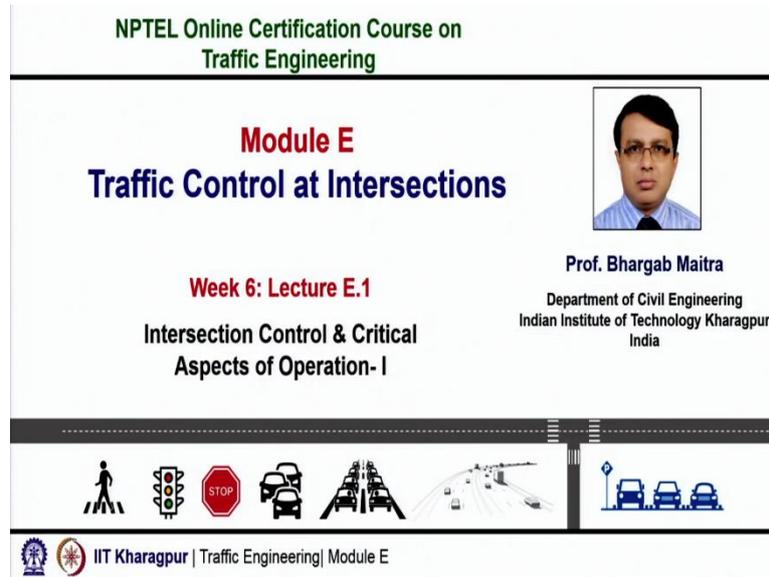


Traffic Engineering
Professor Bhargab Maitra
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Lecture 27
Intersection Control & Critical Aspects of Operation – I

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NPTEL Online Certification Course on
Traffic Engineering

Module E
Traffic Control at Intersections

Week 6: Lecture E.1
Intersection Control & Critical Aspects of Operation-I

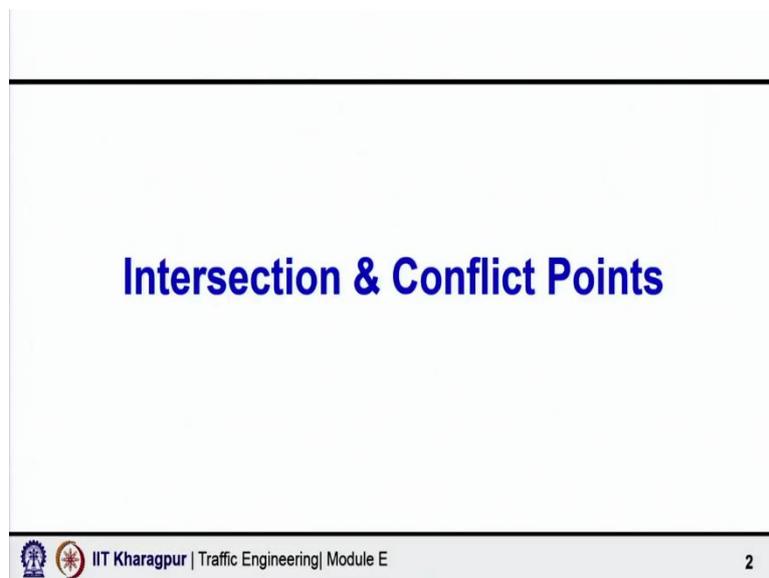

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Welcome to Module E, Lecture 1. In this module, we shall discuss about Traffic Control at Intersections and today's lecture is on Intersection Control and Critical Aspects of Operations.

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Intersection & Conflict Points

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Intersection & Conflict Points

- Intersections are the areas where **two or more roads meet or converge or diverge**
- Intersections are **potential bottlenecks** to smooth flow of traffic, and major **accident spots**
- Therefore, key considerations in intersection design are
 - ✓ Satisfying operational traffic-flow needs with **available capacity**
 - ✓ Enhancing road **users safety**



To start with first, what are the intersections and the basic understandings about the conflict points. Intersections as you know are the areas where two or more roads meet, cross, converge or diverge. Often, we travel and we come across intersections where the road we are taking is crossed by another road that may be of the same order. Sometimes maybe lower order than the road what we are using for travel. Sometimes that may be even a higher order route.

So, intersections are very important and are of interest to traffic engineers as these are the potential bottlenecks to smooth flow of traffic because traffic from different directions are coming. They are going to different other directions, so bottlenecks are created. And therefore, these are the potential bottlenecks for smooth flow of traffic.

Second, these intersections are also accident spots. So, the safety problems are very much there at intersections and in fact a good number of accidents and road fatalities do occur at intersections only. So, intersections are very much of concern to traffic engineers. And for the overall efficiency and safety of traffic operation on a road network. Because intersections are an integral part of any road network.

Because of these reasons, the key considerations in intersection design or improvement are number 1, how to satisfy operational traffic flow needs with available capacity? Every physical infrastructure has got a capacity. A road has also got a capacity. An intersection also got a capacity. So, how within the available capacity, we can satisfy operational traffic flow needs? Certain quality of service or level of service.

Second, how to enhance safety of all road users? Because intersections, not only vehicles move from different directions but also pedestrians are using the intersection heavily. Often in urban

areas, even in rural areas, you will find intersections are the points where pedestrians are crossing the road, bicycles are crossing the roads and they are vulnerable road users.

So, you have motorized vehicle. You have non-motorized modes of transport including pedestrians and bicyclists who are commonly known as vulnerable road users. They do not have protection. So, they are directly exposed. And if they are hit by any vehicle, then the impact is very high.

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Intersection & Conflict Points

- **Conflict points** are locations in or on the approaches to an intersection where traffic movements merge, diverge, or cross

Major: Crossing

Major: Crossing (Turning)

Major: Weaving

Minor: Diverging

Minor: Merging

No Conflict

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So, why these intersections are as I said in the previous slide, why these are major accident spots? The reasons are very simple. The main reason is that there are so many conflict points at intersections. So, what are the conflict points? Conflict points are those locations in or on the approaches to an intersection where traffic movements merge, diverge or cross. I have shown in this slide a number of possible conflicts.

First one if you see, it is basically indicating a major conflict. A vehicle traveling towards east and a vehicle travel towards south and therefore, they are crossing each other. So, when they are crossing, they are sharing the same location. So, we are talking about intersections which are at grade that means at the same level all movements are happening and at the same time all movements are happening. Then only the conflicts are coming.

So, it could be also crossing or turning conflicts. I have shown three possible situations where such kind of turning-cum-crossing conflict may occur. Also, weaving may occur. Typically, when we are talking about intersection, an appropriate example is maybe the vehicle was actually on the right lane. And now, from intersection the vehicle wants to take the left turn.

So, vehicle now the green arrow you can follow, from the right there is already traffic moving in the left lane or in the middle lane and maybe the vehicle wants to it is a 3-lane available for the same direction of movement. So, the vehicle from the rightmost lane wants to go to the leftmost lane crossing the middle lane traffic.

And because that vehicle which is shown as the green path or the green line wants to take a left turn. So, that kind of waving may occur. Now, all these are essentially some form of crossing. So, they are all called as major conflicts. All these crossing, crossing-cum-turning and weaving. These are called major conflicts.

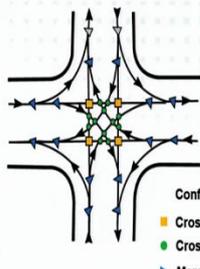
There are also possible other conflicts say for example as I have shown. It may be a diverging conflict, one point. Road is getting divided into two different routes. So, at that junction traffic is coming. Some are going to left. Some are going to right. So, they are diverging. Similarly, they may merge. That is what is shown here. And the last one, I have kept it here just to show you when there is no conflict. That means two vehicle paths are not crossing each other at the same level and at the same time.

So, when there is no conflict, there is no problem in that intersection. But whenever so many different types of conflicts will occur in an intersection, obviously there is a possible safety issue or a potential safety issue. So, obviously there is a kind of potential safety issues. How many conflicts can occur in an intersection? Let us look at this next slide.

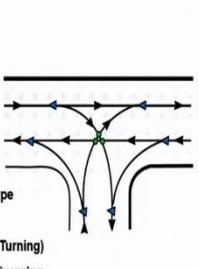
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Intersection & Conflict Points

Single Lane Approach Four-legged Intersection



Single Lane Approach Three-legged Intersection



Intersection Type		4-Legged	3-Legged
Vehicle Conflicts	Crossing + Turning	4+12	0+3
	Merging	8	3
	Diverging	8	3
Total		32	9

• Intersection **crashes** are related to the **number of conflicts** at the intersection



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I have taken here two intersections. One is the four-arm intersections. That means intersection has got four approaches. The other is a T-intersection or three arm intersection. If you take the first one and if we consider on each approach exactly there are two lanes, one for upstream; one for downstream movements. Then so many conflicts can happen as I have shown in the diagram, different types of conflict, major and minor.

Altogether, if there are 4 approaches and all movements are allowed from all approaches. That means if a vehicle is approaching from one side, the vehicle can go straight, can take left turn or also can take right turn. And like that from all the 4 approaches, all 3 movements are allowed. In that case, only 4 vehicles there will be as many as 32 conflict points. So, you can now understand why the safety issue is so pertinent and so relevant when we talk about intersection. And why intersection safety is so important to traffic engineers.

If you take a three-arm intersection again with similar kinds of movements. That means from all 3 approaches, all possible movements are there. Here in this case, from each approach there will be 2 movements and if you allow that then there will be a total of 9 conflict points. Even for the first case, where there are 4 approaches, if you make some of the roads as one-way roads, make one road as one-way road, make both roads at one-way, then some of the movements will get eliminated. So, some of the conflicts also will get eliminated.

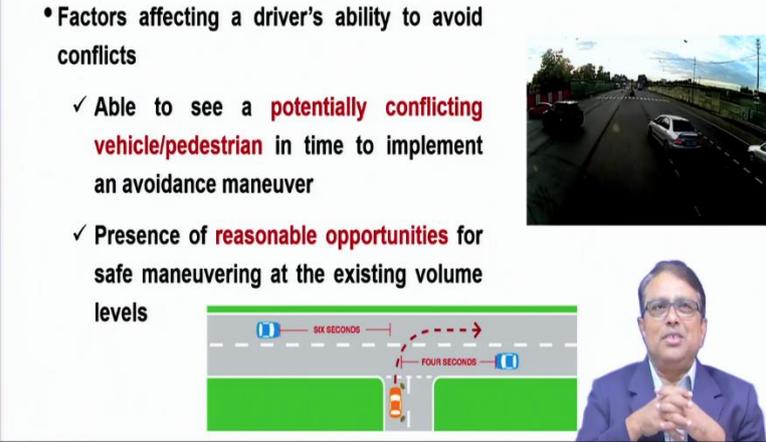
So, the number of conflicts does not depend only on the intersection orientation. But also, it depends on how many traffic movements and what are all movements that are allowed to occur in an intersection. Over and above, I have just considered here the traffic part of it; motorized vehicle. Often there are pedestrians. So, if pedestrians are also crossing the road at the

intersections, then there will be additional conflict points. And those conflicts will be between pedestrians and vehicles. And that is why it is found that intersection crashes are directly related to the number of conflicts at intersection. If we can reduce the conflicts, we are actually in a way, enhancing the safety of that intersection.

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Intersection & Conflict Points

- Factors affecting a driver's ability to avoid conflicts
 - ✓ Able to see a **potentially conflicting vehicle/pedestrian** in time to implement an avoidance maneuver
 - ✓ Presence of **reasonable opportunities** for safe maneuvering at the existing volume levels



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Now, with this background, let us try to understand what are the factors that influence a driver's ability to avoid conflicts. Primarily, there are 2 things which are very important. One, a driver must be able to see a potentially conflicting vehicle or pedestrian in time well in advance to implement an avoidance maneuver. That avoidance maneuver could also be a stopping maneuver.

That means I am driving a vehicle. I see another vehicle or a pedestrian and I should be able to stop my vehicle safely without crash. So, drivers ability to see a potentially conflicting vehicle or pedestrian in time to implement an avoidance maneuver. This is very important for safety.

The second, presence of reasonable opportunities for safe maneuvering at the existing volume levels. That means, if you consider the figure below where I have shown a T-intersection, you can see a vehicle is approaching and trying to take right turn. Now, that vehicle at this T-intersection should be able to take that provided he is given a reasonable opportunity to do this maneuvering.

That means what I am trying to say in a way that if the vehicle volume on the major road, let us consider this southern arm is actually minor road. Let us consider that. And vehicle wants to take turn right turn on the major road. So, if the major road traffic is very high, then one after

another vehicle is coming, then the gap between two vehicles at the time headway is very less. So, the drivers may not get opportunity even to complete that maneuver safely. So, this has different implications.

Implications also on operational efficiency of the intersection because maybe a long queue will occur or sometimes people drivers may be desperate also. Then they start taking risk and then even with a shorter gap, they try to do the maneuver. So, both cases, the safety is affected. Even it may lead to the or it may affect the operational efficiency of the intersection.

The video what I have shown here, you can see the car is moving and the bike is coming from the north bound from the northern side and going to south. So, this marginally marginal error can make a crash to happen. So, that is why it is so important and intersection safety is so important to traffic engineers.

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Intersection & Conflict Points

- Intersection design aims to **minimize** the number and/or severity of **potential conflicts** between cars, buses, trucks, pedestrians, etc., whenever required, through:
 - ✓ **Priority control** by “yield” signs and “stop” signs
 - ✓ **Space segregation** by channelized islands, grade-separators, etc.
 - ✓ **Time segregation** by traffic signals



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Intersection design, because of all these reasons aim to minimize the number and or severity of potential conflicts between cars, buses, trucks, and even with pedestrians whenever required. So, all our attempt as traffic engineer is how we can reduce the number of conflict or the severity of potential conflict. Why I am talking about severity?

Because I have told earlier, the crossing conflicts are generally different types of crossing conflict, maybe there: weaving you know, direct crossing. But they are all some way or the other, they are actually crossing conflict. So, the crossing conflict are major conflict. The merging and diverging are called minor conflict. So, can we avoid major conflict and instead

of that can we make convert that to minor conflict? Then also the level of potential conflicts may be changed. And overall, there would be an implication on the safety performance.

Now, how we do that? Primarily, there are 3 ways to achieve it. Number 1, by providing priority control. How we do that? By providing yield signs or stop signs. I shall discuss much more or in details about all these aspects. Here, I am only mentioning broadly the 3 different ways this objective can be achieved. So, first by priority control using yield signs or stop signs.

The second by space segregation. So, you may provide an island in between to regulate the movement. Even you can do separation of movement by grade. Simple kind of flyover use. Two movements are happening but they are happening at different level not at the same level. So, if they are not happening at the same level, the conflict is eliminated because the movements are happening at different levels. So, there is no conflict. So, grade-separation; by providing grade-separation.

Third, by doing the separating the traffic movements or conflicting movements, use with the help of traffic signals. What essentially, we are doing? We are doing time segregation. That means, all movements are happening. All movements are happening at the same level but at different times. So, if movement A and movement B are conflicting. Then movement A when it is happening, B stopped. When B is happening, A is stopped.

So, the time is distributed. Sometime this movement is allowed to happen. Some movement the other conflicting movement or movements are allowed to happen. So, by providing priority control, using space segregation or using time segregation. These are the 3 instruments available to traffic engineers. These are available to traffic engineers to minimize the number and or severity of potential conflicts.

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Levels of Intersection Control



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Levels of Intersection Control

- The control of an intersection can be exercised in three levels

Level	Details
Level-I	Passive control: Basic rules of the road <ul style="list-style-type: none">• Guide signs, warning signs, etc.• Road markings
Level-II	Semi-control: Direct assignment of right-of-way using YIELD or STOP signs <ul style="list-style-type: none">• Channelization<ul style="list-style-type: none">✓ Traffic islands, Roundabouts
Level-III	Active control: Movements of road users are regulated through <ul style="list-style-type: none">✓ Traffic signalization✓ Grade separation



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With this background, now we go to the next part that what are the levels of intersection control. The basic understanding has already been given. Based on that now, we shall see how then the levels of intersection control can be defined. There are 3 levels of control that may happen for intersections. We may call it as Level 1, level 2, level 3 or you can call them as passive control, semi-control and active control. What is passive control? Passive control is when basically you leave the operation primarily depending on basic rules of the road.

When we are driving vehicles, there are certain rules, regulations, we are supposed to follow. These are all fundamental or basic rules. I shall again discuss in details further. Often, we also provide guide signs, warnings, road markings even to inform driver, to communicate to driver clearly, maybe that you are approaching an intersection; that information is given to drivers.

So, that also helps us to improve the overall safety performance. But primarily the governing thing is basic rules of the road.

Sometimes, it may not be adequate. You are not still able to manage an intersection. You have issues with safety. Accidents are occurring or crashes are occurring. So, you go then to the next higher level that is semi-controlled, not active controlled but semi-controlled. Here what we are doing? We are actually directly assigning the right-of-way using yield or stop sign. I have told you earlier what is yield sign, what is stop sign. So, we are actually doing direct assignment of right-of-way using either yield sign or stop sign.

Here also often we use channelization, different forms. It may be just a traffic island or maybe complete roundabout. And through all these we try to improve the safety of the traffic using that intersection. That sometimes work under some circumstances likely to work but may not work under all scenarios. It depends on so many other factors will come.

So, if it is still not working, still accidents are happening or capacity issue is getting dominated and affecting the overall quality or overall level of service, then you go to the next level, further level, one level up. That is active control. Now, here these movements of road users, the movement of road users are regulated through two alternative strategies. One, by traffic signalization. That means now, what we will do? We will do time segregation. We will segregate the conflicting movement by time. Same intersection at grade only. All movements may happen but conflicting movements normally will not happen together.

I said normally. Most cases will not allow conflicting movement but some cases some minor movements we allow also. So, that is what I said: most cases. So, that is one possibility. You do traffic signalization. So, largely the conflicting movements are eliminated. They do not allow conflicting movements to occur at the same time.

This may have implications. This may enhance safety. Also, there are some other safety issues you may experience with that and the capacity may not be adequate now. Even the traffic is growing further. Signalization you may do. You may do time segregation but then you may find as a result there may be long queue. So, what you will do? The highest level then, further up. Go for grade-separation.

That means you augment the intersection with additional infrastructure, create grade-separated facilities. Again, a variety of possibilities are there. So, many possibilities are there. But all are

basically you are trying to do grade-separation or separating the conflicting movement by grade. So, the capacity does not get affected and the safety is enhanced.

But remember that, not that every place we will go for level 3 or go for grade-separation. If you simply have fever, you do not take immediately antibiotic. Antibiotic should be taken when it is required. Initial thing maybe you take a paracetamol tablet. So, same thing. Intersection first we try with level 1 or passive control. Then semi-control. Then does not work, go for active control. First signalization. That also does not work, brings some issues, we go for then grade-separation.

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Levels of Intersection Control

- Adequacy of intersection control depends on:
 - ✓ If drivers are able to **perceive and avoid** type and level (number) of **conflicts** by their own judgment
 - ✓ If **capacity** of the intersection is **adequate** to serve the **traffic demand** with desired level of service



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How to judge the adequacy of intersection control? Again, primarily 2 aspects are very important. One if drivers are able to perceive and avoid type and level or the number of conflicts by their own judgment. Suppose you consider level 1 operation. How do you judge whether the level 1 operation is adequate?

If nearly all drivers are able to perceive and avoid conflicts by their own judgment that means the sight distance is good, the volume is also like that which is manageable and which is giving good opportunity and safety is high, then that is fine. So, how many such conflicts can be avoided by drivers by their own judgment? That is very important.

Second, if the capacity is adequate to serve the traffic demand with desired level of service. What I mean that? Suppose your current level is signalization, level 3. But because of that, you may find long queue is happening, control delay. I have not yet defined that. I will tell all those things. Control delay is very important.

They are used to define the level of service in an intersection. Delay is too much, specifically control delay. Then the level of service will be lower than what it is expected, what is expected. The level of service will be lower than expected. So, in that case, you will again try to do for further upgradation.

So, 2 things are very important as I said here. If drivers are able to perceive and avoid type and number of conflicts. How many conflicts are able to avoid by their own judgment. And second, if the capacity of the intersection with the present level of control is adequate to serve the traffic demand with desired level of service.

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Levels of Intersection Control

Level I : Passive Control

- Applicable at any intersection where **right-of-way is not explicitly assigned** through the use of traffic signals, STOP, or YIELD signs
- Driver is expected to **obey the basic rules** of the road such as right-of-way rule, etc.
- ✓ The driver of a vehicle **approaching an intersection** must **yield the right-of-way** to any vehicle or pedestrian already in the intersection



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Levels of Intersection Control

- ✓ When two vehicles from different roads are approaching an intersection at **around the same time**, driver of the vehicle on the left must **yield the right-of-way to the vehicle on the right**
- Passive control measures like **traffic signs, road markings**, etc. are used to **complement** the intersection control
- **Sufficient sight distance** is essential for safe operation



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Now, go to level 1. Little bit more discussion about the passive control. Such kind of controls are applicable at any intersection, mostly the minor intersections, where the right-of-way is not

explicitly assigned through the use of traffic signal, stop or yield signs. That means the basic rules of road that is governing the operation. There is no defined priority of one road as compared to the other road. Under such and the traffic volume is also not so high, you go for passive control.

And here, the drivers are expected to obey the basic rules of the road such as right-of-way rules. For example, the driver of an approaching vehicle at intersection must yield the right-of-way to any vehicle or pedestrian already in the intersection. That means I am approaching that intersection. I find that already another vehicle is entered into the intersection. So, I have to give priority to that vehicle. I should not again try to enter into the intersection.

Or I find a pedestrian is crossing the road. If the pedestrian is already crossing the road, right, then I should stop and I should allow the pedestrian to cross safely, then I should do the maneuvering. That is one kind of thing, right-of-way rule. The second is very important and very common that people do not follow, when two vehicles from different roads are approaching an intersection at around the same time, then drivers of the vehicle on the left must yield the right-of-way to the vehicle on the right. Because if you consider Indian driving, Indian, the way the drivers use the road in India, there the driver's seat is on the right hand, right side.

So, driver can see the right side very clearly. So, if a vehicle is coming from the right, in that vehicle, the driver is again on the right side. So, he is on the other side of the vehicle. So, the driver should actually, the driver which is approaching and should always give priority to the vehicle which is approaching from the right. Here you can say the red vehicle and blue vehicle. The red vehicle is approaching from south, wants to go to the north direction. And the blue vehicle is approaching from the east, want to go to the west direction.

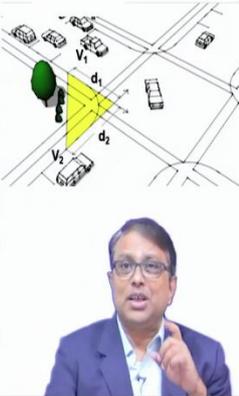
Now, as compared to the vehicle, right vehicle, the blue vehicle is approaching from the right side. So, the right vehicle stopped, red vehicle stopped and allowed the blue vehicle to cross the intersection safely before the red vehicle crosses the intersection. You can see that. Now, passive control measures like traffic signs, road markings etcetera are also used to complement the intersection control. And here the significant sight distance and sufficient sight distance is very very important. In this case, sufficient sight distance is very very important. Why? Because drivers should be able to see each other.

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Levels of Intersection Control

Sight Triangle at Intersection

- Drivers of vehicles on either road must **able to see** each other in a sufficient time/distance to be able to **halt their vehicles**, if needed, without a collision
- The area for clear visibility i.e. sight triangle should be determined with respect to the **stopping sight distance** for each road corresponding to the design speed
- The triangle is **dynamic** and the position of one vehicle affects the position of the other



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So, here I would connect you to the concept of sight triangle at intersections which you have already studied in your transportation engineering course earlier. Drivers, both drivers should be able to see each other in sufficient time or distance to be able to halt their vehicles, if required, without a collision or without a crash.

So, that means, if a vehicle is approaching, another other vehicle is also approaching, they should be able to see each other. So, that the corner should be free. In Indian condition that does not happen. Because all developments all establishments are there in the corner. The shops will be in the corner. Markets will be in the corner.

Everybody will try to build something in the corner. So, sight distance availability at the intersection is a major concern and is a major cause of accidents or crashes at intersections. So, the sight distance availability is very important. The area for clear visibility, that is the sight triangle as shown in yellow should be determined with respect to stopping sight distance for each road corresponding to the design speed. Because two roads may have different design speed.

So, the vehicles may travel at the corresponding design speed. So, at the corresponding design speed, both vehicles should be able to stop safely before colliding with each other. Of course, this triangle is dynamic and the position of one vehicle affects the position of the other.

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Levels of Intersection Control

Safe Stopping Distance at Intersection

- To ensure safe operation with no control, both d_1 & d_2 must be greater than safe stopping distance at the point where visibility is established
- Safe stopping distance:

$$d_s = 0.278Vt + \frac{V^2}{254(f \pm 0.01G)}$$

where,

- d_s = Safe stopping distance (m)
- V = Design speed or 85th percentile approach speed (km/h)
- t = Reaction time (s)
- f = Standard friction factor for stopping maneuvers
- G = Grade (%) (positive for upgrade and negative for downgrade)



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Now, you have already studied still I would like to remind you. So, here it is mostly what we try to ensure that stopping sight distance should be available a minimum. And stopping sight distance depends on the distance travelled during the perception reaction time and also the braking distance.

So, I have shown here, if small t is the reaction time, V is the design speed or 85th percentile speed in kilometres per hour, then you can calculate what would be the distance travelled during perception reaction time. And the second component, V squared by 254 f plus minus 0.01 G , that is the braking distance.

$$d_s = 0.278Vt + \frac{V^2}{254(f \pm 0.01G)}$$

Now, G is considering the effect of grade. So, there is upgrade, there is downgrade or it is a level road, the stopping distance is going to vary. So, you are familiar with this formula and this way we can calculate then how much will be the side or what will be the sides of that sight triangle.

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Levels of Intersection Control

Sight Distance Analysis at Intersection

- Consider a situation where ($d_1=d_s$), then for the intersection to be safely operated under the basic rules of the road: $d_2 \geq d_s$
- If for any of the sight triangles $d_2 < d_s$
 - ✓ Implement control using **stop or yield signs** or traffic signal
 - ✓ **Lower the speed limit** on the major street to a point where sight distance are adequate
 - ✓ **Remove or reduce sight obstructions** to provide adequate sight distance

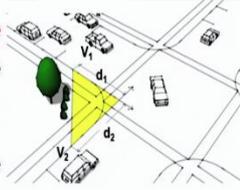


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Levels of Intersection Control

Sight Triangle at Intersection

- Drivers of vehicles on either road must **able to see** each other in a sufficient time/distance to be able to **halt their vehicles**, if needed, without a collision
- The area for clear visibility i.e. sight triangle should be determined with respect to the **stopping sight distance** for each road corresponding to the design speed
- The triangle is **dynamic** and the position of one vehicle affects the position of the other



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Now, consider a situation where d_1 is equal to s . You can see here what I have set my d_1 . d_1 is the for that road with speed V_1 and d_2 is the required distance for the road speed V_2 . So, what we are seeing, if d_1 equals to d_s , that means, the required stopping sight distance for that road then, if the design speed is same, then d_2 also should be at least either stopping signs, stopping sight distance or higher in order to be safe considering the same design speed. If the design speed is different, then the d_s value for with respect to d_2 that vehicle will be again different.

Now, for any condition where the d_2 is less than the required sight distance for the same vehicle, then there are multiple ways we can handle the situation to enhance safety. First, implement control using stop or yield signs or a traffic signal or lower the speed on the major street to a point where sight distances are adequate. We can easily do that because sight distance

as you have seen in this slide directly depends on V . So, if the speed is reduced, the sight distance also, required sight distance also will be lower. So, reduce the speed and enhance the safety.

Third, if possible, remove or reduce sight obstructions. If there is a building which is actually restricting the sight distance or there is a permanent structure, remove that structure and increase the sight triangle so that you know required sight distance is available. So, all the three will give us good result.

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Summary

- Intersection & Conflict points
- Levels of intersection control
 - ✓ Passive control
 - ✓ Semi-control
 - ✓ Active Control
- Passive control
 - ✓ Right-of-way rules of the road
 - ✓ Importance of sight distance
 - Sight triangle at intersection
 - Safe stopping distance at intersection

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So, if I have to summarize, I will say that we discussed in this lecture about the intersections. What are intersections? The conflict points. Why is safety important at the intersections? And then what are the different levels of control primarily the passive control, semi-control and active control.

And then we discussed in detail a little bit in details about the passive control saying that the right-of-way rules of the road that governs this operation. And then another requirement, important requirement, is the sight distance. So, the concept of sight triangle and safe stopping distance at intersection.

And if the required stopping sight distance is not available, then either remove the obstacle to make sure that the sight triangle available is adequate or reduce the speed so that the available sight distance is sufficient for the vehicle to stop or as I said that implement control using stop or yield sign. That actually is level 2 control. So, in the next lecture we shall continue and we shall start discussion about the level 2 control. Thank you so much.