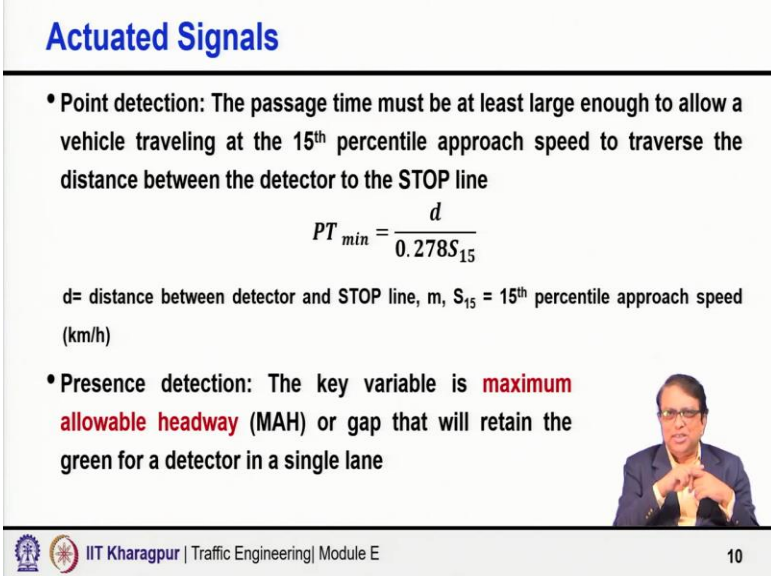

Now, for point detection, I have told you what is point detection what is presence detection. Now, for point detection the passage time must be at least long enough to allow a vehicle traveling at the 15th percentile approach speed. Because we have to satisfy the requirement of most of the vehicles which are approaching.

So, whatever is the 15th percentile approach speed that we calculate and what we are saying these passage time must be large enough that minimum required passage time should satisfy this criteria to allow a vehicle traveling at the 15th percentile approach speed to traverse the distance between the detector to the stop line.

Now, the detector point detector is not placed at the stop line it is placed. So, if this is the stop line, the point detector is placed before that and this distance is actually the distance d. So, distance between detector and this stop line and S15 is the 15-percentile speed. So, if I know the speed, if I know the distance, then I can easily calculate how much time it will take for the vehicle once it crosses the detector point detection part detector, then it should be able to cross the stop line.

$$PT_{min} = \frac{d}{0.278S_{15}}$$

So, that is d by basically speed, but since d is in meter and speed is in kilo meter per hour, so, the 0.278 is coming. So, it is d by 0.278 S15. Now, when there is a present detection, presence detection that means, as I said earlier, it could be point detection or it could be area detection. So, when it is passage detection it is only that distance. So, once you have crossed this, you should be also able to cross the stop line, that is the only thing.

But for area detection or presence detection, the length of the detector is also important. So, the key variable what is important here in this context, when you are talking about what should be the passage time, then the maximum allowable headway or the gap that will retain the green for a detector in a single lane that becomes important, how to calculate it?

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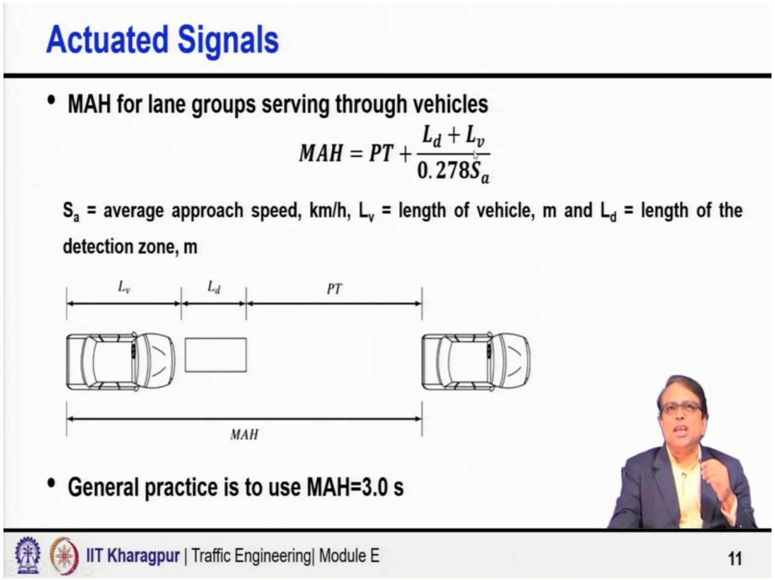

Now, maximum allowable headway should be passage time, but not only passage time here plus Ld plus Lv by 0.278 Sa, what is Ld? Ld is the length of the detector. It is area detectors. So, how much what is the length of that area which is under detection? And Lv is the length of the vehicle remember that the detector will keep on sending pulse as long as even a part of the vehicle is within this length Ld.

$$MAH = PT + \frac{L_d + L_v}{0.278 S_a}$$

So, that is the reason MAH equal to PT plus in this case, Ld plus Lv by 0.278 Sa, what is Sa? Sa is taken here the average approach speed, not in this case 15th percentile speed, this is average approach speed. General practice is to use MAH as 3 seconds. So, if MAH is you are using as 3 second, you know what is the length of the detector, what is the typical length of a vehicle, you can actually calculate the passage time.

And when it is a point detection, as I said here, then the PT and MAH even if we consider it in that sense, they are the same thing. Why? Because Ld is 0 and since it is a point detection, all the vehicle has got a length, and even if multiple pulses is coming it really does not matter. We do not count the number of pulse, we only count that whether there is a pulse, even one pulse multiple pulse, it is all the same, it only says at least one vehicle is waiting for the service.

So, the Lv is also not so important. So, Lv is ignored, Ld is also ignored in a way you can consider them 0 for this particular context or application. Actual length of the vehicle will be there. But for point detection, the length is not important, because as I said that one or more pulse, it is all the same, it only tells you that at least one vehicle is waiting to get a service.

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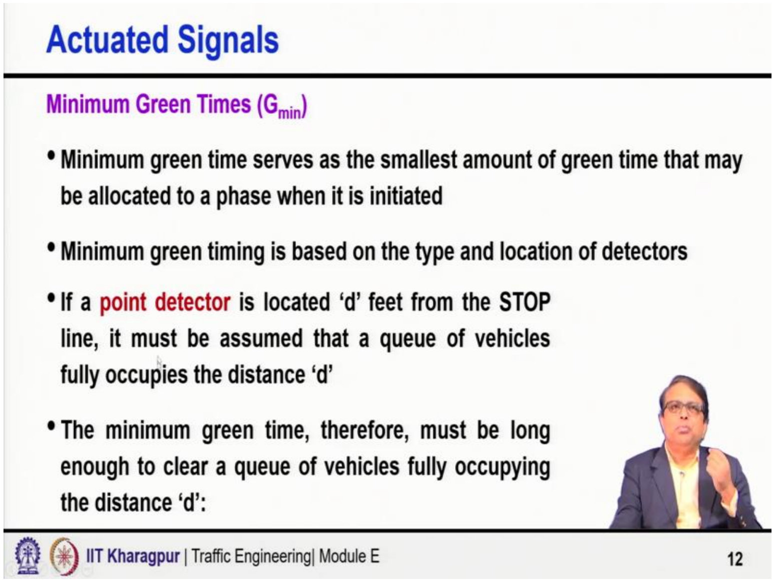

Now, what should we then, next part is minimum green time, minimum green time serves as the smallest amounts of green time that may be allocated to a phase when it is initiated. So, minimum green time has to be retained, once you are giving green to a phase you want to at least continue that up to the minimum green time.

Now, minimum green timing is based on the type and location of detectors and if a point detector is located, again I am saying point detection area detection both we have to understand clearly. So, if there is a point detector we are using, then d feet is the distance. Yes, because in manual it is used given the formulas are given based on feet so I have written it.

If a point detector is located d feet from the stop line, then it must be assumed that the queue of vehicles fully occupies the distance d. So, we will assume that up to distance d fully occupied, So, the minimum green therefore, must be long enough to clear a queue of vehicles occupying distance d. So, here is your stop line here is your point detector, we are assuming that the entire thing is occupied with vehicle. So, how many vehicles can occupy the length d? And how much time will be required to clear those vehicles?

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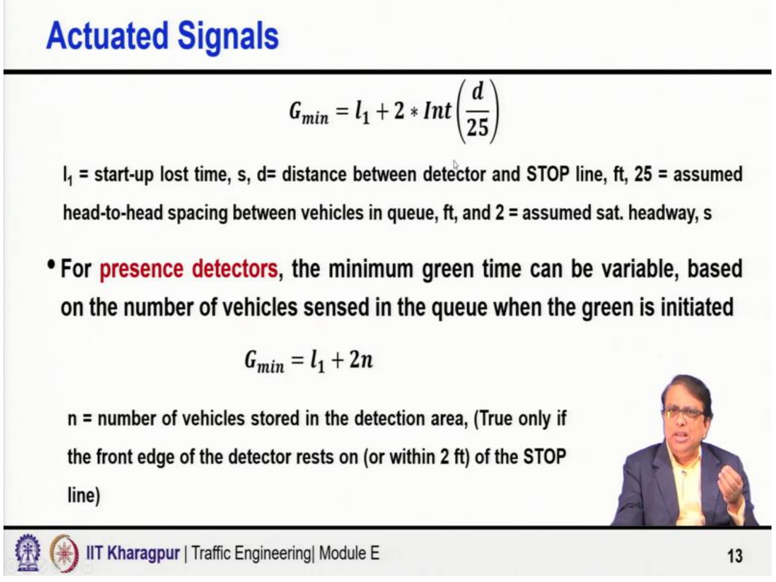

We can calculate that. So, that will be l1, 1l is the start-up lost time because, now the green will be given. So, vehicles are waiting, so, there will be start-up lost time plus how many vehicles, if d is the distance then average in feet then here as per the manual 25 feet is taken head to head spacing between vehicles in queue.

$$G_{min} = l_1 + 2 * Int\left(\frac{d}{25}\right)$$

So, d by 25, 25 is that assumed head to head spacing between vehicles in queue and the 2 and feet. So, d by 25 that many number of vehicles you take the integer take it on the higher side multiplied by 2 seconds is assumed as the saturation headway. So, 2 seconds multiplied by that many vehicles are to be cleared. So, 2 second is the saturation headway multiplied by d by 25 in integer higher number and plus you are considering the start-up last time. So, that way we can decide what will be the G minimum.

Now, for presence detectors or area detection the minimum green time can be variable based on the number of vehicle sensed in the queue when the green is initiated, because you have an area. Now, how many vehicles are there? Maybe 1 vehicle also could be there multiple vehicles also could be there, it depends on what is the length of detection area, how much is the length of the detection area, vis-à-vis, how much is the average length of a vehicle, how many vehicles are there it could be 1 vehicle it could accommodate more than 1 vehicle in the presence area.

$$G_{min} = l_1 + 2n$$

So, G minimum means obviously, start-up loss time plus 2 into n, why 2? 2 is the same 2 here that is the saturation headway multiplied by assuming there are n number of vehicle stored in the detection area. This is only this part is true when the frontage of the detector rests on or within 2 feet of the stop line that means the area detection is done actually from the stop line or very close to the stop line, then it is l1 plus 2n. If not, if like the point detector, if that area detection is also done from a distance d from the stop line, the starting point of the detection zone or detection area is actually if that is d distance from the stop line, then obviously, this component also will be added. So, that is what is done here.

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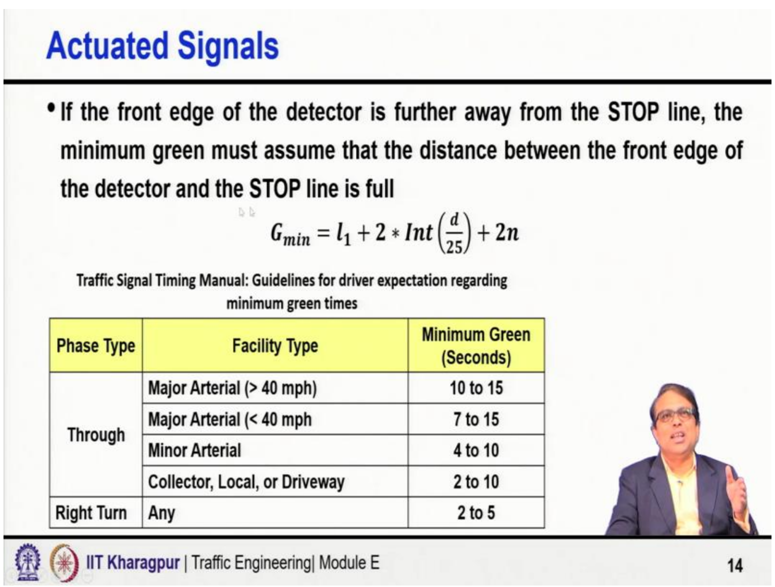

So, if the front edge of the detector is further away from the stop line, the minimum green must assume that the distance between the front edge of the detector and the stop line is full. So, in that case, G minimum will be l1 plus 2 into this part plus 2 into n. So, here traffic signal timing manuals, it gives you some typical values different type of phase through right turn, what is the facility type, if this major arterial with speed greater than 40 mile per hour speed less than 40 mile per hour. Then what is the minimum green time that is recommended some recommended values are there.

$$G_{min} = l_1 + 2 * Int\left(\frac{d}{25}\right) + 2n$$

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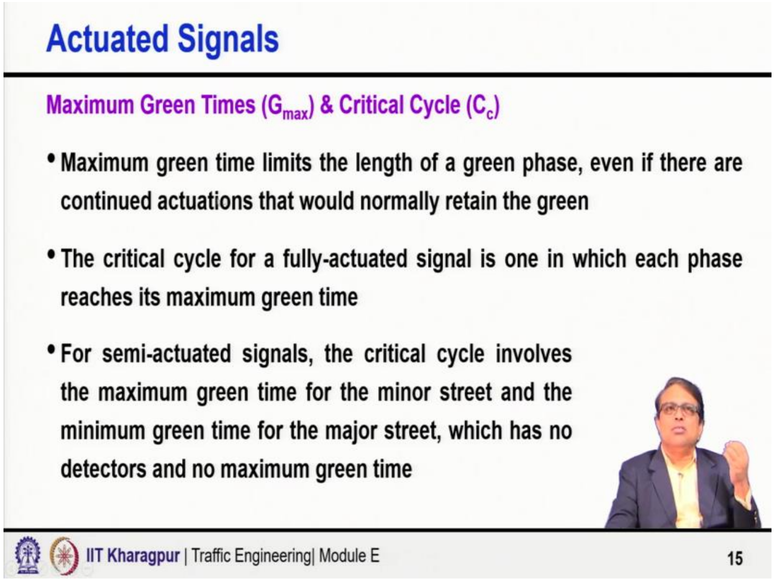

Now, coming to the maximum green time and critical cycle. Maximum green time limits the length of the green phase even if there are continued actuations that would normally written the green that means we are saying what we had, what is green extension. Before the passage time, if there is one second actuation then extend the green. How long we will extend? Shall we keep on extending as long as there is a vehicle? No, there is also maximum time that is the maximum green, and what is the critical cycle? Critical cycle for a fully actuated signal fully actuated please carefully note that is one in which phase reaches each phase reaches its maximum green time.

So, if it is fully actuated, then my critical cycle will be every phase will assume that with the maximum green time, then whatever is the total cycle length you require, that is the critical cycle. But if it is a semi actuated operation, then the by default the green should be for the through movement. So, for semi actuated the through movement, where it is supposed to be default should be green, unless there is an actuation from the minor approach.

So, in that case, the critical cycle will be maximum green for the actuated phase, minor road plus the minimum green, not the maximum green, but the minimum green for the through traffic or the major arterials along the major arterials, that is what is said here. So, for semi actuated signal, the critical cycle involves the maximum green time for the minor street and the minimum green time for the major street which has no detectors or and no maximum delay in time.

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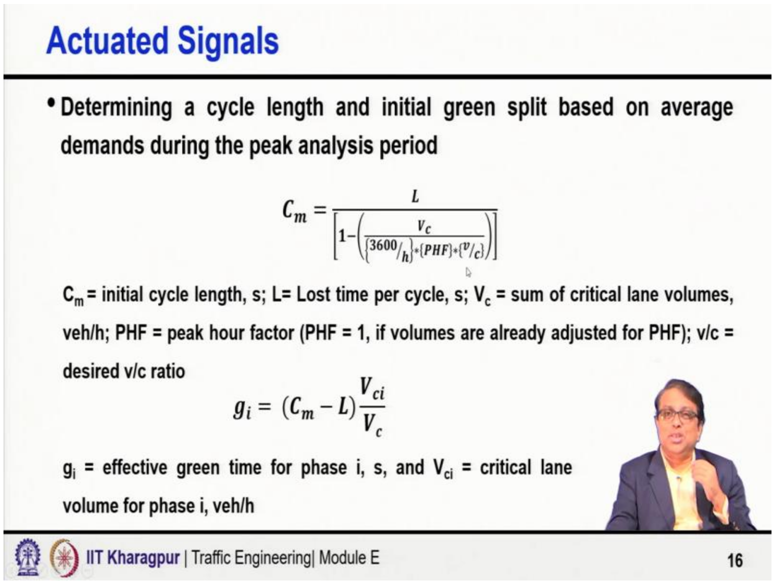

Now, how we can calculate the cycle length in general? You are familiar with this formulation, we discussed this when we talked about the critical time budget approach, also the planning level analysis, planning level analysis of intersections, not the operational level analysis, but the planning level analysis, we used a very similar equation a little bit changes some adjustment, but fundamentally it is the same approach.

But you remember when we talked about the time budget method, then we told this one as design C. But here, we are not calling it as design C, I am telling it as it is initial cycle length, because this is not a pre-timed operation, this is actually actuated operation. So, initially, we are calculating based using this formula, which is very well known to you.

$$C_m = \frac{L}{\left[1-\left(\frac{V_c}{\{3600/_h\}*\{PHF\}*\{v/_c\}}\right)\right]}$$

Now, obviously Vc is the sum of critical lane volume, peak hour factor, you know, why it is hourly flow rate and then peak 15-minute flow rate we want. But obviously, if your volume is already adjusted, then the PHF further will not be applied, you can use PHF as 1. Now, once you have done that, then you can calculate gi effective green time, what will be that? It is the cycle length minus the total loss time into Vci by Vc for a particular phase i, what is the critical volume divided by sum over critical volume for all the phase. So, Vc is some of critical lane volumes for the all the phase. So, that way you can get it you are familiar with this.

$$g_i = (C_m - L)\frac{V_{ci}}{Vc}$$

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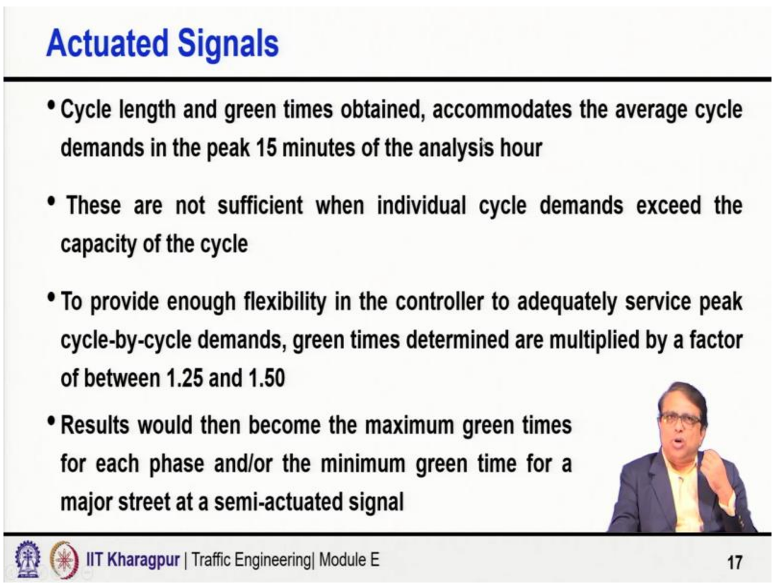

Now, cycle length and green time obtained accommodates the average cycle demand in the peak 15 minute of the analysis hour. Because we have taken PHF or we have adjusted the volumes itself considering the peak hour. So, therefore, further PHF, we are not applying we are taking it as 1, but any of the peak 15-minute hourly flow is accounted for. So, that should be fine.

These are not sufficient when individual cycle demands exceeds the capacity of the cycle, which may happen which do happen and that is why we are actually bringing the actuated signal control. So, to provide enough flexibility in the controller to adequately service peak cycle by cycle demand even when the fluctuation the average value what we have taken even in a cycle maybe the value demand is much higher than that. This such kind of fluctuations is the basic objective, why we are we want to account for such fluctuations in the signal design that the actuated signal is coming.

So, if we just keep that cycle length, then even if the demand is slightly higher the cycle will not be able to accommodate that. So, to provide enough flexibility in the controller to adequately service peak cycle by cycle demand, green time determined are multiplied by a factor between 1.25 and 1.50. So, make it higher than the result would then become the maximum green time for each phase and the minimum green time for a major street at a semi actuated signal as explained earlier.

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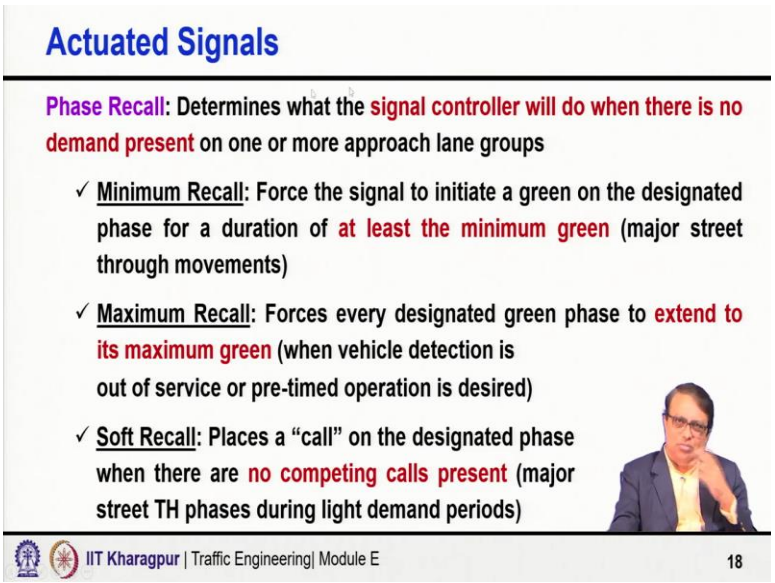

Now, one important thing is called phase recall. Phase recall is what? It determines what the signal controller will do, when there is no demand present on one or more approach lane groups. You remember earlier say recall is on with that red mark, that yes recall says the vehicle is waiting.

Now, Phase recall is something which tells you signal controller what you will do, you are presently giving green to a phase, it has a minimum green, it has a maximum green it has a PT value and then it should actually go to the next phase as per program rule in the controller. But suppose there is no vehicle in the conflicting one or the next phase, what it should do, that is coming under phase recall.

So, determines what the signal controller will do when there is no demand present on one or more approach lane groups. So, there are four possibilities primarily, one is the minimum recall that we enforce the signal to initiate green on the designated phase for a duration of at least a minimum green that means what will do, it is mostly the major straight through moment.

So, even if there is no actuation or indication that a vehicle is waiting, still you give the green. Because that is the normally the major street through movement in all possible cases and you just give a green, but give a green only for the minimum green. But the period of minimum green. Second is maximum recall same thing, but in this case, you give green to its maximum green you may ask if I am giving maximum green like this also what is the point, then why how way you thing that we are doing an actuated control way. Actually, this is more suitable or done when vehicle detection is out of service or pre-timed operation is desired.

You have saying that, okay, I do not want to operate with a you know with actuation either maybe my vehicle detection is not working or my I want the pre-timed operation to happen, then whatever it is, it has to go to the next phase let it go to the next phase and let it give the maximum green. That is the phase recall, we will do. It could be soft recall, which is again interesting it tells that it places a call on the designated phase a particular designated phase, which is normally the major street through phases during light demand period because that is where by default we want to give we like to give maximum green there.

So, it places a call on the designated phase when there is no competing call presence. No other competing call is present that means vehicle has not arrived, mostly minor movements will have such kind of situation. So, in that case, what you do? You give a soft recall that means you give it back to major straight through phase during light demand period. Because in all possibilities, you are more likely to get vehicle on the major street through phase rather than the other minor approaches.

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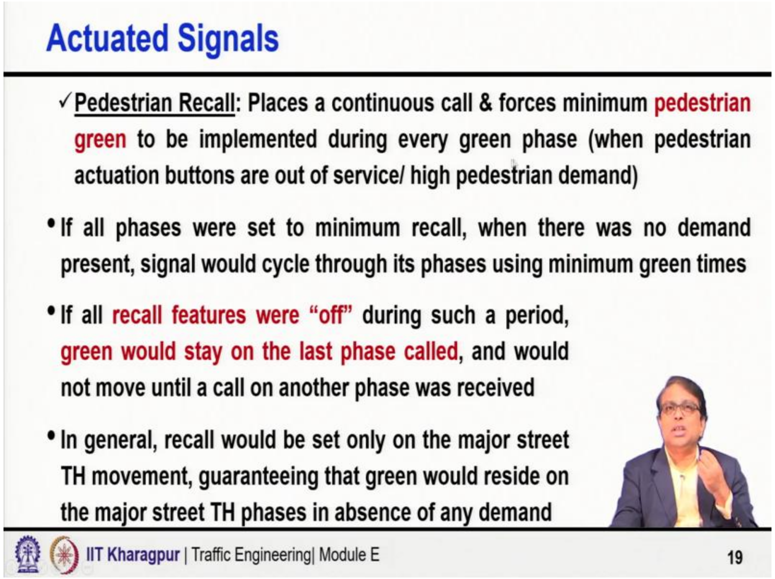

It could also be pedestrian recall that mean places a continuous call and forces minimum pedestrian green to be implemented during that every green phase. Again, when we are doing pedestrian recall under not under normal situation this kind of things maybe allowed when pedestrian actuation buttons are out of service. Again, like the first case we said in a that the maximum we are giving because the vehicle detection is out of service.

So in this case pedestrian recall is given when the pedestrian actuation buttons are out of service. So, it is not working or you know there is always a high pedestrian demand during that particular time period and for that particular moment. So, if all phases were said to minimum recall. So, just now with all this understanding this consider what will happen if all phases were set to minimum recall then what will happen when there was no demand present signal would cycle through its phases because all phases are on recall, but minimum recall.

So, what will happen it will run through all the phases using minimum green time. If the recall features were off, then you are not asking recall unless there is a vehicle actuation. Unless you sense the vehicle you are not asking the controller to change. So, if recall features were off during such a period, then green would stay on the last phase called wherever the green is given. no, we will continue and would not move until a call on other phase was received.

Unless next phase or somewhere there is a vehicle which is detected and the call is send, that yes there is a vehicle so, now it will change till the time if everything all the features recall feature where off, then whatever is the green given in the current phase that same green will continue. In general recall would be set only on major street through movement guaranteeing that green would reside on the major street through phase in the absence of demand on any of the minor approaches that short is mostly done, I have told it also that you can see here soft recall, major street through phases during the light demand period.

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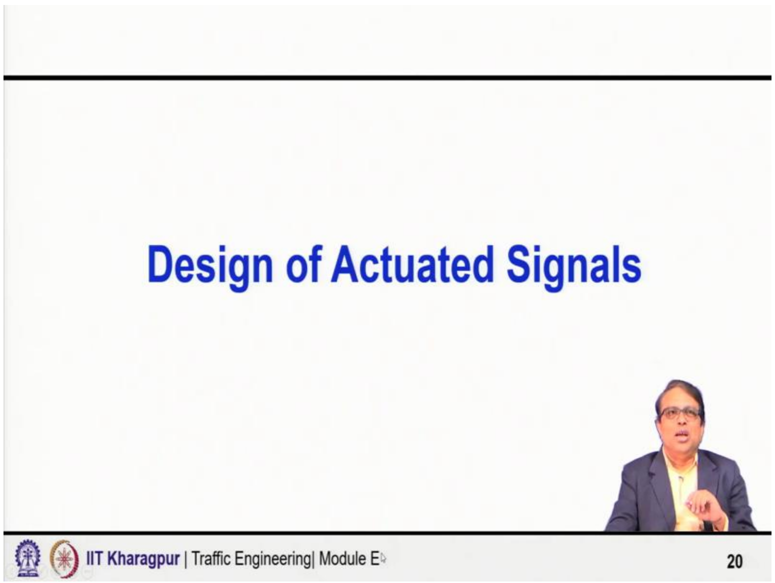

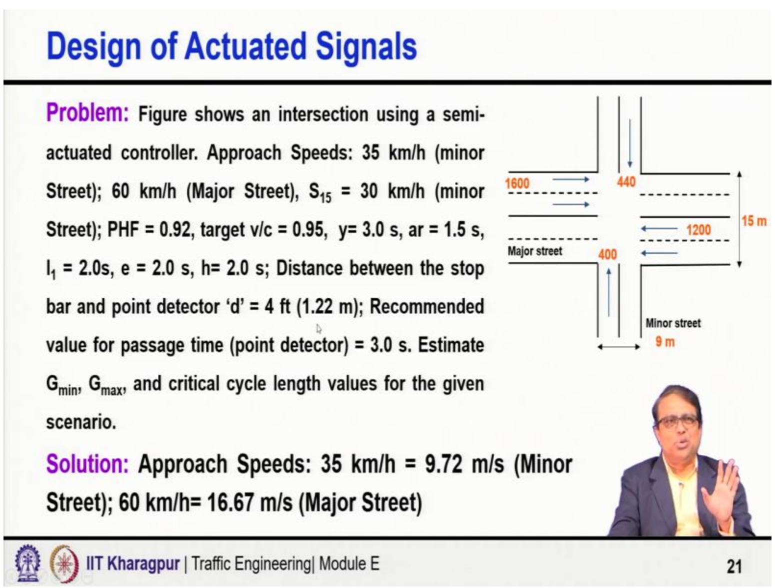

Now, a small design problem very simple one you can see it is a north, south, east, west two corridor is there one is a major corridor another is a minor one minor street minor street is 9 meter and here it is 15 meters the volumes are given and all other data target v by c, ambar, all red loss times, gain everything is given all the data's. So, I do not want to read out each and every input data what I would explain very quickly you can see in detail. The approach speed we are taking in meter per seconds from the kilometer per hour.

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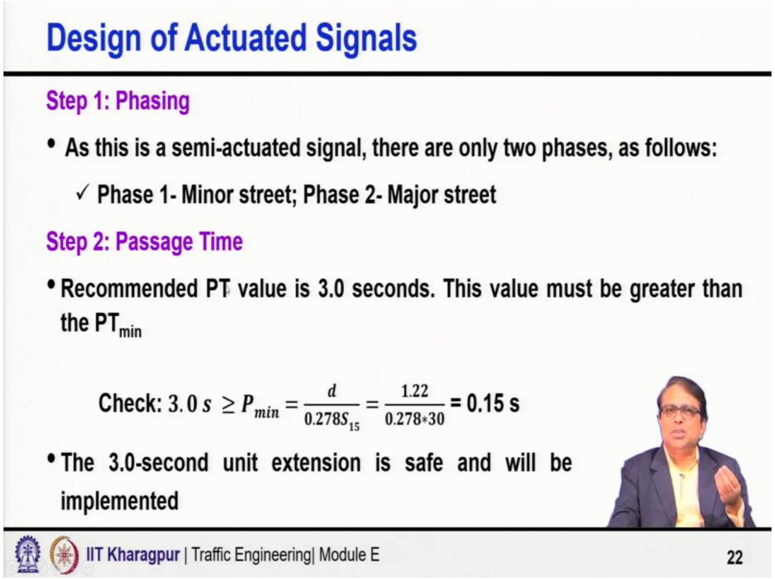

What we do here it is only two roads and only two straight movements no left turn no right turn. So, just a two-phase signal one for the minor street one for the major street. Now, what should be the passage time and it has said that recommended value point detector and it is saying 3 seconds.

Now, 3 seconds is given but we need to check whether this 3 second this check to be done whether it satisfy the PT minimum, what is PT minimum? You remember that I told here that what should be the PT minimum, d by 0.278 S15, d is the distance between the stop line and the detector point detector. So, that we need to check here that is what we are trying to do.

So, what we did here we checked it that what is the P minimum d by 0.278 S15, S15 is 30 kilo meter per hour, d is given these 1.22 meter when expressed in meter. So, 0.15 second it is 3 seconds is quite you know larger than 0.15 seconds. So, 3 seconds is good enough. So, you say that we just showed you that you need to check the PT minimum whether that requirement is satisfied. So, the 3 second unit extension is safe and can be implemented.

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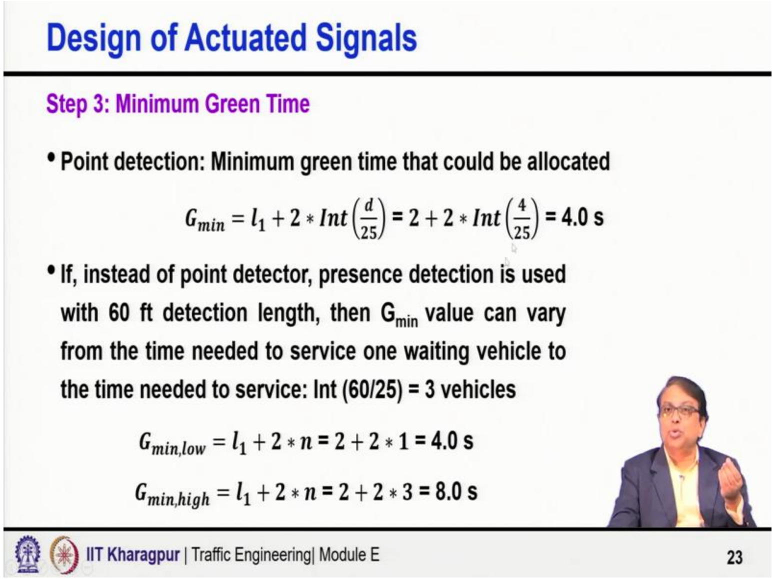

Then the minimum green time minimum green time could be what, lost time 2 seconds again plus 2 saturation headway into integer of d by 25. Now, d here is 4, 4 feet here this is given in feet. So, I retained it in feet only I give the input in feet also 4 by 25, you can see here d is the distance in feet and 25 is to assumed head to head spacing of vehicles in queue in feet. So, that is what we have done here. So, we have given the input and calculated what is the G minimum. Now, suppose instead of a point detector it would have been a area detector or presence detection and with detector length of detection length of 60 feet, then what would have happened, 60 feet maximum could accommodate 3 vehicles.

So, there could be 1 vehicle there could be 2 vehicle there could be 3 vehicle. So, even the G minimum would have a lower value or lowest value and the highest value. Lowest value would have been with one vehicle placed on the detector. So, l1 plus in that case 2 into n and the highest value should be 60 by 25 round off to upper integer is 3. So, it could have been 8 seconds. So, in that case this is not for this problem, but just I wanted to show this suppose instead for point detection is it would have been area detection or presence detection. Then how would we have we could have calculated.

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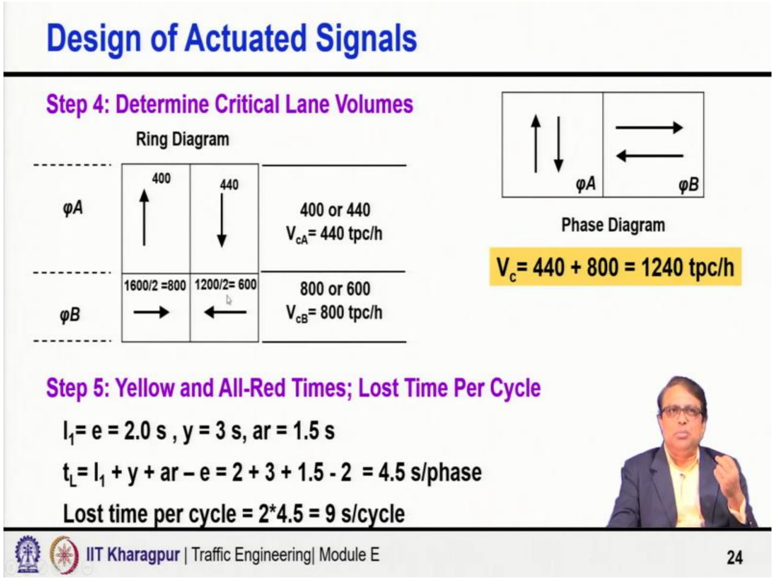

Now, coming to this thing going back to original problem, forget about this component this I wanted to see as an extra thing that suppose in case of instead of point detection if the area detection would have happened then how we could calculate. Now, coming to this one you know it is simple problem two phase signal.

So, you can see 400 440 VcA is 440 here you per lane you take it is 800 and westbound eastbound is 800 per lane and east eastbound is 800 per lane and westbound is 600 per lane. So, which one will be critical in B 800 or 600? Obviously, 800, which one will be critical for phase A 400 northbound or 440 southbound? Obviously 440 southbound. So, Vc you can calculate and here are the all the inputs are given lost time all-red lost time per cycle.

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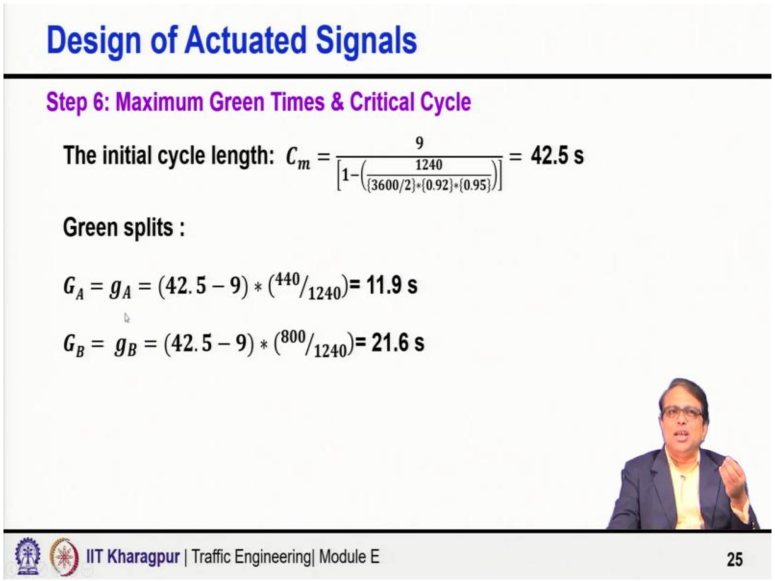

Then you can calculate the initial cycle length using this formula which we have already discussed. Once you have done that, you can calculate GA and GB and here the effective green time and actual green time will be same because of this lost time all-red the values as given in this context is such that they will become same. You can check in detail you will get the same value. In this case there is no difference for this problem.

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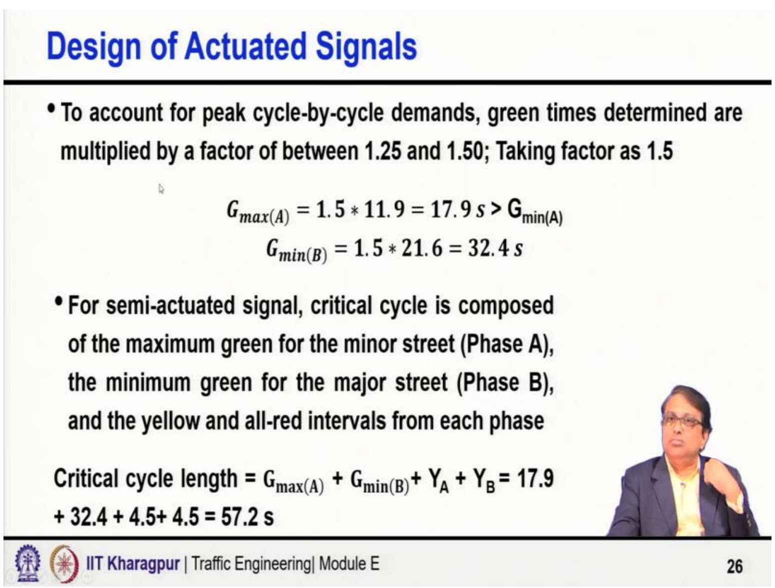

Now, what we said to account for peak cycle by cycle demand, we want to probably we need to make it higher. So, let us say we use the factor 1.5. If so, then what will be the GA max? It will be

1.5 into 11.9, 11.9 we calculated here, but we had increasing it 1.5 times. Similarly, 21.6 increase it by 1.5 times 32.4.

Now, again what we are taking here whatever the green time we are giving are we satisfying the required minimum green time. Yes, we found that it is greater than GA minimum. So, it is acceptable. So, then what will be the critical cycle length G max A that is 17.9 again plus 32.4 seconds plus yellow YA plus YB be that as usual all these are known to you already. So, I need not explain much.

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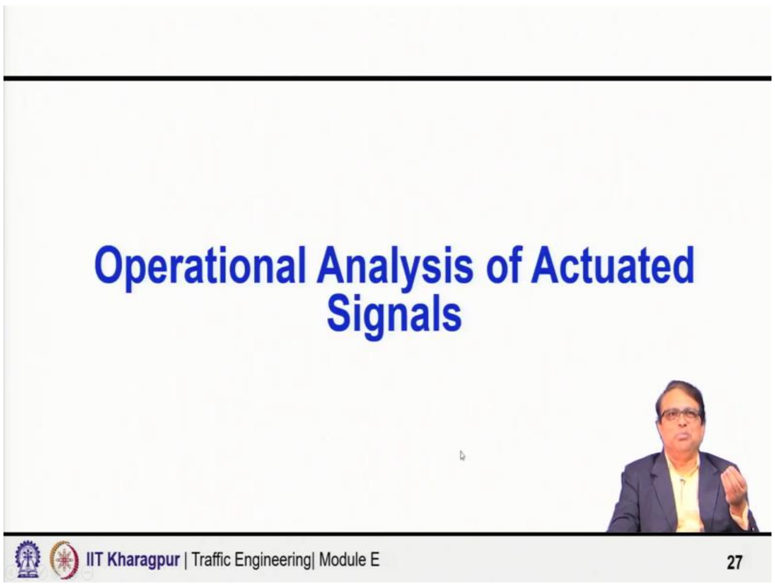

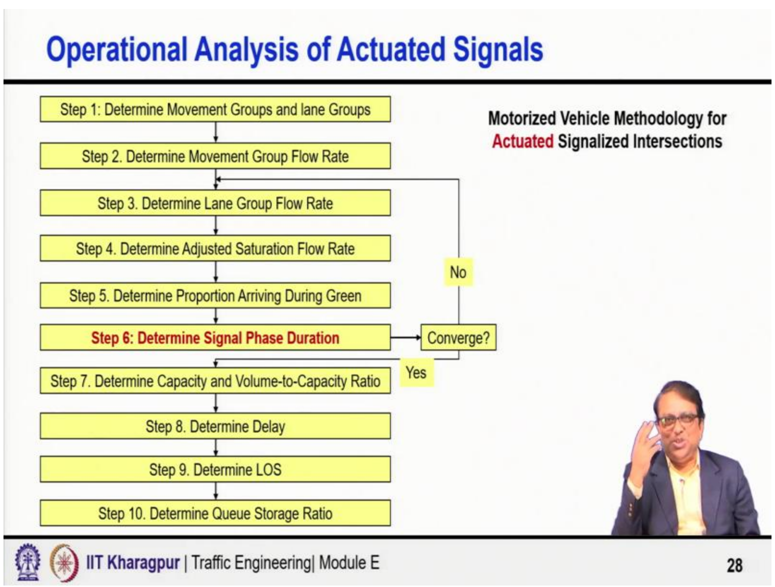

Now, coming to the operational analysis, I will not go into details because it is a very detailed procedure, but you know the operation and analysis of isolated or pre-timed intersection, when we do we follow a 9-step procedure. I discussed so, many previous lectures were actually dedicated on operational analysis of fixed timed signal.

So, here for actuated signal, these steps are more or less same, only one step is added that is step 6. This is the new one I have highlighted it. So, now the 9 step becomes 10 steps for actuated signal. And the step 6 is new determine signal phase division. Yes, you can see, it is actuated. So, phase also phase duration also will vary from cycle to cycle. But for operational analysis, we need to calculate a representative what phase duration we take for our analysis, operational analysis, determination of that one. So, that is new.

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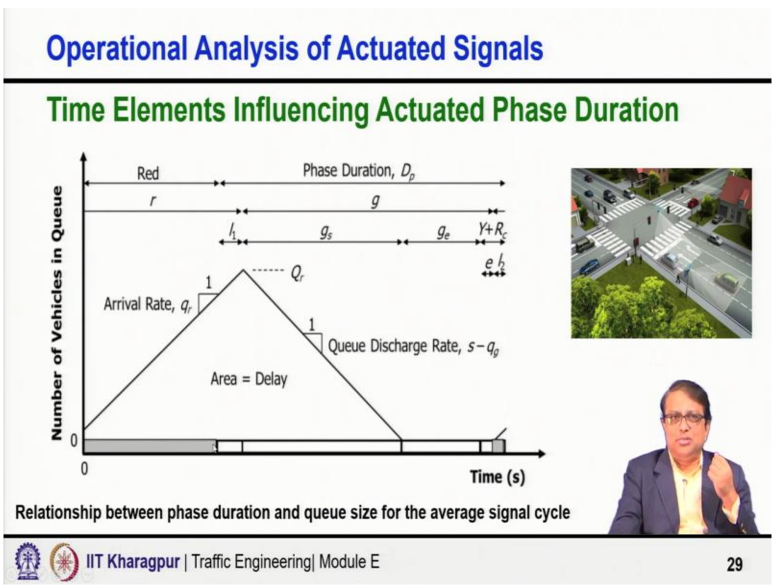

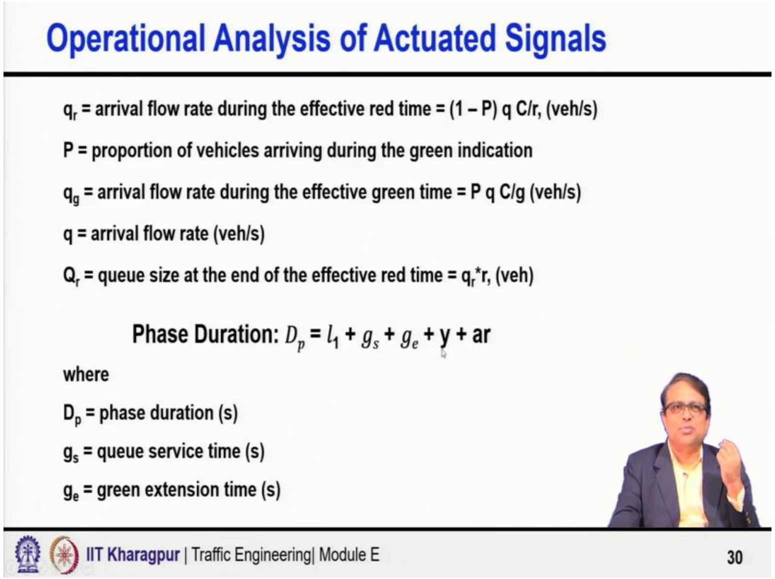

How to do that? One interesting concept here is the time elements influencing actual phase duration. For example, this is the red this is the clearance a start-up lost time shown as l1. So, arrival rate if it is Qr, then arrival rate continue, continue even beyond rate up to start-up lost time. Then the discharge starts happening queue discharge at the rate of saturation flow.

So, this line is showing the queue discharge rate and when it reaches here, that is the this point, all queued vehicles are cleared. So, this is called gs green time to clear the queued vehicle in a way. But then since it is actuated signal, the green will be extended further subject to all condition and this will be called as green extension. So, the total green will be gs plus g and obviously along with that amber, all-red, all those will come as usual before the signal turns to red again. So, this is the red portion, this is the phase duration. So, what will be this phase duration?

Phase Duration: $D_p = l_1 + g_s + g_e + \mathbf{y} + \mathbf{ar}$

Phase duration in this case will be l1 that is start-up last time, you will know that plus gs, what is the gs, gs is basically the queue service time, how much green you require to clear the queue, that is called the queue service time. So, in this one here the discharge starts happening and here no vehicle in the queue. So, this green is called gs, that is the queue service time plus then because it is extension actuated signal. So, the green extension may happen subject to other conditions. So, ge plus y plus ar that is the way the phase duration is.

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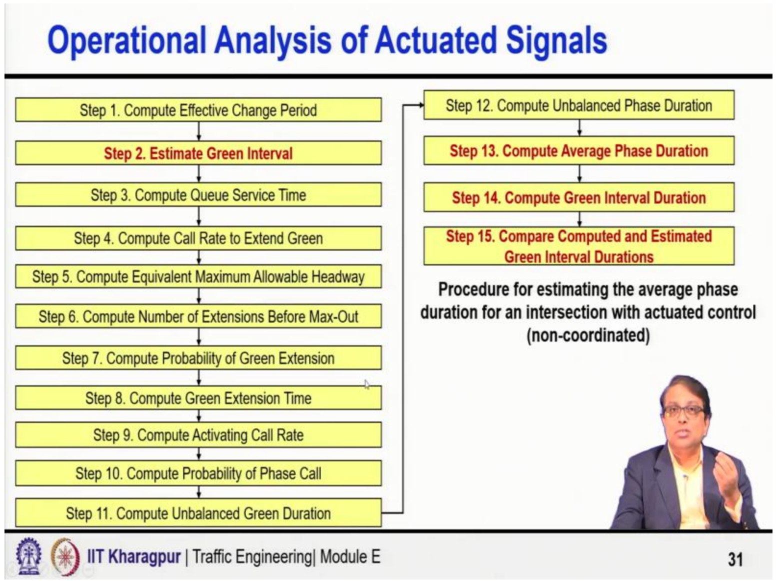

How to calculate this, the that particular step itself related to step 6 determination of signal phase duration, there is again a very detailed procedure at 15 steps are there, very rigorous and so, many equations so, many formulas are given if you are interested you please refer to highway capacity manual. I will I am not going to discuss in details about these all 15 steps, what all I would like to say here, here basically we are starting with first the compute effective green change period and then we are estimating a green interval.

Now, then through series of steps, we are again finally coming to compute average phase duration and compute green interval duration. So, you have a step 2 estimate green interval and in step 14, we are again coming back compute we are computing actually green interval duration. Now, this green interval duration what we are computing in step 14, we are comparing it with the what we estimated in the beginning in step 2.

If they are matching if the green interval estimated green interval and computed green interval are in close agreement, then the process is over we are going out. If they are not same, then whatever we have computed in step 14. Now, that value we will take it in step 2 as estimated that will be our estimated green interval whatever we have got from previous iteration in step 14 will be now the estimated green interval and the whole process will be repeated. So, if you are interested you look at that highway capacity manual.

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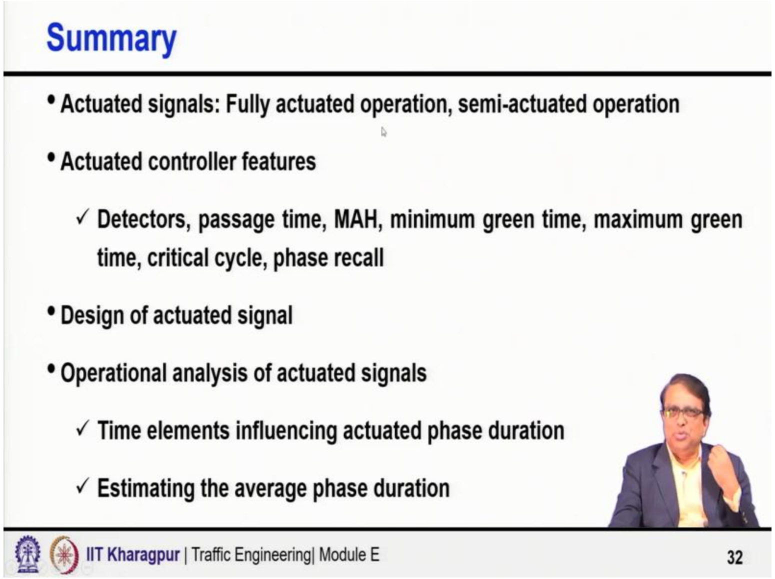

So, to summarize this lecture, I would say we discussed quite a lot and several aspects related to actuated signal, talked about fully actuated operation, semi actuated operation then actuated control and feature, detector, passage time, maximum allowable headway, minimum green, maximum green, critical cycle, what is phase recall and then talked about design of actuated signal and little bit just mentioned to you some aspects I am not seeing in details. In details, we cannot discuss within this course, because it will that itself will take maybe another two three lectures. So, we just told you that an introduction about the operational analysis. So, with this I close this lecture. Thank you so much.