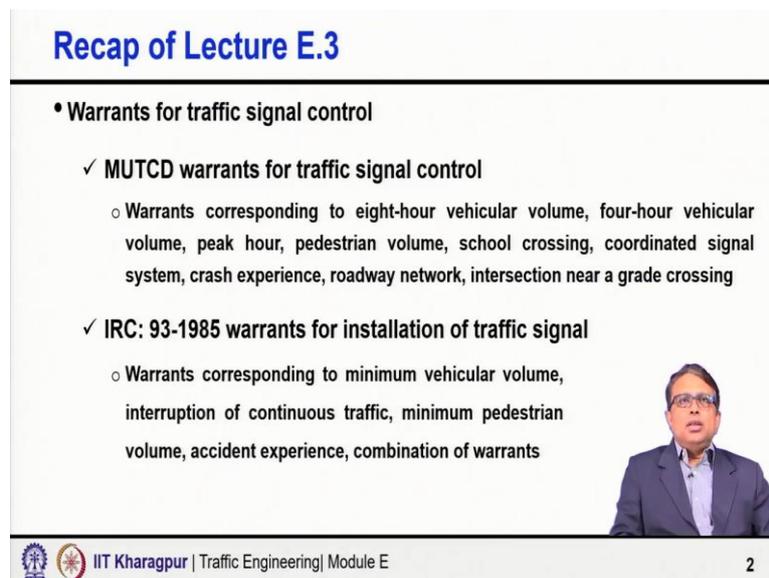


Traffic Engineering
Professor Bhargab Maitra
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 30

Intersection Control & Critical Aspects of Operation - IV

Welcome to Module E, lecture 4. In this lecture also, we shall continue our discussion about intersection control and critical aspects of operation.

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Recap of Lecture E.3

- Warrants for traffic signal control
 - ✓ MUTCD warrants for traffic signal control
 - Warrants corresponding to eight-hour vehicular volume, four-hour vehicular volume, peak hour, pedestrian volume, school crossing, coordinated signal system, crash experience, roadway network, intersection near a grade crossing
 - ✓ IRC: 93-1985 warrants for installation of traffic signal
 - Warrants corresponding to minimum vehicular volume, interruption of continuous traffic, minimum pedestrian volume, accident experience, combination of warrants



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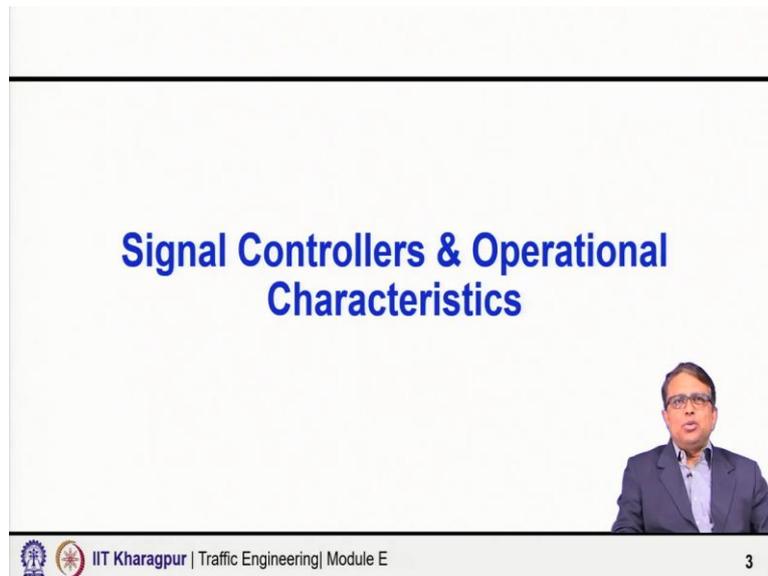
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In lecture 3, I mentioned to you about various MUTCD warrants for traffic signal control warrants corresponding to 8 hour traffic volumes, peak hour traffic volumes, 4 hour traffic volumes, pedestrian volumes, school crossing, signal coordination requirement, crash experience, network roadway, intersection near a grade crossing all these warrants we discussed.

Then I briefly mentioned to you about Indian Roads Congress guideline 93-1985 and the 5 warrants which are given in IRC 93-1985 two are related to minimum vehicular volume and interruption to continuous traffic all relate both are related to vehicle volume, then one related to pedestrian volume and another related to number of accidents that are crashes that record is available.

And then the last one is combination of warrants, the warrants are not getting satisfied 100 percent but multiple warrants are getting satisfied to a large extent. So, IRC 93 actually includes mostly the same aspects as mentioned is MUTCD, but MUTCD has got additional aspects or additional considerations in the form of warrants.

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Slide 3: Signal Controllers & Operational Characteristics

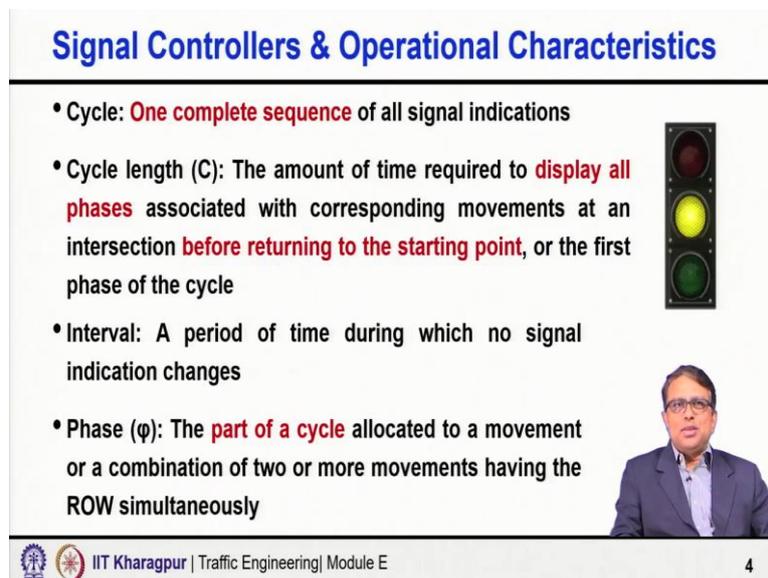
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3

The slide features a title 'Signal Controllers & Operational Characteristics' in blue text. Below the title is a small video inset of a man in a suit. At the bottom left is the IIT Kharagpur logo and text 'IIT Kharagpur | Traffic Engineering | Module E'. At the bottom right is the number '3'.

With this background today, we shall now discuss about signal controllers and operational characteristics as we are talking about traffic signals.

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Slide 4: Signal Controllers & Operational Characteristics

- Cycle: **One complete sequence** of all signal indications
- Cycle length (C): The amount of time required to **display all phases** associated with corresponding movements at an intersection **before returning to the starting point**, or the first phase of the cycle
- Interval: A period of time during which no signal indication changes
- Phase (ϕ): The **part of a cycle** allocated to a movement or a combination of two or more movements having the ROW simultaneously



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The slide features a title 'Signal Controllers & Operational Characteristics' in blue text. Below the title is a list of four definitions. To the right of the list is a vertical traffic signal icon with red, yellow, and green lights. Below the list is a small video inset of a man in a suit. At the bottom left is the IIT Kharagpur logo and text 'IIT Kharagpur | Traffic Engineering | Module E'. At the bottom right is the number '4'.

Therefore, it is important to tell you about some very basic and elementary terminologies which are extremely important and we will keep on referring to these terms often during our discussion about signal controller and operational characteristics. First about the cycle, cycle is one complete sequence of all signal indications like if you start thinking that the starting from red then red, then green, then amber and then again going back to red, then the same sequence will continue.

So, wherever you start one complete sequence of all signal indications, that is called cycle. Now, what is cycle length, simply the time required to complete a cycle or one complete sequence of all signal indications, I am telling something slightly different way in a slightly different way, because we have not yet discussed about the concept of phase, but otherwise it is same as what is written here the amount of time required to display all phases associated with corresponding movements at an intersection before returning to the starting point or the first phase of the cycle.

So, overall in a very simple terms that the time required to complete one cycle, that is the cycle length, in cycle what we do as you know the basic objective is to do the time segregation of conflicting movements. So, suppose if you simply consider that East-West and North-South 2 roads are intersecting and suppose, if you consider only straight movements are allowed from all approaches.

So, maybe firstly we allow North-South movement to occur, first you allow North-South movements to occur without allowing East-West movements then you stop the North-South movements and you allow now East-West movements to occur. So, these 2 are actually called in 2 phases. That means the part of the cycle allocate to a movement or a combination of 2 or movements having the same you know, having the right of way simultaneously. That means, maybe what we are doing first you are allowing North-South movements to occur simultaneously and then the East-West movements to occur simultaneously.

So, these are the 2 phases and what is the interval? Interval is a period of time during which no signal indication changes, that means, you are giving some time for the North-South movements. So, during that time, the signal is always green for North-South and red for East-West. So, that is the time duration will be called as time interval. Similarly, when you are stopping North-South, we are allowing East-West movement to occur with green indication that will that green remains for some time during that time the signal indications are not changing. So, that is again call an interval.

So, overall cycle is a complete sequence of all signal indications cycle length is the time required to complete one cycle and interval is the period of time which no signal indication changes and phase or phases are or phase is a part of cycle a located to a movement or combination of 2 or 3 movements having the right of way simultaneously. So, with this elementary concept of cycle length, interval phase.

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Signal Controllers & Operational Characteristics

Types of Traffic Signal Controller

- Broadly categorized as **pre-timed** and **actuated** according to the type of control they provide

Pre-timed Control

- Pre-timed control consists of a **fixed sequence of phases** that are displayed in repetitive order
- The cycle length, phase sequence, and intervals are **constant and fixed**
- The operation of a pre-timed controller can be described as **coordinated or not coordinated**



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Let us now go and discuss about various other aspects, related to signal controllers and operational characteristics. First type of signal controller, broadly signal controllers may be classified as pre-timed and actuated according to the type of control they provide. So, broad 2 categorizations one called pre-timed and other called actuated.

What is pre-timed control? Pre-timed control exists or consists of a fixed sequence of phases that are displayed in repetitive order. That means typically, what it is suppose you know, we can go to the field may let us talk about an urban intersection, typically, we can carry out the traffic volume studies, we can measure the traffic volumes, and we can identify the morning peak hour.

And during the morning peak, based on that measured traffic volume, we decide what will be my cycle length, how many phases will be there, how much green time will be given for every movement or every phases and then that we do not change that means every day morning certain period of time, we operate the signal with the same cycle length same phasing, same green time distribution for different movements and no other changes happening.

Maybe Of course, this is still fixed timed or pre-time control, when we may have one signal setting in the morning and other signal setting in the evening. Because you know morning the traffic will be towards the CBD and the evening the traffic will be away from the CBD. So, for different movements, the required green time will be different, but we are considering a typical work day, a typical evening peak or morning peak and accordingly deciding the cycle length, green time phasing everything.

And that every day, every week day, every morning, every evening peak we are operating with that same right same cycle length, phasing green time, everything same. So, that is called pre-time signal. Now, the pre-time operation of a pre-time controller can be described as coordinated or non-coordinated.

Of course, I have not yet discussed about the signal coordination. But very briefly, when signals are closely spaced, we want to adjust the timings, green timings in such a way that once the vehicle is discharged a bunch of vehicles is discharged from the upstream signal and they reach to the downstream signal, the moment the bunch of vehicles is reaching to downstream signal that green time is given for the downstream signal.

The whole idea is so in signals are closely placed and the vehicles are in platoon and the platoon has not dispatched too much because the spacing is not so high. So, at that time, the vehicle should be able to pass through subsequent signals without stopping again and again. So, that is the coordination.

So, the pre-timed control could be with coordination, if there are such closely spaced signal and the operation, you want to do it in a coordinated manner or you want to go ahead with coordinated signal system then the operation could be coordinated or it could be non-coordinated that means simply as an isolated intersection is it is operating. But what is the problem with, of course most of the signals in India are operating like pre-timed control, but there are certain disadvantages of pre-timed controller.

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Signal Controllers & Operational Characteristics

Actuated Control

- It consists of a defined phase sequence in which the presentation of each phase depends on whether the phase is on recall or the associated traffic movement has submitted a **call for service through a detector**
- **Green interval duration** is determined by the **traffic demand** information obtained from the detector
- The **termination** of an actuated phase **requires a call for service** from a **conflicting traffic** movement
- Operation of an actuated controller can be described as **fully actuated, semi-actuated, or coordinated-actuated**



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One may be that every Monday, every Monday or every day every weekday at 10 o'clock, the traffic is exactly not same or you fix up the signal or decide the signal setting for a period of may be 9 to 11 o'clock or 8 to 10 o'clock, whatever maybe the morning peak 8 to 10 o'clock, but 8 to 10 o'clock every 15 minutes or every half an hour whatever interval you take the traffic volume is not going to be same every day not even every interval the traffic volume is going to be exactly the same, it will not happen because the nature of traffic is like that, you go to them as are our town traffic at any location tomorrow exactly at the same time same weekdays working hours you go and measure it, it may not be exactly the same.

So, it may happen that we are at a typical peak of peak morning peak evening peak, whatever you take, you are designing the signal for that traffic volume, but the traffic volume may not be really same during the entire period for which the fixed time signal is installed or designed, it will vary. So, we can go for actuated signal that means we can design the signal based on actual arrival actual traffic demand.

So, that means we are actually sensing the traffic through detector and accordingly we are optimizing the whole signal operation. Of course, this is one particular type of actuated control, there could be a variety of control say for example, maybe a major road major peak of the time the traffic is very heavy on that route and a minor route is there occasionally only traffic is coming.

So, if you design it with a fixed time signal or as I have said earlier, the pre-timed to control then you will always give some green time for the minor street actually maybe many of the time there is no vehicle. So, the green is actually wastage. So, in that case, if we have if we can do actuation for that particular to handle that particular traffic movements, then we can optimize the overall signal setting or make the operation even more efficient.

So, in that case, to the detection could be in one approach, detection could be in multiple approach, a variety of actuation is possible but always it is actually to make the system more efficient. So, green interval duration in that case is determined by the traffic demand information obtained from the detector we know that how much green time will be there it is not fixed, it depends on how much traffic demand we are getting. We are sensing through our detector or sensor.

So, every time things may change, things may change very abruptly things may change only some to certain extent, it all depends on what rules you are following what kind of actuation you are doing and all those things will you know determine the actual operation. And of course, the termination of an actuated phase requires a call for service from a conflicting traffic movement. When you go back when you know that another approach something is a vehicle is waiting.

And of course, there will be not that always you sense a vehicle and you will jump to that moment you will not do that, but there will be other criteria minimum time, maximum time, minimum how much green you want to give maximum how much you want to go, all such kind of rules will be there. So, it is not just one-time type, it is not just one type, there are multiple types of actuated operations that are possible or actuated control that are possible. So, it could be fully actuated, it could be semi actuated, it could be coordinated actuated you know what is coordination. So, coordination will be maintained, but it will still be actuated.

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Signal Controllers & Operational Characteristics

Fully Actuated Operation

- Implies that **all phases are actuated** and all intersection traffic movements are detected
- Green time is allocated in accordance with information from detectors and programmed rules established in the controller for capturing and retaining the green
- The **cycle length, sequence of phases, and green time split** may **vary** from cycle to cycle



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So, first let us come to fully actuated signal fully actuated as applicable, where all the movements, we are actually sensing that means, we have sensors or detectors and we are measuring all the traffic volume from all approaches. So, implies that all phases are actuated, because since we are measuring traffic from all approaches, that means, all phases are actually activated and all intersection traffic movements are detected, then we can have better optimization as per the real context, we are optimizing the signal setting.

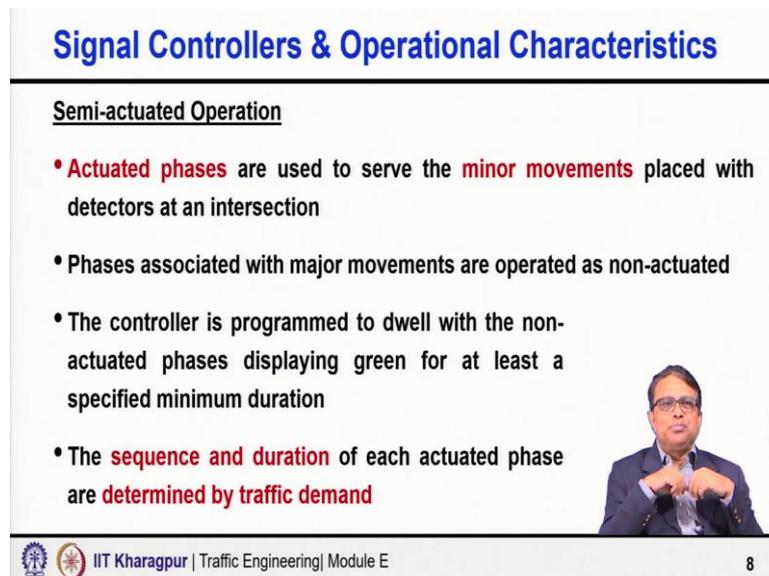
So, that really good, green time is allocated in accordance with information from detector some time maybe more traffic approaching more traffic is approaching from one approach. So, you give more green time there in that next cycle, maybe another approach a little bit more traffic you give more traffic there, more trouble green time there. So, the green time is allocated in accordance with the information from detectors and programmed rules established in the controller for capturing and retaining them.

So, there are a set of rules which are predefined and controller knows all those rules and with all those rules the controller will make a decision or allocate the green time. So, for example, you may decide that once I give green, I will give at least a minimum of so much green time. And if I decide once the detector has detected a vehicle, then maybe I should go back and give a green within certain time, that the delay should not be more than this much.

So, many ways you know the programmed rules are formulated programmed or the rules are formulated. So, many ways that rules are formulated. So, the cycle length sequence of phases green times pleat all may vary from cycle to cycle, everything is flexible as the traffic is

approaching from different approaches of the signal or the intersection accordingly as per real time detection the signal is optimized some phase may be skipped sometimes some phase may be there for some time, the green time may vary the cycle time may vary the sequence of phase also may change sometimes everything is flexible and optimized. So, that is fully actuated operation.

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Signal Controllers & Operational Characteristics

Semi-actuated Operation

- **Actuated phases** are used to serve the **minor movements** placed with detectors at an intersection
- Phases associated with major movements are operated as non-actuated
- The controller is programmed to dwell with the non-actuated phases displaying green for at least a specified minimum duration
- The **sequence and duration** of each actuated phase are **determined by traffic demand**

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Next semi actuated operation. Typically, it is done when there is a major road and most of the times do anyhow need green to allow movement of traffic on the major roads. So, that is where the majority of green is expected to be. But there is a minor road. So, on the minor road we put sensors or detectors and that becomes the activated phase there could be minor more than one minor road also like this.

So, actuated phases are used to serve minor movements placed with detectors at an intersection. So, the major movements we are not installing detectors because by default they are to be green majority of the time. So, detection is not required there. So, the rule is that by default the majority movements will be given green. It is only when you your detector tells you that vehicles are waiting on the minor approaches. Then only that comes from detection then only as per the rules what you have set a priory the green time will be given for the minor movements.

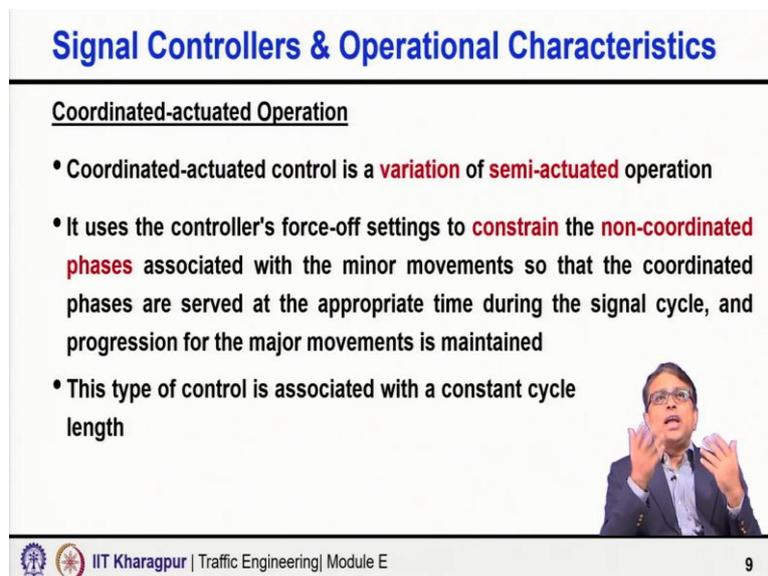
So, the phases associated with the major movements are operated as non-actuated as I said, because there we do not want to use detectors, because by default the major movement should get green otherwise also they should get green the controller is programmed to dwell with the

non-actuated phases displaying green for at least a specified minimum duration that when is not that the moment you detect that on a minor approach vehicle is waiting does not mean the automatic immediately will go and give green to the minor approach.

There could be some kind of precondition like this that once you give green to non-actuated phases, you will give green at least for a minimum duration specified minimum duration. Now, the sequence and duration of each actuated phase are determined by the traffic demand how much actually is the demand. So, whenever you detect some vehicle, then only will give some otherwise, maybe there are 2 minor approaches like that, in some cycle, you may not get a vehicle in one of the minor approaches.

So, that might not approach green will not come. So, not you know that we are not fixed that every cycle, every minor phase or actuated phase will be given a green it may be given a green if there is a demand and if it fits to the overall rules that you have framed earlier. Otherwise, no.

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Signal Controllers & Operational Characteristics

Coordinated-actuated Operation

- Coordinated-actuated control is a **variation** of **semi-actuated** operation
- It uses the controller's force-off settings to **constrain** the **non-coordinated phases** associated with the minor movements so that the coordinated phases are served at the appropriate time during the signal cycle, and progression for the major movements is maintained
- This type of control is associated with a constant cycle length

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Then coordinated-actuated operation, coordinated-actuated operation, it is something interesting and it is a kind of a variation of semi actuated operation that means, some of the or the minor approaches are actually actuated or we are doing detection there and those are the phases which are actuated.

So, they are still actuated, but the major stream traffic is not actuated, major stream major movement is not actuated and that major movement coordination with other signals that is also maintained that means, one thing is very important here, the cycle length will not be different

over time. Cycle length will be fixed and within the cycle leg the amount of green time minimum green time given for this major movement that is also fixed.

So, maybe there are but whether or how much green time will be given to the minor that will depend on the actual actuation. So, if you detect the vehicle then maintaining the coordination along the major road with all the signals which are actually coordinated on the major road traffic then you will that will be protected and then it will handle the minor road movements as per the actuation.

So, what I have written here, it uses controllers force of setting to constrain the non-coordinated phases associated with minor movements. So, that the coordinated phases are served at the appropriate time during the signal cycle and progression of traffic along the major roads or for the major movements is maintained that we do not disturb. And as I mentioned earlier, this type of control is associated with a constant cycle length because you know that you will understand it more as I you know go ahead with my lectures in this module.

That if you want to do coordination of signals, then all signals which are coordinated they should have the same cycle length. So, here also the cycle length I cannot change when the green to be given in each cycle also I cannot change, but the flexibility is when and whether I will give green time or how much green time I will give for the minor moments which are actually where the vehicles are detected using detection and those are actually phases are actuated phases.

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Signal Controllers & Operational Characteristics

Summary

Type of Operation	Fixed Cycle Length	Applicability	Locations
Pre-Timed (Isolated)	Yes	Where detection is not available	Isolated intersections, Work zones
Pre-Timed (Co-ordinated)	Yes	Traffic is consistent, closely spaced intersections, and cross street is consistent	CBDs, Interchanges
Semi-Actuated	No	Where defaulting one movement is desirable, cross road carries light traffic	Highway operations
Fully Actuated	No	Detection is provided on all approaches	Rural high-speed locations, Intersections of two arterials
Actuated (Co-ordinated)	Yes	Arterial where traffic is heavy and adjacent intersections are nearby	Sub-urban Arterial




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So, in summary, I have to say the type of operation could be pre-timed isolated here the cycle length is fixed. Applicable where detection is not available and isolated intersection work zones such kind of places it is applicable, second pre-timed could be coordinated again cycle length is fixed, it could be semi actuated if it is semi actuated then signals length is not fixed, fully actuated of course, everything is flexible. So, no way the signal length is fixed, coordinated actuated again the signal cycle length is fixed. And I have mentioned here where what kind of operation is suitable just an idea, not exclusive but just an idea.

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Signal Controllers & Operational Characteristics

Operational Modes for the Turning Movements

Permitted Movements: Permitted **right-turning** drivers **yield to** conflicting oncoming **vehicles** and **conflicting pedestrians**. Permitted **left-turning** drivers **yield to** conflicting **pedestrians**. The efficiency of this mode depends on the availability of gaps in the conflicting streams

Protected Movements: The protected mode gives turning drivers the **right-of-way** during the associated turn phase, while all **conflicting movements** are **required to stop**



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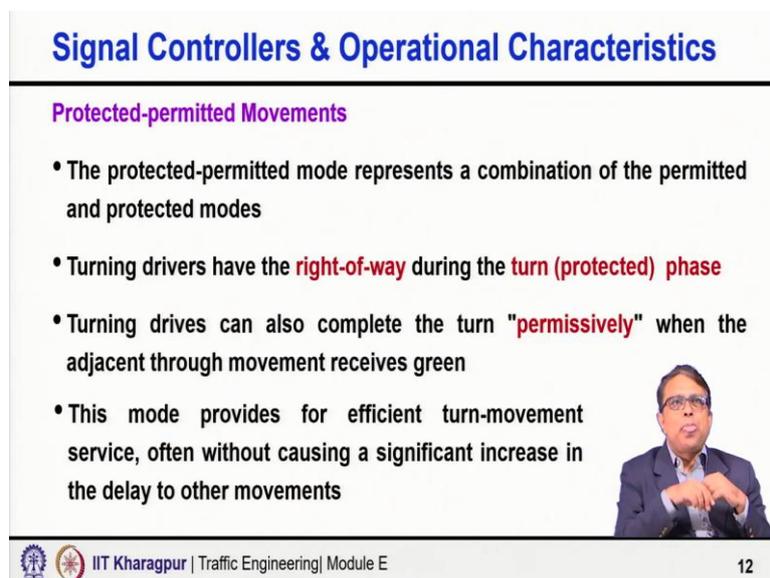
Now, let us go to the operational modes of turning movements. There are 2 types of turning movements permitted movements, protected movements, permitted right turning drivers yield to conflicting on coming vehicles and conflicting pedestrians. So, permitted left turning drivers into conflicting pedestrians. The efficiency of this type depends on the availability of gaps in the conflicting streams what I am saying, say it is all talking about the turning movements. So, from one approach, maybe traffic is taking right turn that is one movement.

Now, that movement is happening across the movement which is straight movement from the opposite direction, both are allowed some cases it is allowed for it is considered to be safe and overall vehicle volume combination is such that it can give you an efficiency without compromising the safety. So, if it is like that, that say right turning divers into oncoming vehicles and also a pedestrians are crossing the conflicting pedestrians.

Left turn normally, the opposite vehicle is not a problem because of the vehicle will come on the other lane or the direction of travel. So, here the drivers may yield to conflicting pedestrians, that conflict is possible. So, that is called permitted movement.

Protected movement where the turning movements turns are happening without any other conflicting movement. That means when I am allowing right turn, my right turn is going smoothly vehicle from opposite street is not permitted there at the time, pedestrians are not also, given green at that time, to in order to conflict with the right turning traffic, same thing the left is given means for the left portion where the distance earlier crossing. Now, pedestrian will not cross at that time. So, that is called protected to protected permitted both are there.

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Signal Controllers & Operational Characteristics

Protected-permitted Movements

- The protected-permitted mode represents a combination of the permitted and protected modes
- Turning drivers have the **right-of-way** during the **turn (protected) phase**
- Turning drives can also complete the turn "**permissively**" when the adjacent through movement receives green
- This mode provides for efficient turn-movement service, often without causing a significant increase in the delay to other movements

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Now, also, it could be sometimes protected-permitted combinations, protected-permitted movements what is that? The protected permitted mode represents a combination of the permitted and protected mode. So, what will happen turning drivers have the right of way during the turn phase. Sometimes you were just maybe you are allowing the right turning traffic and it is protected but other time so, you have a protected phase. So, no other conflicting moments will be allowed.

But also, when the straight opposing straight vehicles are allowed. Maybe this right turning is also, giving a permitted turn both are there. So, that is what I said the turning drivers have the right of way during the turn it is the protected phase and turning drivers are also, can also, complete the turn permissively when the adjacent through movement receives green that when opposite movement is happening with the green, but you are still given permitted right turn.

So, some vehicles may take permitted turn, some vehicles at other time may take protected phase and complete the turn. So, this mode provides for efficient turn movement service often without causing a significant increase in the delay to other movements, but one has to see that the safety should not be compromised and only certain traffic combinations certain scenarios, this kind of things may be accepted.

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Signal Controllers & Operational Characteristics

	Through movement without turning movement
	Through movement with protected left and right turns from shared lane
	Through movement with permitted left and right turns from shared lane
	Through movement with permitted right turn from exclusive lane and permitted left turn from shared lane
	Through movement with protected right turn from exclusive lane and permitted left turn from shared lane

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Now, I am showing you here the first case a solid arrow with a distinct arrowhead indicating through movement without turning movement, second case shared lane all are protected solid arrows, solid arrow means protected from one lane, all movements are happening all are protected movement, second case solid arrow all 3 are from the same lane.

So, again shared lane, but both right and left are permitted. So, using dotted line, third fourth case straight and left happening from one lane shared lane right happening from another lane exclusively lane right one, but exclusive permitted the shared lane left permitted last one separate lane right one it is protected shared movements left and straight left is permitted. So, all different combinations are possible.

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Signal Controllers & Operational Characteristics

Signal Phase Sequence

- Signal phase plans are generally illustrated using **phase diagrams** and **ring diagrams**
- A phase diagram shows all movements being made in a given phase within a **single block** of the diagram
- A ring diagram shows **which movements** are controlled by **which "ring"** on a signal controller



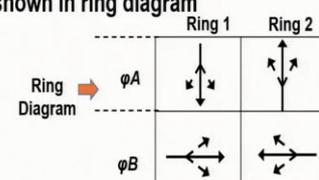
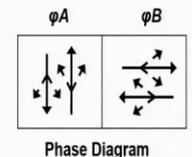
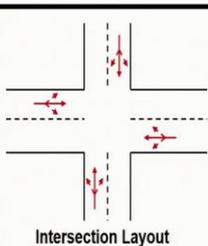
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Now, let us come and discuss about the signal phase sequence, signal phase plans are generally illustrated using phase diagram and ring diagram. A phase diagram shows all movements being made in a given phase within a single block diagram and ring diagram shows which movements are controlled by which ring on a single controller.

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Signal Controllers & Operational Characteristics

- **Modern controllers** use **dual-ring structure**: Allow concurrent presentation of a green indication to two phases - more efficient as they can adapt phase duration and sequence as per need of individual movements
- Phase diagram shows a phase involving two opposing through movements in one block, but each movement would be separately shown in ring diagram



Intersection Layout

Phase Diagram

Ring Diagram

Ring 1 Ring 2



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Now, what is that now, these days most of the modern controllers use dual-ring structure. Now, what is dual-ring structure? Now, this dual-ring structure allow concurrent presentation of green indication to phases concurrent presentation of a green indication to 2 phases and these are this kind of controllers are called more efficient, considered more efficient, why? Because they can adapt phase duration sequence as per the need of individual movement. Earlier time

most of the controllers were not dual-ring structure not having dual-ring structure, it was single ring structure.

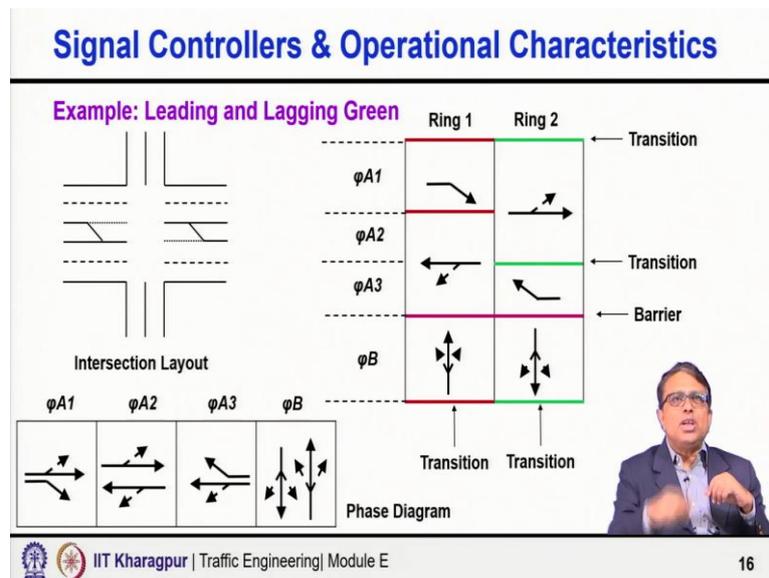
So, all the movements non-conflicting movements which were allowed in a phase are under one ring and therefore, the maximum movement which will have highest volume or so, will dominate the green time requirement for that phase. But now you have dual-ring structure and which is more efficient because such kind of controllers can adapt phase duration and sequence as per need of individual movements.

So, that is why always we are seeing here, ring 1 and ring 2, because they are actually dual-ring structure and the controllers have dual-ring structure. So, if you in the right side, if you consider from every approach, we are allowing all 3 movements left and right are permitted. And you know, let us consider that we are using a 2-phase diagram phase one as usual what we are doing, we are allowing vehicles approaches approaching from north and approaching for south to operate to move, they may go straight, take left or take right just one phase, the second phase North-South blocked. Vehicles which are approaching from East and West are allowed to move again straight left right, left and right are permitted turn only. So, that the 2 phase.

So, the ring how the ring is getting distributed is shown here. So, in this case you have vehicles approaching from North and vehicles approaching from South both are allowed in this phase. So, vehicles approaching from North and vehicles approaching from South are controlled by 2 rings, ring 1 and ring 2 same in the second phase the East-West, the East vehicles approaching from West and vehicles approaching from East are controlled by ring 1 and ring 2 respectively.

So, that is what I have shown the phase diagram shows a phase involving 2 opposing through movements in one block. But each movement would be separately shown in the ring diagram that is what we are saying. East and West approach vehicles which are approaching from Eastern West are shown separately in ring one and ring two similarly vehicles approaching from North and South in phase A is again shown differently in ring one and ring two respectively. So, that is what we are saying.

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Now, if you see here also, again I have given you an example that here let us say that we are operating this intersection with 4 phase right as shown here, you can understand a protected right turn then straight and left in phase two like this, you can follow the arrow heads and understand phase 3 approach vehicle same like phase 1, phase 3 the vehicles which are approaching from East side and the phase B is like North-South movements are allowed.

So, if you put it in the ring diagram, then this is the phase which has got two movements you know, one is right and other is straight and shared left. So, right in ring 1, straight and shared left ring 2, but straight and shared left continue also, in phase 2. So, the ring diagram, it is not a separate one. So, you save actually, the last time I will discuss it later further.

That is what is the advantage also, now phase 3 again ring one, the phase 2 ring one will continue, but ring 2 has to change because now you are allowing the protected right turn. So, that is what has come and then in phase B you have one ring for south bound movement another ring for the south bound movement.

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Signal Controllers & Operational Characteristics

Example: An Exclusive Right-turn

Phase Diagram

ϕA ϕB ϕC

Ring 1 Ring 2

ϕA Transition

ϕB Transition

ϕC Barrier

Transition

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So, another example here also, where you can see here the it is a 3-phase operation phase A, phase B and phase C. Phase A both right turns protected right turns you are using and then East-West straight and left permitted left and then North-South, straight left right and left or right turning are permitted. So, obviously, the corresponding ring diagrams are shown here.

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Movement Groups and Lane Groups

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Movement Groups and Lane Groups

Movement Groups

- A **turning movement** served by one or more **exclusive lanes** and no shared lanes should be designated as a **movement group**
- Any lanes not assigned to a group by the previous rule should be combined into one movement group



Lane Groups

- **Exclusive turn lane(s)** should be designated as a separate lane group
- **Any shared lane** should be designated as a separate lane group



Now, there is also, a concept of movement groups and Lane groups. Now, a turning movement are by one or more exclusive lane and no shared lane should be designed for as a movement group and any lanes not assigned to a group by the previous rule shall be combined into one movement group. So, you can see here the turning movements served by one or more exclusive lane. So, the left turning is an exclusive lane here say exclusive left turning movement group, then any lanenot assigned by the previous rule should be combined into a movement group.

Here you can say right we are is not exclusive it is from shared lane. So, through and right movement groups are formed together as one movement group. Now, coming to lane group, exclusive turn lanes should be designated as a separate lane group and any shared lanes should be designated as a separate lane group.

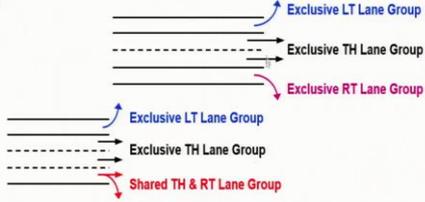
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Movement Groups and Lane Groups

- Any lanes that are not exclusive turn lanes or shared lanes should be combined into one lane group

Lane Group Possibilities

- Exclusive left-turn lane(s)
- Exclusive through lane (s)
- Exclusive right-turn lane(s)
- Shared left-turn and through lane
- Shared left-turn and right-turn lane
- Shared right-turn and through lane
- Shared left-turn, through, and right-turn lane



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And any lanes that are not exclusive right in the turn lane or shared lane should be combined into one lane. So, here the concept is very important. So, here you can say this is an exclusive left turn. So, it is exclusive left turn lane group. This is in this case, an exclusive right turn. So, it is an exclusive right turn lane group.

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Movement Groups and Lane Groups

Movement Groups

- A **turning movement** served by one or more **exclusive lanes** and no shared lanes should be designated as a **movement group**
- Any lanes not assigned to a group by the previous rule should be combined into one movement group



Lane Groups

- **Exclusive turn lane(s)** should be designated as a separate lane group
- **Any shared lane** should be designated as a separate lane group



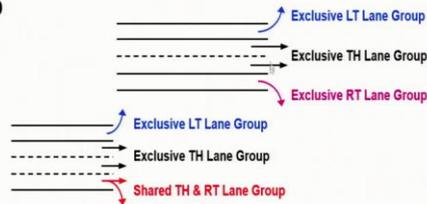
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Movement Groups and Lane Groups

- Any lanes that are not exclusive turn lanes or shared lanes should be combined into one lane group

Lane Group Possibilities

- Exclusive left-turn lane(s)
- Exclusive through lane (s)
- Exclusive right-turn lane(s)
- Shared left-turn and through lane
- Shared left-turn and right-turn lane
- Shared right-turn and through lane
- Shared left-turn, through, and right-turn lane



And what I have said. So, exclusive turn lanes, this with this rule 2 lane groups are their shared lane in this case in this photograph is not there, but there are 2 straight movements. So, any lane that are not exclusive turn lane or shared lane. So, therefore, another lane group if we are formulating. But in this case the right lane is a shared one. So, one is exclusive left turn group and other is exclusive through lane group and another as far this second rule of lane groups the right turn and through shared lane group.

So, another lane group. So, lane group possibilities could be exclusive left turn lane, exclusive through lane, exclusive right turn lane, then shared left turn and through turn, shared left turn and right turn, shared right turn and through, shared left through and right, all these are possible lane groups.

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Movement Groups and Lane Groups

Typical Movement Groups and Lane Groups

Number of Lanes	Movements by Lanes	Movement Groups (MG)	Lane Groups (LG)
1	LT, TH & RT	MG1:	LG1:
2	TH/LT Exclusive RT	MG1: MG2:	LG1: LG2:
2	LT/TH TH/RT	MG1:	LG1: LG2:
3	LT/TH TH Exclusive RT	MG1: MG2:	LG1: LG2: LG3:

For simplified procedure, sometimes movement groups are used for analysis

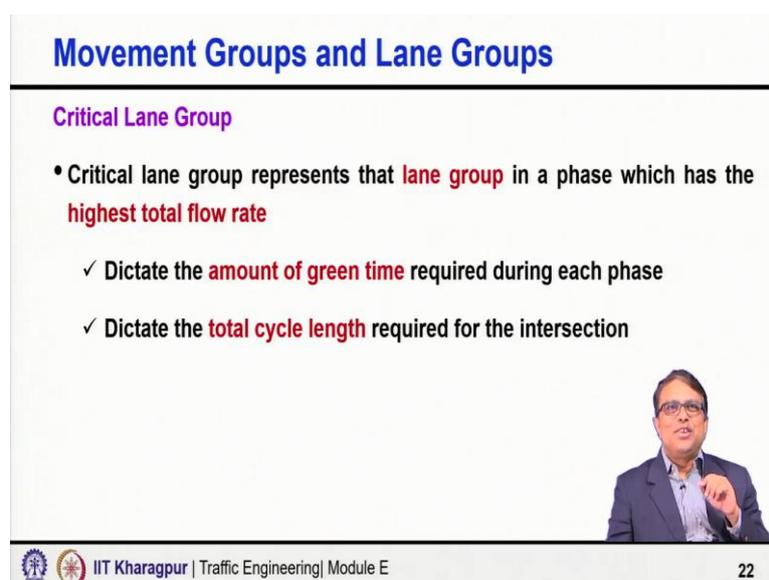


Here I have shown an example with this I will close almost. So, here I have shown the movements by lane. So, this will give you even more clarity left through right shared from one only all 3 movements are happening. So, lane group wise also, only one movement group and also one lane group not different. Here lane group and movement group will not be different next place one shared lane through and left another a one shared lane through a left and other exclusive right turn.

So, the movement groups are also like this straight and left one movement group and right exclusive right is one movement group lane group also is same. So, no way the movement group and lane groups are different in this case, but look at the third case even one shared lane for straight and left and other shared lane for straight and right when you consider movement group, it is all together you have to allow all these segments to happen together. So, this is one movement group, but when you come to lane group lane group is left and straight total one lane group, shared lane and then the right and straight another lane.

Third one, one straight and left shared, then one through lane exclusive one right turn exclusive. So, the movement group wise here to straight and left together. So, first 2 are combined as one movement group an exclusive right turn is another movement group, when you come to lane group, these are 3 left and straight, only straight and exclusive right. So, this will be 3 lane group. So, this gives you better clarity, how the lane groups and movement groups are different and where they will be different not that always they will be different.

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Movement Groups and Lane Groups

Critical Lane Group

- Critical lane group represents that **lane group** in a phase which has the **highest total flow rate**
 - ✓ Dictate the **amount of green time** required during each phase
 - ✓ Dictate the **total cycle length** required for the intersection

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So, whenever we are talking about lane group, then the critical lane group also comes into picture.

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Movement Groups and Lane Groups

Example: Determine critical lane groups

Ring Diagram		
$\phi A1$		231 or 263 $V_{cA} = 263 \text{ veh/h}$
ϕB		472 or 516 $V_{cB} = 516 \text{ veh/h}$
ϕC		283, 128, 140 or 351 veh/h $V_{cC} = 351 \text{ veh/h}$

Phase Diagram

$V_c = 263 + 516 + 351 = 1130 \text{ veh/h}$

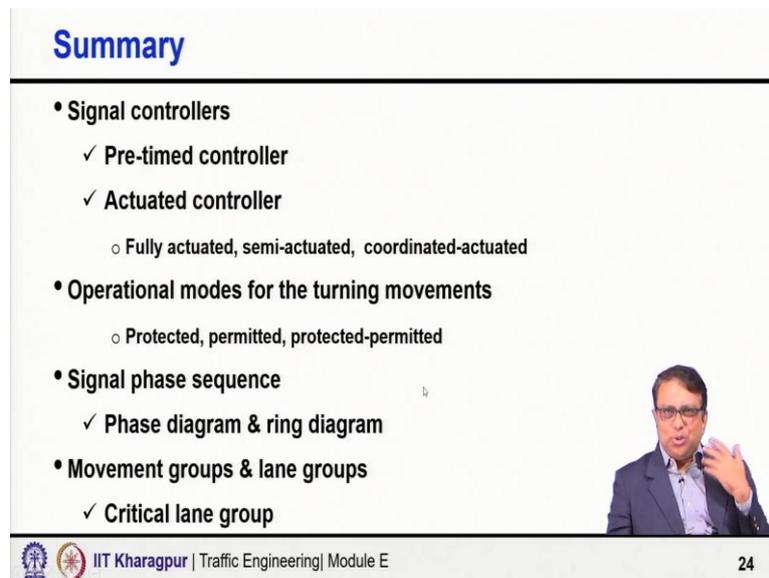
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Here is a small example which shows you that suppose in Phase A you have got to movement exclusive right 231 to 263. So, what is critical the highest value because that that has to be that is to be accommodated by the signal setting, when I am giving green time I should keep that 263 in mind, if I can handle 263 I can also be able to handle 231. So, this is the critical volume in phase A.

Similarly, you can follow in Phase B the critical volume is 516 in phase C the critical volume is 351. Because you have many one exclusive right turn 128, 283, 140 and 351 but the highest one that will dominate. So, 351 is the critical volume. So, overall critical volume if we say critical volume in Phase A, critical volume in Phase B and critical volume phase C. So, 1130 vehicle per hour.

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Summary

- **Signal controllers**
 - ✓ Pre-timed controller
 - ✓ Actuated controller
 - Fully actuated, semi-actuated, coordinated-actuated
- **Operational modes for the turning movements**
 - Protected, permitted, protected-permitted
- **Signal phase sequence**
 - ✓ Phase diagram & ring diagram
- **Movement groups & lane groups**
 - ✓ Critical lane group

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So, in summary what I will say we discussed here about the signal controller, the pre timed controller and actuated control and also within actuated controller it could be fully actuated could be semi actuated could be coordinated actuated. Then operational modes of turning lane then it could be protected, permitted in some special case it could be protected-permitted both. Signal phase sequence we discussed about the concept of phase diagram and ring diagram and also mentioned to you about the critical lane group and the critical volume, how I can get the critical volume. So, thank you So, much. We shall continue our discussion in the next class.