Introduction to Multimodal Urban Transportation System

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Lecture - 49

Urban Transport & Sustainability: Electronic Toll Collection (ETC)

Welcome back friends. Now that you have been exposed to the different types of ITS architecture and you have familiarized yourself a little bit with the different views in ITS architecture be it the enterprise view or the physical view or the logical view. Now let us in this lecture give you an example of how the different ITS architectures or the different systems can be actually applied for certain specific transport related cases, right. So in this lecture, we will be looking at the case of electronic toll collection.

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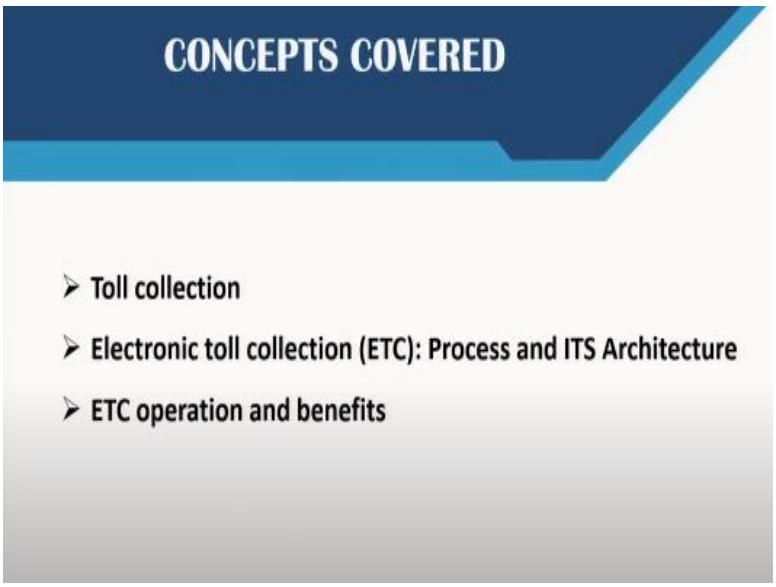

So we will introduce you to—what is toll collection, how electronic toll collection processes are carried out, what is the relevant ITS architecture to it. And then we will give you an example if you move from manual toll collection to electronic toll collection, what are the benefits and why you need ITS in the transportation arena.

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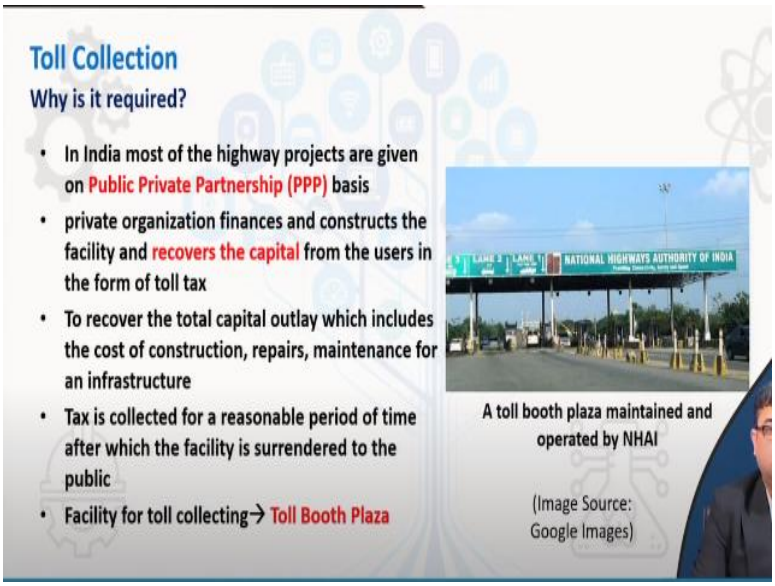

As you may be very well aware that traditionally highways were financed by public money. The money that was gathered either through direct taxes or through indirect taxes. For example, the taxes that we pay at the petrol pump or just a portion of your income tax that you pay. So all of those used to be used to develop or to construct our national highways by our various public agencies. But as budget has become tighter and tighter, we have moved towards this model of building highways using private partners along with public agencies as well. So this whole PPP model has been developed. And as a result of this model, what we have seen is that the private entities now collect tolls from the users of that facility. And these tolls are used to not only regain the money that the private players have invested, but also can be used for maintenance and operations of that facility during the toll period. And also obviously, the private entity would want to make some profit out of that as well. So tolls are now being collected at various highway segments, and the place where the tolls are collected are known as the toll booth plazas. So what we have seen that at toll booth plazas at some of the very busy highways, you would see long queues that starts forming at such toll booth plazas, which causes considerable amount of delay to the traveling public and also we are observing that such delays in turn are resulting in a lot of emissions at those locations as well. Because the vehicles are stalled and if a lot of large number of vehicles are queued up and are stalled at those locations, then the emissions are even higher.

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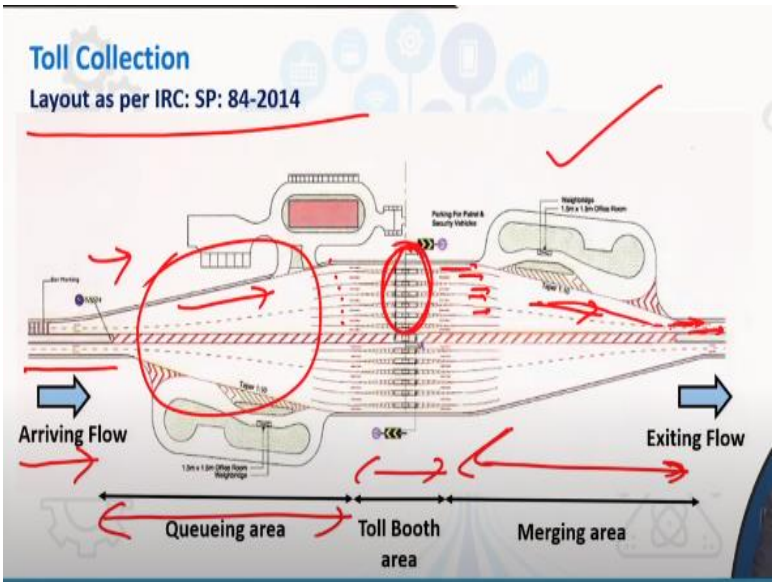

So all of this has given rise to the need of developing electronic toll collection systems, right. So but if you look at the original layout of as per IRC SP 84 in 2014. This is how a generic toll plaza design should look like. If the vehicles are arriving in this direction and if it is a two lane highway that usually splits here, which is the queuing area, which then splits into different number of lanes based on how many toll booths you have at that at that location. So you have a queuing area, then you have the toll booth area, and then again, all of those vehicles that emerge out of the tolling booth, they have to again merge back into the two lane. So you have a merging area as well. So eventually all of these toll lanes have to merge back in. So what causes the delay is not only the time taken by the vehicles to cross this toll booth, or to make the transactions at the toll booth, but also this merging and diverging areas. So people have to diverge from two lanes to seven, eight lanes, and there is some time that they take to realize which lane they should go to. They slow down, look for the lane that has the least queue and then select that lane. And then once they are merging back in, they have to be very careful that there are two or three other vehicles that are coming out of these lanes. They should not meet with an accident. Hence, they slowly merge back in into the two existing lanes. So all of this put together creates a lot of delay.

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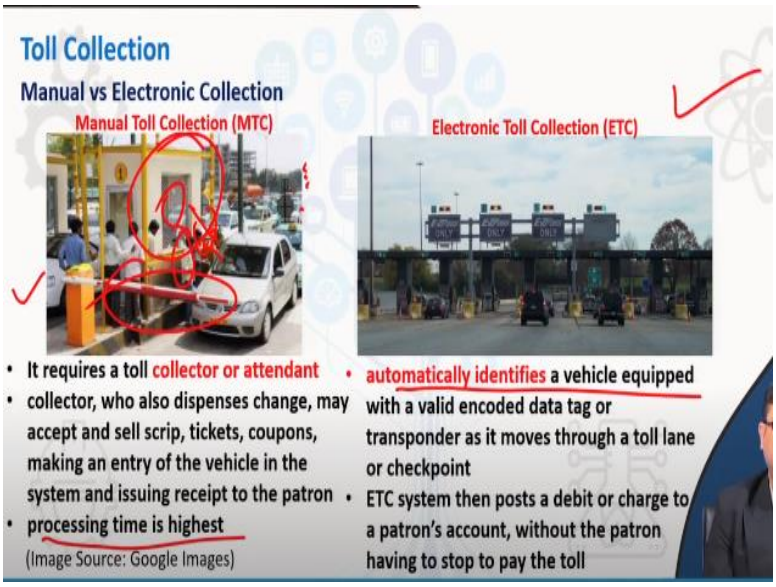

However, what the electronic toll collection attempts to minimize is the delay at the at the toll booth itself. Because what usually happens at the toll booth is that during manual toll collection, you have a person sitting inside the toll booth right here. Again, they are giving you or receiving from you a token based on from where you have entered the highway, and then you are using that token. The person inside the booth is calculating how much you have to pay. And based on that, you are making that payment. If you do not have exact change, then the person is giving you change. And all this is taking up a lot of time. There is a lot of delay that may happen. Processing time is the highest in case of manual toll collection. So imagine this happening at peak hour when everybody is trying to go to their go to work. There is a highway that is in the suburban part of your area. It is very common nowadays in many of the large cities in India, you have highways, which are tolled, are in the suburban part of your area, for example in NCR, and then you are all going into New Delhi for your job. And then during the morning peak hours, there may be tremendous amount of rush and the queues that are very long. However, what electronic toll collection allows you to do is to automatically identify the vehicle and the vehicle has a tag attached to it and the tag is connected to the individual driver's bank account and once the tag is identified and the vehicle is identified, then automatically the amount of money is deducted from the tag and you almost do not even have to stop at the toll plaza. There are no boom barriers at the toll at the electronic toll plaza counters and you should just be able to go through directly because your transponder is read. So it

in ideal conditions it should not provide any delay. But maybe since you have to at least diverge and merge into those particular lanes so you will have still have some delay. But your delay when as compared to manual toll plaza collection is minimized to a large extent.

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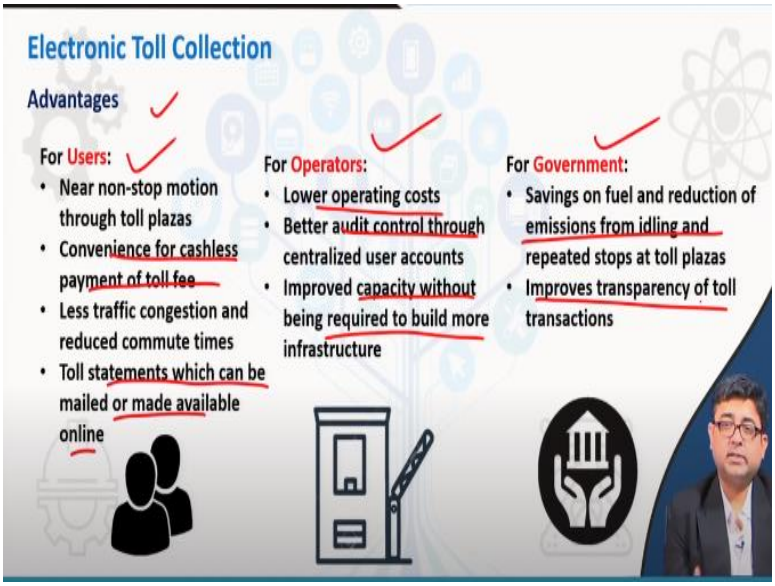

So it has all kinds of advantages for the users, operators as well as the government. For the users we have already discussed. There is almost no delay at all. Convenience of cashless payment. So you do not have to search for cash or exact change. And the toll statements can be easily mailed to your home online or to your email account. For operators, it is low operating cost for them. They do not have to have many people employed at that booth. Everything can be made online. Better audit of all these reports can be done. All these transactions can be done and improved capacity without requiring more infrastructure. So usually what happens is if the queue start on building up, people usually think oh, we need more toll booths. But putting in more tollbooth is putting in more money into the infrastructure and money may be scarce. So in order to improve the efficiency of the system the use of electronic toll collection helps. Again, like we had said earlier in the last lectures, one of the goals of any ITS system is to improve the efficiency of the system. And this is how, in our electronic toll collection case, it is improving the efficiency of toll collection and also for the government as a whole. It reduces emissions from idling vehicles, and it also improves the transparency of toll transaction. So there is no corruption that can happen at the toll plazas due to toll collection. All the electronic devices help in transparency as well.

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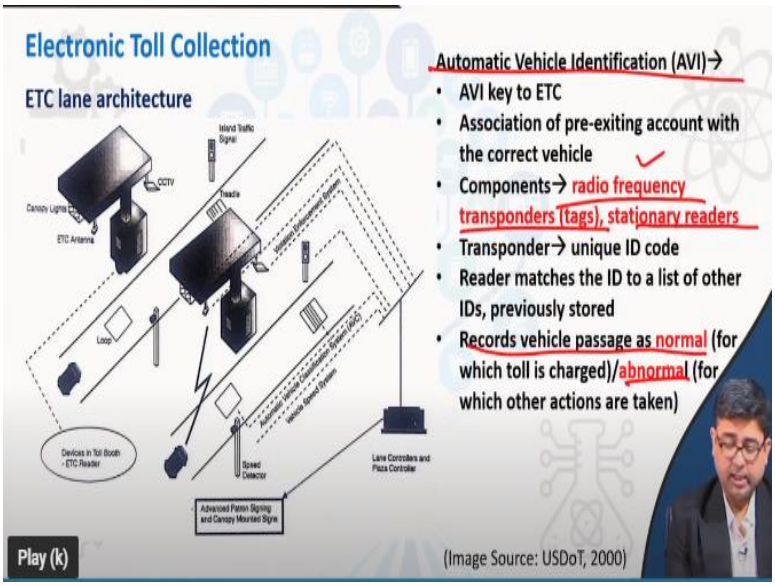

What are the keys ITS devices or ICT components that are necessary for electronic toll collection? One is the automated vehicle identification (AVI) system. AVI is key because using this system itself you will be able to deduct automatically the money required in order to process that vehicle through the toll plaza. Unless and until you know that this vehicle belongs to which person and the person's bank account is this, you will not be able to make the transaction happen electronically. So automatic vehicle identification is usually done by reading your registration plate number. Your registration plate number is backed in the database with the RTO. The RTO has all the information related to the person with this registration. For example his address, PAN number bank account information, so on and so forth. Then the AVI system automatically identifies the vehicle. It unfortunately identifies the vehicle and not the driver. We do not even want to identify the driver because if it is my vehicle and for example, my wife is driving it but our bank accounts are the same, so it does not matter if I am driving it or my wife is driving it. We still end up paying the toll. It is the vehicle that is identified and not the person driving the vehicle who is identified. RFID tags are attached to your vehicles. You may be now getting familiar to the RFID tags. Many of the vehicles are now mandated to get. Those are called FASTags. They are giving you these tags. They usually work on the radio frequency transponder technology. And there are stationary readers on top of the toll plazas that read these RFID tags. When the vehicle passes through the toll gate, if everything is normal then the transaction happens. If something is abnormal, for example, there is not sufficient balance in your bank account or your bank account number does not match, so then it

automatically sends you the bill to your home. And then you can pay it online with a penalty fee of course attached with it.

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So FASTag like I said, is one that the Government of India has now introduced. So what happens is you have this FASTag sticker or tag on your windshield that is read by the tag reader that is on top of the toll plaza. And once everything is normal, it reads it detects that this is the right vehicle for which the tag is given. And also the transaction happens that your bank account has sufficient balance and then this automatically opens up and you can go. So it is usually mentioned that you have to slow down your speed in order for this entire transaction to happen. You cannot travel at for example, 80 kilometers per hour and the transaction would be happening. For that you will need a very high speed communication technology. People are working towards open tolling where you can just drive at your normal speed and you will be tolled. But for that you would need not only good communication system networks, but also good lane behavior as well. So since in Indian conditions, our lane behaviors are not very good and the communication technology is still developing. So we would still require you to slow down a tad bit for this transaction to happen. But you do not have to come to a complete standstill and you do not have to wait at the toll booth. So this is how electronic toll collection, via FASTag, which is happening currently in India. You will see almost 180 toll plazas across national and state highways. I think that number is increasing as well. Because now all toll plazas are mandated to have ETC booths at their premises.

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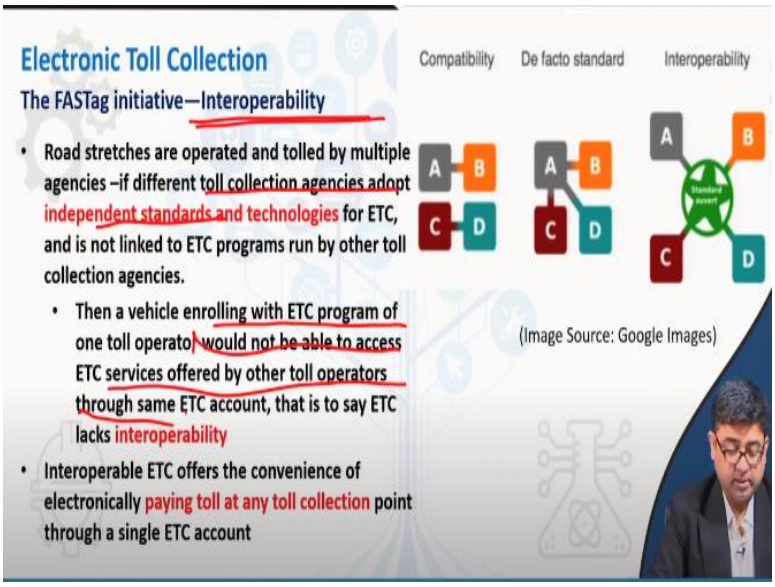

The other thing with such kind of electronic toll collection initiatives are the interoperability of these tags. These tags should be not only be specific to one particular toll plaza or one mechanism of paying electronic toll. It should, it should be interoperable. So if different toll collection agencies adopt independent standards and technologies, then a vehicle enrolled with an ETC program of one toll operator would not be able to access ETC services offered by another toll operator. So if there is difference between one highway using a different toll operator, and that toll operator has different standards for electronic toll collection versus the other state highway, then the FASTag for example, would work only in certain places. Then it does not bring efficiency to the system as a whole. So all these initiatives have to be interoperable so that the minimum standards are uniform throughout the nation. And if you have that transponder on your car, any toll booth, any toll plaza, any state you are in that should be able to work and you should be able to sail past the toll gates.

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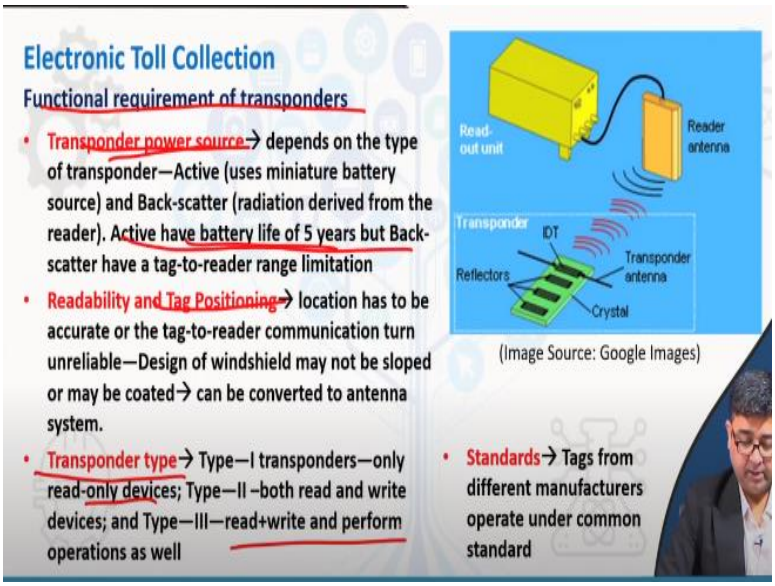

So now the minimum functional requirements of the transponders for example, have a power source. It has to have an active battery life. Since you are in the business of designing a system, so when you are designing, you need to know the specification. If you were in a business of designing pavements, for example, then you would have to know everything about how much how much mix do you need? What is the mix design, so on and so forth, right? What is the aggregate sizes, what proportion of the aggregates do you need? So all of those goes into pavement design. So similarly here, when you are doing your system design, you have to know, every little minor detail about what are all the elements that goes into the system. What is the average active battery life of each of these? Tag positioning is a very important thing in toll collection. If the tag is positioned, not at the right place on your windshield, the tag reader at the top of the toll plaza will not be able to read your tag on the car properly. If it does not read properly, then again, you get an abnormal transaction and then even though you pass through the toll plaza, you would have to pay a penalty maybe because your registration plate number has now been now been captured. All of these add to the system capacity and the system efficiency. So if you have to have an efficient system, you have to pay attention to detail. You have to design the system in such a manner that everything works, every small minor detail. You cannot say that well I did not have battery on my tag reader, on my transponder. And there was no power source. So I am not able to read any of the FASTags that are going through. That should not be an excuse. So you have to think about all of these what happens, which type of transponder you want to have. A transponder that can only read devices

but cannot write anything, cannot overwrite. Or do you want a transponder type III, which can read, write and perform operations as well. All of those things are something that you have to design in a very detailed fashion.

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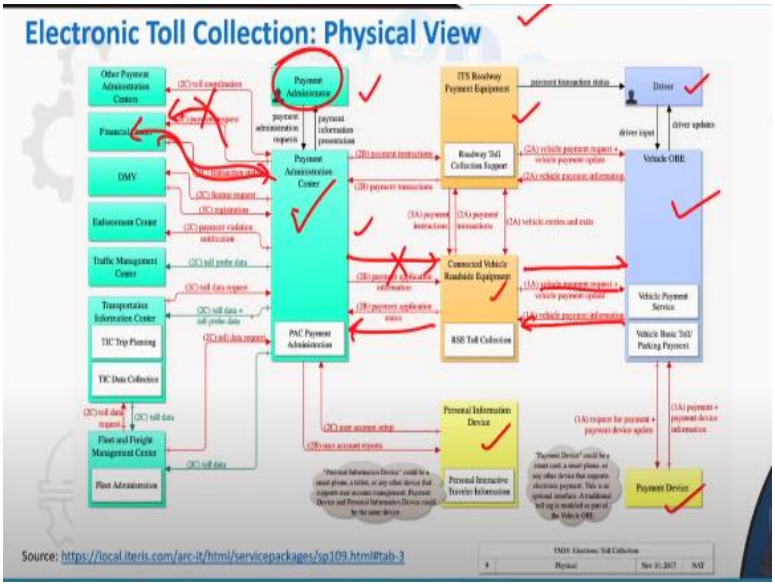

If you look now at the physical view of the entire electronic toll collection system. So you would again remember that they are all in different specific colors. The light green color represents all the centers. The light brown are the vehicles or the roadway pavement or the roadway systems. These are the light blue or the vehicles and the driver in the vehicle. And then yellow are the payment devices. So what is happening is every time a vehicle is arriving at the toll plaza, the vehicle is being there is an information flow that is going from the roadside equipment to the vehicle saying payment request. Once the vehicle is receiving this request meaning the vehicle or the tag on the vehicle is receiving this request. Then the vehicle payment information is going back to the roadside equipment to the roadside equipment. Roadside equipment meaning the reader on the top of the toll plaza. That payment application status is going to the administration center as well. Now, all this payment, all this information has to be collected and monitored at a TMC, Traffic Management Center. So the Traffic Management Center has a payment administrator, who is looking at all of this. And the traffic management center in turn is connected to your financial center, right to your banks. Now the payment request goes here. The financial center says okay transaction status is a success. Then the payment administration says okay, the money has been received to the equipment on the toll plaza. And then the toll plaza says okay the vehicle can go. All this information instantaneously has to happen. So you can

imagine the communication network that has to be working day in and day out for these all types of things to happen at an instant. You do not have to even wait for it. Maybe within a second all of this thing is happening. So the thing with any kind of application of ICT devices is that when it works, it works brilliantly. But if there is a snag in the system, then the capacity of a system breaks down very quickly as well. So if there is any snag in any of the communication system here or say here, then you would suddenly see that the queues at the toll plazas keeps on increasing. Because now you do not have a manual backup at the queue station. Ideally, you would not have a manual backup. Because if you have a manual person there as well at the electronic toll collection, then there is no cost efficiency involved. So when you do not have a manual person and now there is a snag in the electronic system, then the efficiency of the system goes down very quickly. So you have to ensure that all of these systems work. So I just showed you a very simplistic example of what happens for just one sort of communication to happen. But there are so many different types of information is being flowing between different entities. And all of those channels have to be open every time at every instant so that anything that goes wrong has to be either self-rectified or has to be assigned to somebody at the TMC for example or at the banks or somewhere so that they can help in the rectification of the problem.

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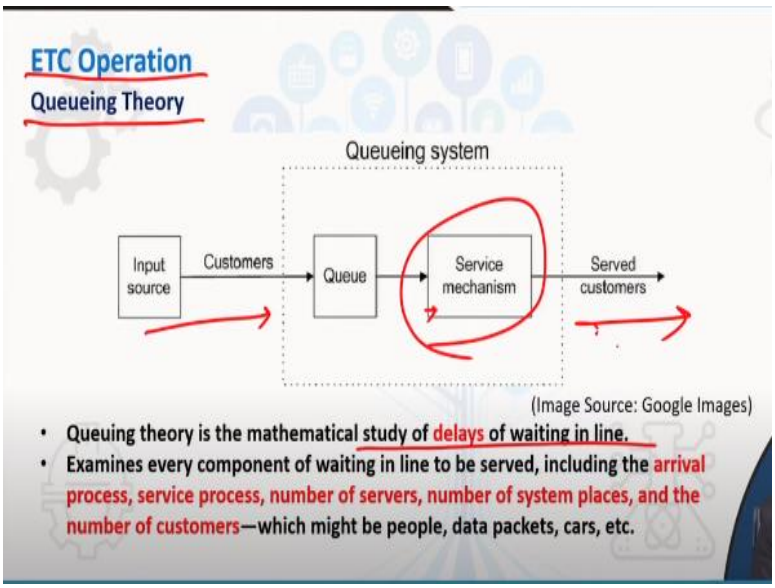

So in electronic toll collection or manual toll correction, the simple theory that is used is the queuing theory that many of you may be aware of. Queuing theory is nothing but the mathematical study of delays of waiting in a line. So if you are a customer you have already experienced this. This is not only in the toll plaza, but anywhere that you

form a queue at say at a ticket counter, at a railway station, or even at a bank counter. So you are a customer waiting in queue. You have some sort of service mechanism. Somebody is helping you at the end of the queue. And once you reach that place, then your service is provided and you get out of the queuing system. So that is the basic understanding of even the toll plazas that you are waiting to be served. You are waiting in the queue to be served. Then you reach the toll booth where you are being served. Even at that time, there is some delay because if it is manual transaction there is some delay and then once you are served, you accelerate and get out of the queue.

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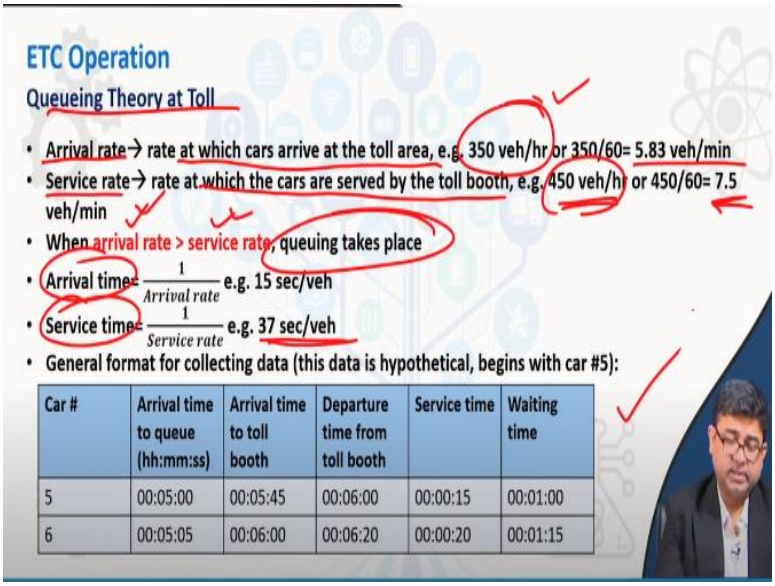

If you understand the queuing theory, then you will understand how electronic toll collection minimizes the delay that happens. And by minimizing the delay for one car you accumulate this reduction in delay for the entire system of cars that are approaching or going through the toll plaza, then you can get the benefit of electronic toll collection. So in queuing theory, some of the terminologies that we usually use are arrival rate and service rate. Arrival rate is the rate at which cars arrive at the toll area. So for example, there may be 300 vehicles per hour that are actually arriving at the toll, the total area, which on average is about 5.8 vehicles per minute. And service rate however, is the rate at which the cars are served by the toll booth, which for example, 450 vehicles per hour or 7.5 vehicles per minute. So in this case, what you are seeing is the service rate being higher than the arrival rate. So when the service rate is higher than the arrival rate that means, fewer number of vehicles are coming and I have the capacity to serve even more vehicles that are arriving at that time, no queue takes place. But when the arrival rate increases or becomes higher than the

service rate that is when queuing starts to take place. Just the inverse of these arrival rates and service rates will give you the service time and arrival time. So service time is nothing but one by service rate. So service time meaning 37 seconds per vehicle. So to serve a vehicle at the toll booth, it takes me 37 seconds. Arrival time is every 15 seconds one vehicle is arriving. So that is arrival time and arrival rates how they are interdependent.

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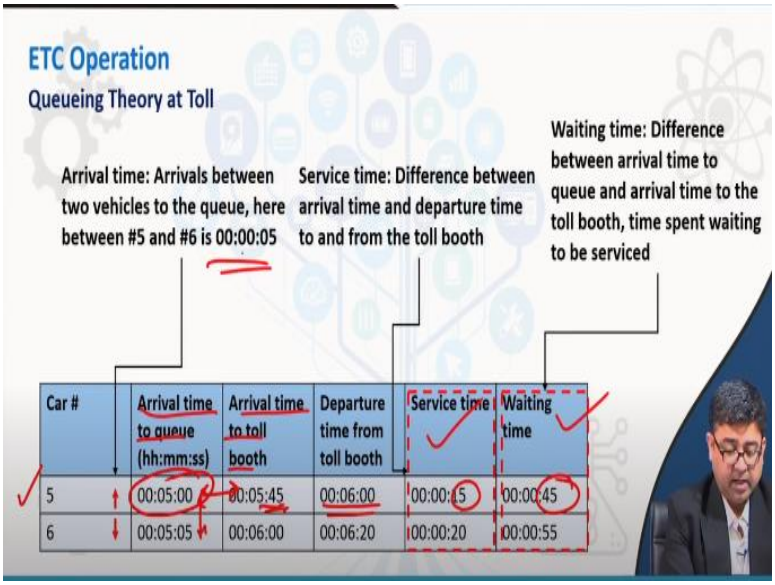

Usually at the toll booths you have these sort of databases that toll plazas keep with them. They say that okay, this is a fifth number car that has arrived. Arrival time to the queue that has arrived at five minutes, say example, at whatever fifth minute timestamp arrived at the queue. So that is when you arrive at the queue meaning at the back of the queue. This car has now arrived at the back of the queue. And then the car has moved up arrived at the toll booth at 5 minutes 45 seconds. So the car was in the queue for 45 seconds and at 5 minute 45 second, it has arrived at the toll booth and it has departed from the toll booth at 6 minutes. So in 15 seconds, it was served and at the 6th minute they have left the toll booth. So their service time essentially was 15 seconds. Their waiting time was 45 seconds, because it took the car 45 seconds to reach from the back of the queue to the tollbooth. So that is what is called waiting time. This is called service time. The arrival time between two cars you can calculate by the difference between when the next car arrives at the end of the queue in relation to the car in front of it. If arrival time has to be calculated the arrivals between two vehicles to the queue here are 5 seconds.

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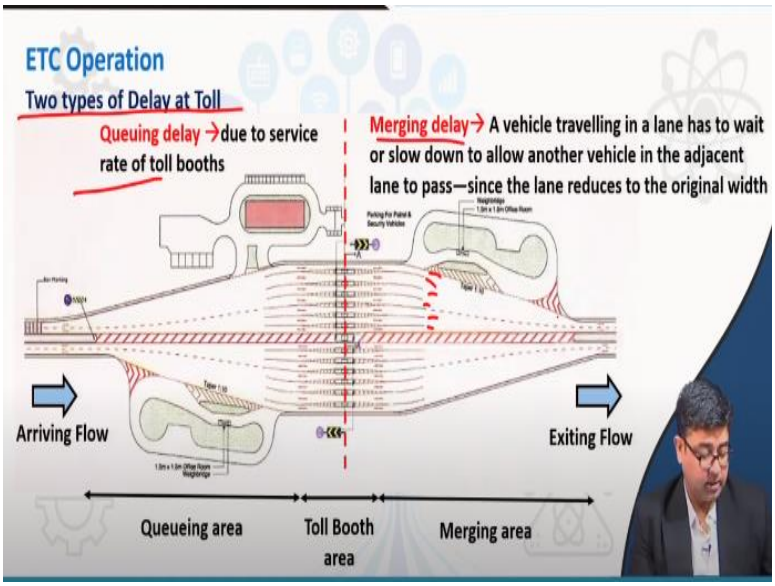

We have also given you an understanding of why delay happens. Delay happens due to two things. Queuing delay, which is when you are queuing up to pay for the tolls and also merging delay when you are trying to merge back because there are seven lanes that have to merge back to two lanes. So all of this takes a little bit of delay as well.

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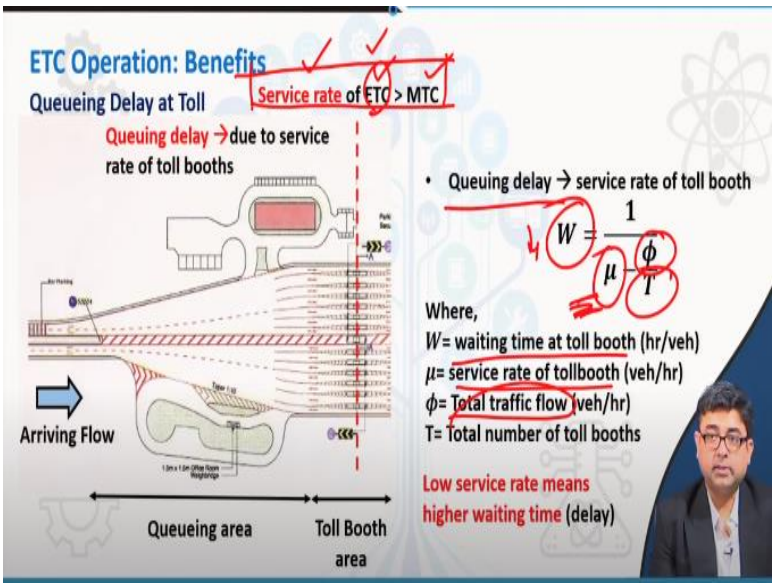

So what happens essentially at an electronic toll collection is the service rate of ETC is higher than the service rate of MTC. So that is how it reduces the queuing delay at an electronic toll collection. Electronic tolls can serve you at a much faster rate, because there is no manual transaction happening. There is no money being exchanged. It is only a transponder that is reading your tolls and it is letting you go.

So the service rate of electronic toll collection is much higher. How do you calculate that queuing delay or waiting time at the toll booth? Waiting time at the toll booth is dependent upon service rate at the toll booth and also the total traffic volume that is coming and also the number of toll booths that are there. So the service rate is very, very important. The higher the service rate, the lower will be the wait time at the toll booth. So since the service rate of ETC is greater than the service set of MTC, that is how it reduces or electronic toll collection reduces the delay at toll plazas.

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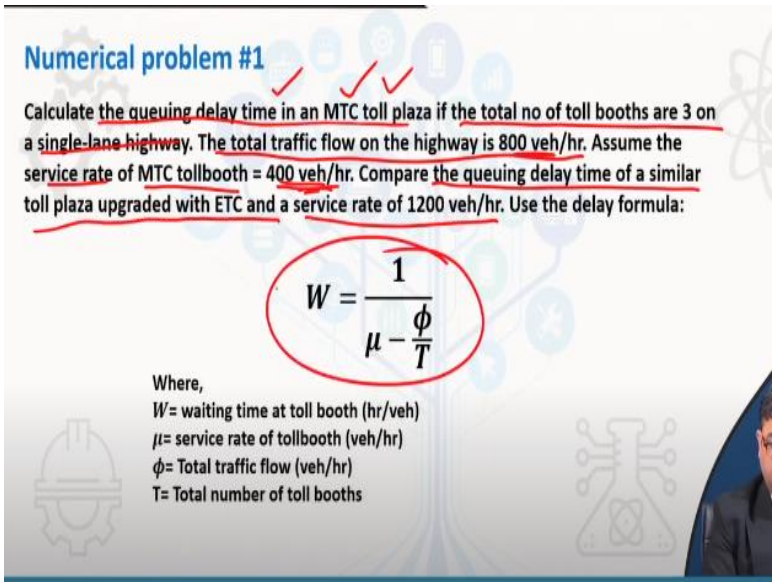

You are given a simple problem and asked to calculate the queuing delay time at a manual toll plaza. If the total number of toll booths are three on a single lane highway. So it is a single lane highway, and now there are three toll booths. The total traffic flow on the highway is 800 vehicles per hour. Assume the service rate of the MTC toll booth is 400 vehicles per hour. So there are 800 vehicles per hour that are coming or the traffic flow on the highway, whereas the MTC tollbooth service rate is 400 vehicles per hour. Then once you are finished measuring the delay at the MTC compare the queuing delay of a similar toll plaza upgraded with ETC and the service rate of 1200 vehicles per hour. Now if this has been upgraded to an electronic toll collection and the service rate there is 1200 vehicles per hour what would be the queuing delay time. So you can both for both the cases you can use this formula.

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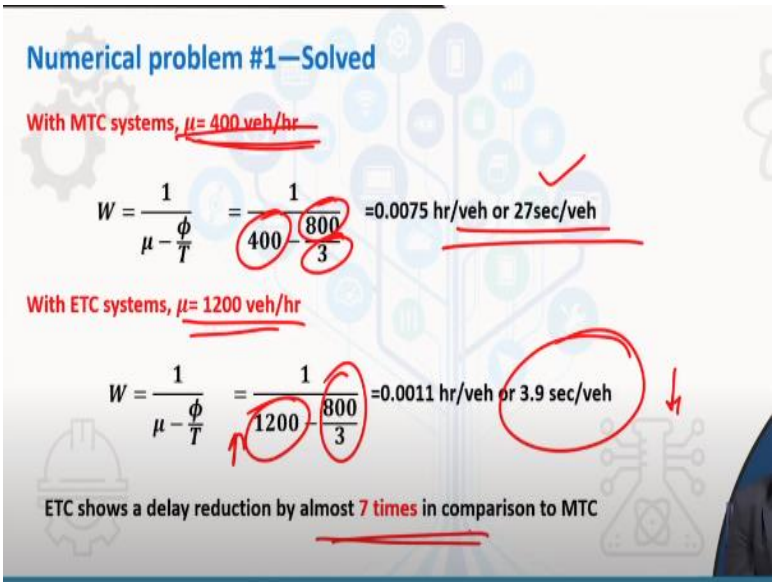

And in the first case, when the service rate is 400 vehicles per hour, you see that you substitute 400. This is already 800 and you have said that there are three number of toll booths. So you see the delay is 27 seconds per vehicle. Whereas at an ETC when the service rate has gone up, this remaining constant, your delay has gone down to just 3.9 seconds per vehicle. So almost seven time reduction in delay due to the application of electronic toll collection. So these are the benefits of for example, ICT devices in this case that we have shown is an electronic toll collection plaza. So this can be demonstrated in any other ITS application that you are thinking of installing in your city or in urban area. This is how you can demonstrate the benefits of it that these are actual efficiency benefits that help that help in transforming your manual operations into an electronic operation.

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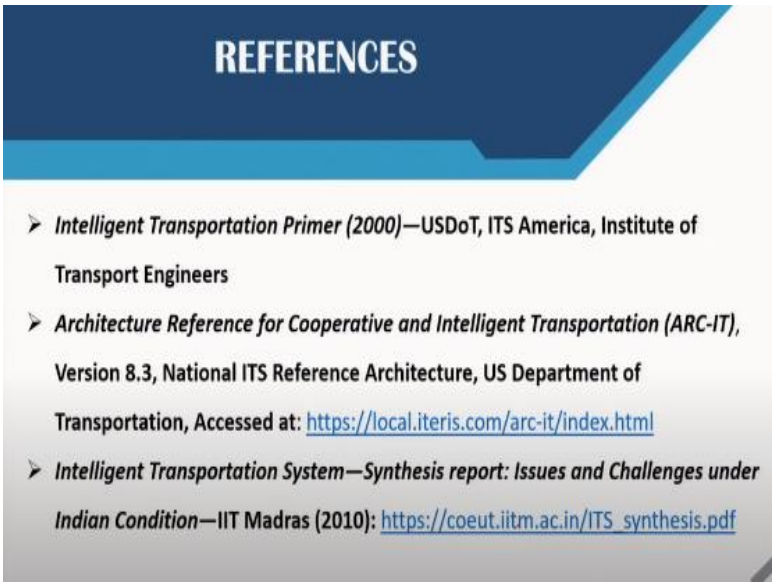

That brings us to the end of this lecture where we have shown you a case study on the application of ICT in electronic toll collection. The references, we are giving you constantly are the same references. So please do read through them.

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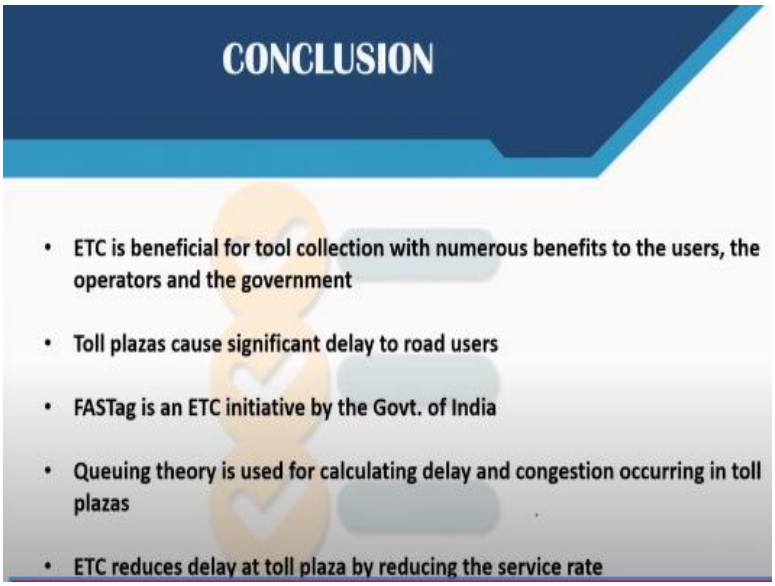

In conclusion, what we have looked at is how toll plazas can cause significant delay to road users and how this delay can be minimized when you are using electronic toll collection. And we have given you an example of queuing theory and how to measure waiting time using queuing theory. Thank you.