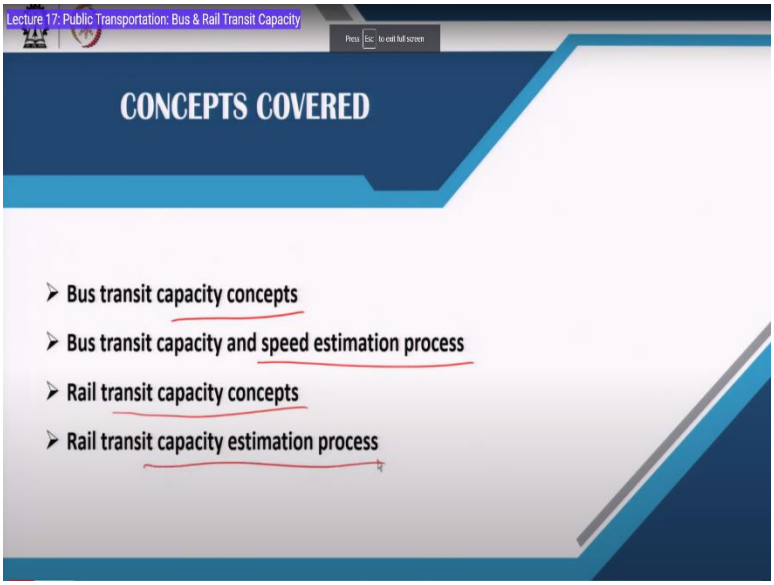
**Introduction to Multimodal Urban Transportation System**
**Prof. Arkopal Kishore Goswami**
**Department of Ranbir and Chitra Gupta School of Infrastructure Design and management**
**Indian Institute of Technology - Kharagpur**

**Module No # 04**
**Lecture No # 17**
**Public Transportation: Bus & Rail Transit Capacity – 1**

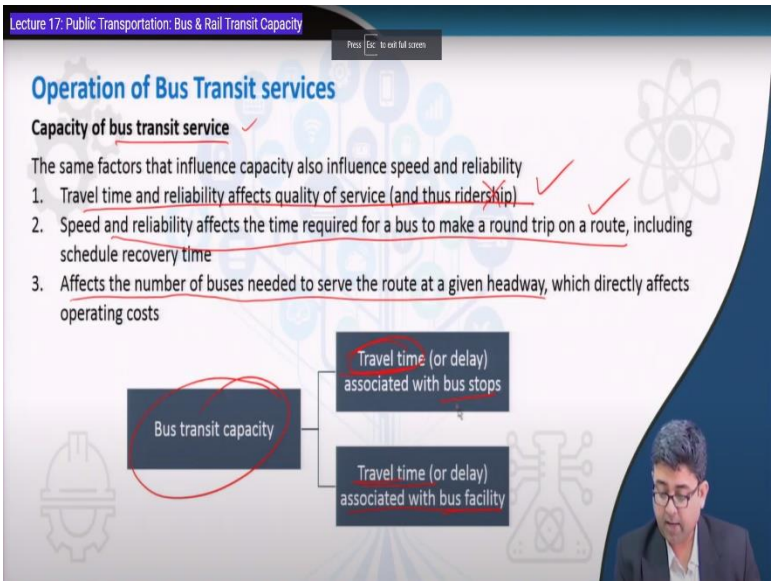
Welcome back friends. Now that you have understood the operating parameters and the operating features of public transportation system, in this lecture we will tell you in detail how to measure the bus and the rail transit capacity. There are 2 parts of this lecture; in the second part of the lecture we will be looking into different types of solved examples.

**(Refer Slide Time 00:51)**




In this part we will introduce you to the concepts of bus transit capacity, and we will look at how capacity and speed estimation process is carried out. Similarly, we will be looking at rail transit capacity concepts and look at how rate transit capacity estimation process is carried out.

**(Refer Slide Time 01:11)**



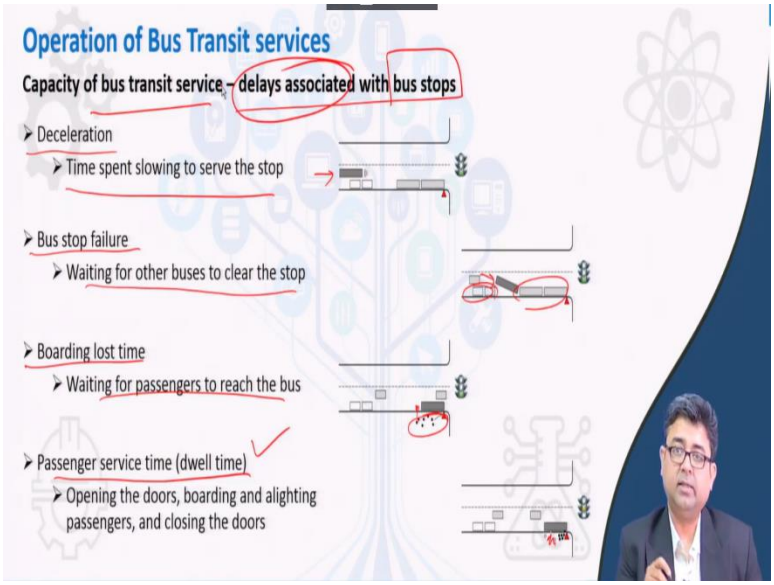

So, when we are talking about the capacity of a bus transit service system, we are looking at travel time, i.e. capacity based on travel time or delay associated with bus facility. So, travel time is something that we are looking at. Travel time with bus stops or travel times with bus facilities. So this is something that you have to start understanding-- that the capacity of a public transportation system can be measured using time.

So usually we think capacity as the number of people that can be fit in a bus service but usually it is number of people that cross a certain point in a given amount of time. Remember the definition of speed and travel times. Travel time and the reliability affects the quality of the service. Unreliable travel times or very high travel times can lead the people not riding that public transportation system.

Speed and reliability effects the time required for a bus to make a round trip. So, both from the users' point and operators' point of view, they all impact the public transportation system. They also affect the number of buses needed to be served on that road or route given a specific headway that it must maintain. If the travel time is too much between the 2 stops then there has to be a greater number of buses in operation that increases the operation cost as well.

So, we looked at the capacity of bus transit service from the point of view of the travel time at the bus stops or travel time associated with the bus facility.

**(Refer Slide Time 03:10)**



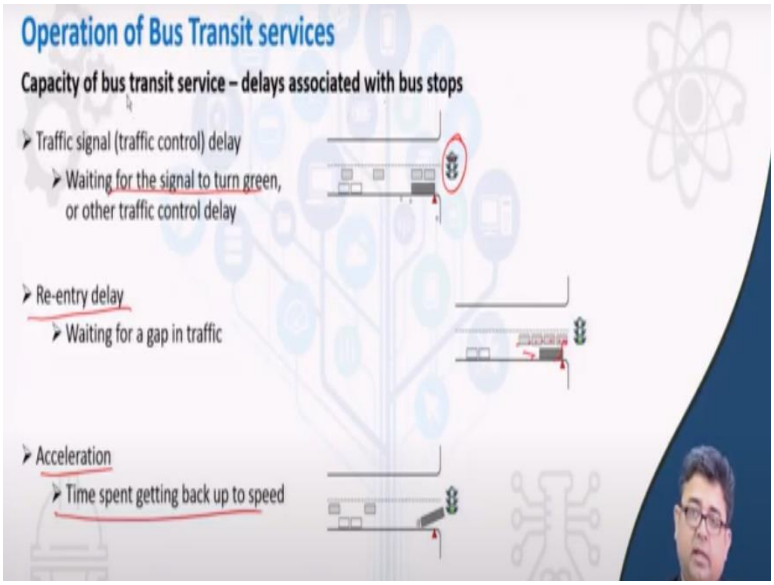

So, let us look at the capacity of a bus transit service and look at what are the delays associated with the bus stops. So, if we look at it from the point of view of the bus stops and how we can minimalize these delays to maximize the capacity. So usually at the bus stops buses decelerate, i.e. slowing down to serve the stop. There may also be bus stop failure, i.e. waiting for other buses to clear the stop.

Maybe there is no space for the incoming bus to stop because there are other buses that are already at the bus stop. Boarding lost time, i.e. waiting for passenger to reach the bus. If you do not have bus bay, then passengers are waiting on the pavement and there is sometime time lag that happens for the passenger to come out of the bus stop and come on the pavement and then access the bus, that is boarding lost time.

Passenger service time is the dwell time. So, deceleration is when bus is reaching a stop and must slow its speed. Bus stop failure is when it cannot get in there because of parked vehicles or other buses are already being served. So, it cannot get in there. Boarding lost time happens when there are lots of people already boarding another bus and cannot reach this bus in time.

And then the actual dwell time which are needed by the passengers to board and alight the bus. So, all of this contributes to the delay associated at bus stops. And these delays essentially reduce the capacity of the bus transit system.

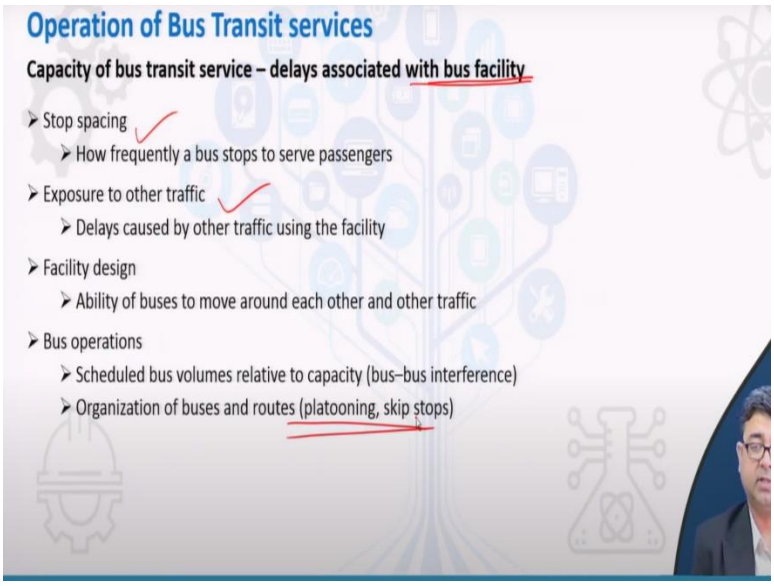
**(Refer Slide Time 04:55)**




The other 3 situations are delay due to traffic signals, waiting for the signal to turn green. You may not have free left turn in our situation or the buses may not be able to turn free left even though there is a left turn lane or may be the signals are no turn on left at red. Similarly, there may be reentry delays so if you have already entered into a bus stop but now there are other vehicles that are not allowing you to get back out.

So, there may be reentry delay and then there are some delay because of accelerating back from your stop to the speed that you want to pick up to. So, all of these things cause delays to the bus service or loss to one particular bus which then can be accumulated to the entire service and then reduces the capacity of the bus system as a whole.

**(Refer Slide Time 06:00)**

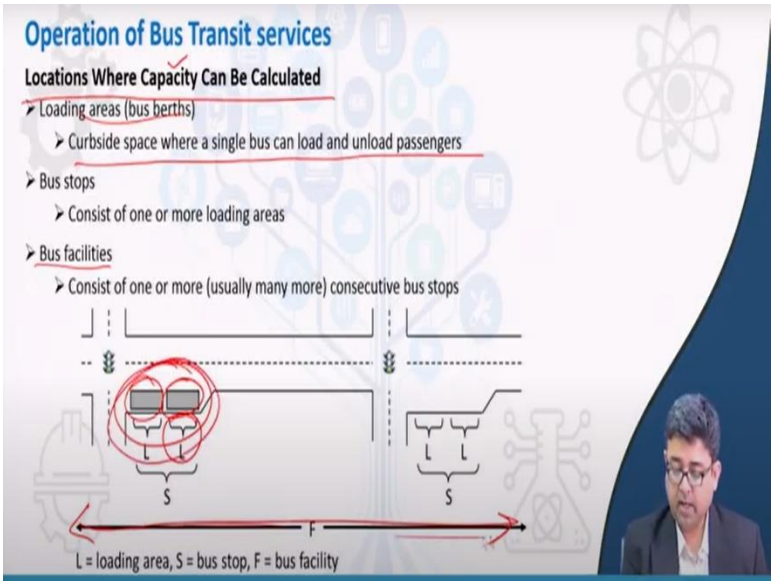



Stop spacing - now if you start looking at delays associated with the bus facilities, you should understand what are the different types of bus facilities. Stops can be one type of facility exposed to other traffic on a mix traffic facility. If you are running your buses on mix traffic situation at-grade, there will be exposure to other kind of traffic which causes delay. If there is spacing on one hand and it is close to each on the other, you may maximize your person capacity.

But if the bus must stop every 20 meters or 30 meters, i.e. in short distances, it reduces speed and the increase the delay and reduces the capacity of the system as well. Facility design - maybe the streets do not provide the turning radius at certain junctions. So the buses have to really slowed down or they may not be able to enter that route or that lane and hence has to go around and that increase the travel time or reduces the capacity again.

And then there may be bus operation factors that come into play. Platooning of 2 or 3 buses bunched together causes again a reduction of the capacity.

**(Refer Slide Time 07:28)**

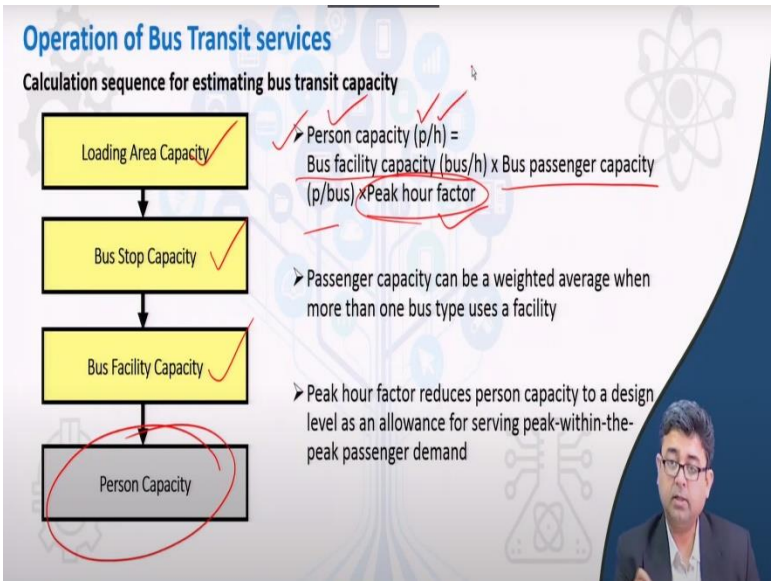



So what are the places where capacity is calculated? When it comes to a bus transit system, it can be calculated at the loading areas of the bus berths. We can calculate the capacity of loading areas that is the curbside space where single bus can load and unload passengers. You can measure the capacity of the bus stop at the loading areas.

So, if there are 2 loading areas in a bus stop, you can measure the capacity of the entire bus stop as well. And then lastly you can of course measure the capacity of the bus facilities which consist of one or more consecutive bus stops. So, this is the entire facility for which also you can measure or estimate the capacity of your public transportation system.

So, you can do it at a very micro level at the loading areas. You can do it at the meso level at the stop or you can do it at the macro level at the facility. You can measure the capacity at 3 different levels.

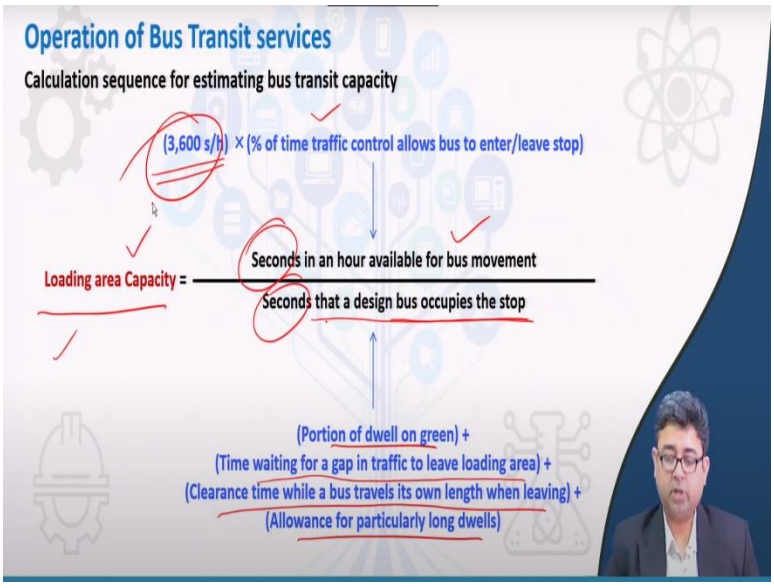
**(Refer Slide Time 08:41)**




So, by knowing the load at the loading area, which is the lowest denomination, we can calculate the capacity and then aggregate up to the bus stop to the facility and then convert it into person capacity. So, the person capacity is nothing but the bus facility capacity times the bus passenger capacity times the peak hour factor. There is always a peak hour factor because remember the previous lecture where we discussed that the bus operation varies based on hours of the day.

There may be peak hours within peak hours that are peak periods. So, there is always a peak hour factor that is a factor that helps us to understand what is the person capacity or the number of people per hour that a public transport service can move.

**(Refer Slide Time 09:35)**



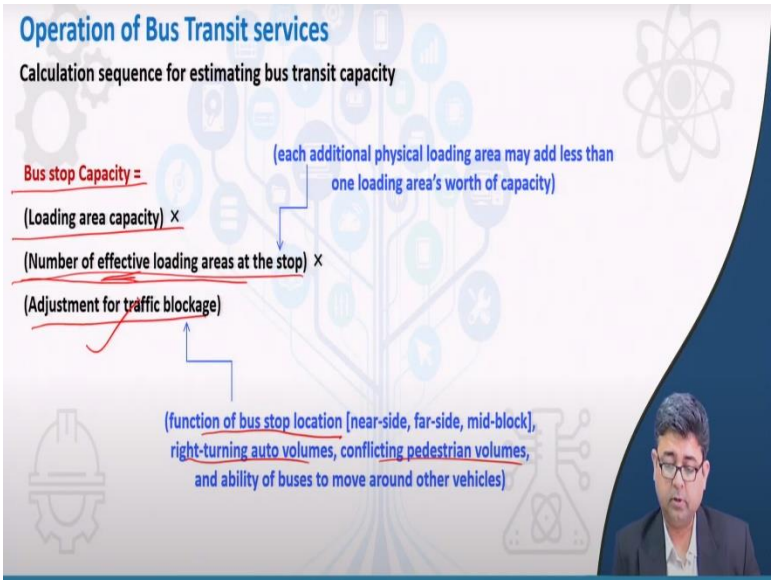
So, there are simple formulae for understanding how to measure or how to calculate loading area capacity. It is the seconds in an hour available for bus movement divided by seconds that a design bus occupies the stop. Both are in the seconds units. So, it is a unitless measure. So, we have to know that how many seconds in an hour is it available for the bus movement. That means there are 3600 seconds per hour multiplied by the percentage of time traffic control allows the bus to enter or leave that stop.

So, you must do some manual calculations you have to understand that you have to be at the bus stop or bus station and figure out how much time? What percentage of time does the traffic environment around the bus stop allows the bus to enter or leave that stop. So, multiply that by 3600 and divide by the seconds that design bus actually occupies that stop.

So, the time that the bus occupies the stop will include the portion of the dwell time. The time waiting for the gap in traffic to leave the loading area, so the bus must leave the loading area, so portion of that time is also needed. Clearance time where the bus travels its own length when leaving. So, when the bus is leaving out of the bus bay its entire length must be crossed.

So that is the clearance time needed. Dwell times are longer if there are large number of passengers loading from that loading area and embarking or disembarking or boarding from that loading area of that stop. So that is the simple enough of ratio to find out.

**(Refer Slide Time 11:39)**

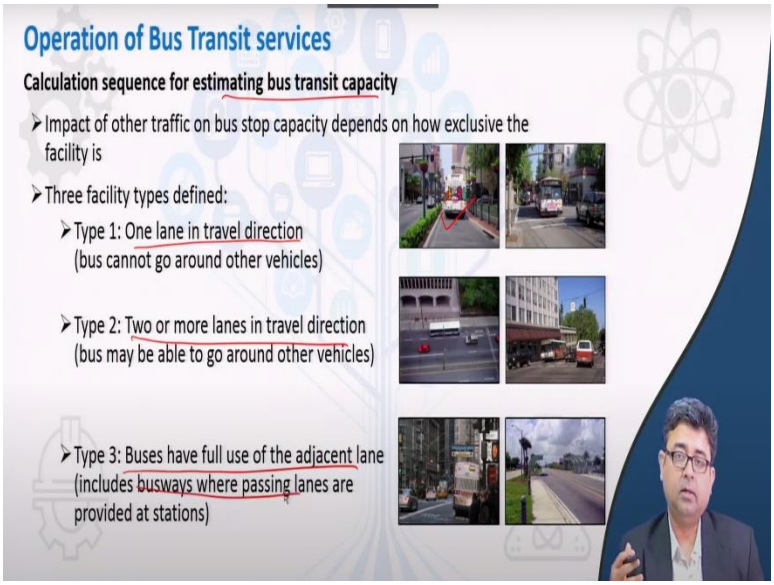


Similarly, bus stop capacity now can be now calculated by multiplying the loading area capacity that we have already figured out by the number of effective loading areas of that stop. There may be 2 loading areas, but one may not be available because of encroachment or because of vehicles parked there. Also, bus may not have stop at the right position.

So, it may have taken up both the spaces and the other buses are unable to come inside this loading area. That is why you have to calculate the number of effective loading areas and not just the number of loading areas at that stop and the adjustment factor for traffic blockage which is the function of the bus stop location if it is blocked by a parked vehicle. For example, for right turning or left turning volumes there is conflict of pedestrian volumes.

So, there are different adjustment factors. These are standard factors that have already been developed based on many operating conditions. You may adopt that for your situation, or you may develop your own factors based on your local traffic condition as well.

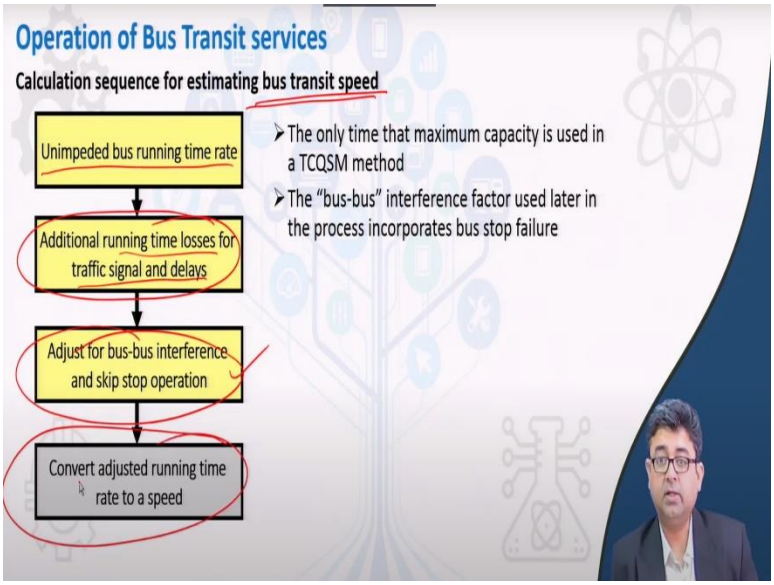
**(Refer Slide Time 12:56)**




Similarly, for calculating and estimating a bus transit capacity you must know what type of facility your buses are running on. Is it a one lane one direction unidirectional facility where the bus cannot overtake any other vehicle? So, if there is some vehicle in front of it, it cannot overtake. That limits the capacity of your system. If there are 2 or more lanes in the travel direction, then your bus maybe able to overtake and access the bus stop or do a turning movement that allows you to move faster in the traffic stream.

Or the type 3, where the buses have full use of the adjacent lane, includes busways. So, you have dedicated right of way for the buses to move. So that type of system is the best for when it comes to having good capacity for the bus system.

**(Refer Slide Time 13:56)**

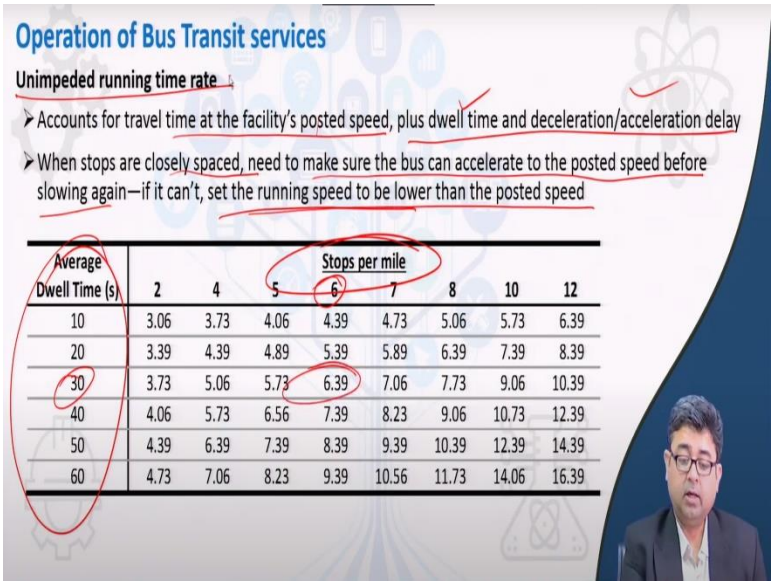



The second thing to understand is how to calculate bus transit speed. So, you must assume some sort of an unimpeded bus running time. So what you usually do is you look at the posted speed limit and you say that the bus, if it was unimpeded, i.e. there is no traffic on the road, this is the rate and this is the number of busses that would pass through the segment in the given period of time.

Based on the speed limit you can calculate the bus speed and assume the rate of buses that is going through that segment. And then you start to account for different types of losses. Now then you try additional running loses for traffic signals and delays and now you add those losses adjust for bus interference and skip stop operation. When, bus bunching happening that reduces the bus speed.

So, all you take it into account all that and then you get the adjusted running time rate. Then you convert this using all these lost times and then finally convert them in to a speed.

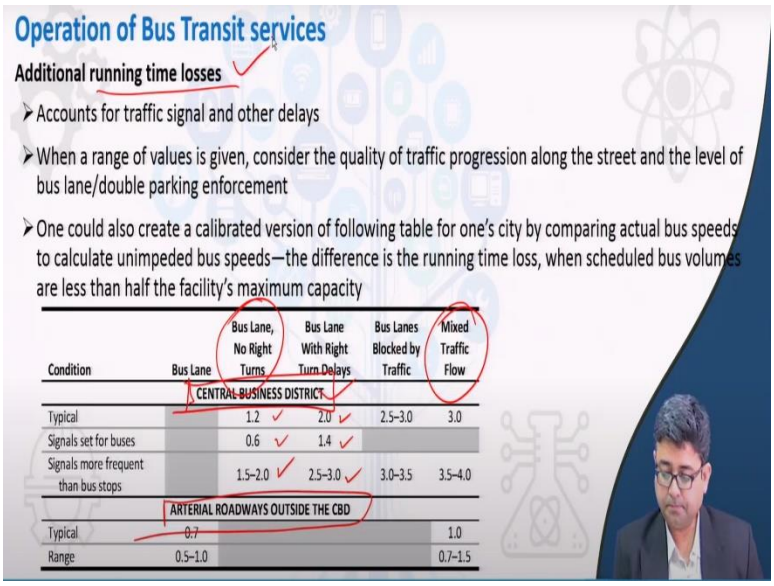
**(Refer Slide Time 15:14)**




What do you mean by unimpeded running time rate? - it accounts for travel time at the facility's posted speed plus dwell time and acceleration/deceleration delays. So, whatever the posted speed is plus your dwell time, acceleration and deceleration delay, will give the unimpeded time rate. When stops are too closely spaced, we need to make sure the bus can accelerate to the posted speed before slowing again. If it cannot then you set the running speed lower than the posted speed.

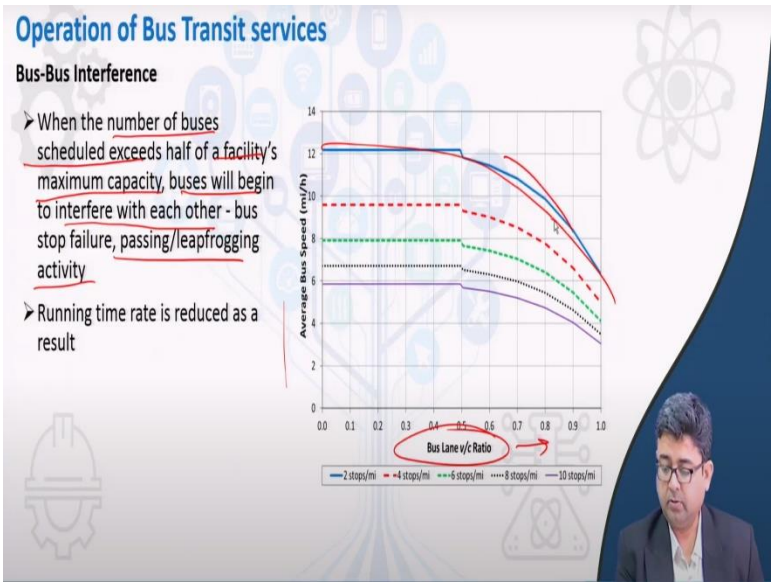
If 2 stops at too close to each other then there might be situation that the bus might be able to reach 60 km per hour top speed. But since the next stop is only 500 meters away it cannot accelerate up to its maximum speed and it can only accelerate up to may be 20 km per hour and then it has to start to decelerate again. So, then the speed that it reaches will never be maximum speed, so you have to then let it run at a lower speed than posted speed limit as well.

So, these are the standard numbers that are given to average dwell time and how many stops per mile you have. So, if you for example have 6 stops per mile and your average dwell time is 10 seconds so this is what you are going to have as your unimpeded running time rate. **(Refer Slide Time 16:44)**




Additional running losses are also running losses because of the right turn lanes; because of mix traffic flow, etc. So, they are different for different types of land uses. For example, arterial road outside the CBD central business district. You have different figures that have been calculated mostly in the western countries. But you get the idea of how to measure this and what may cause the delay. And you can carry out similar running losses or running time losses for your city public transportation network as well.

**(Refer Slide Time 17:21)**

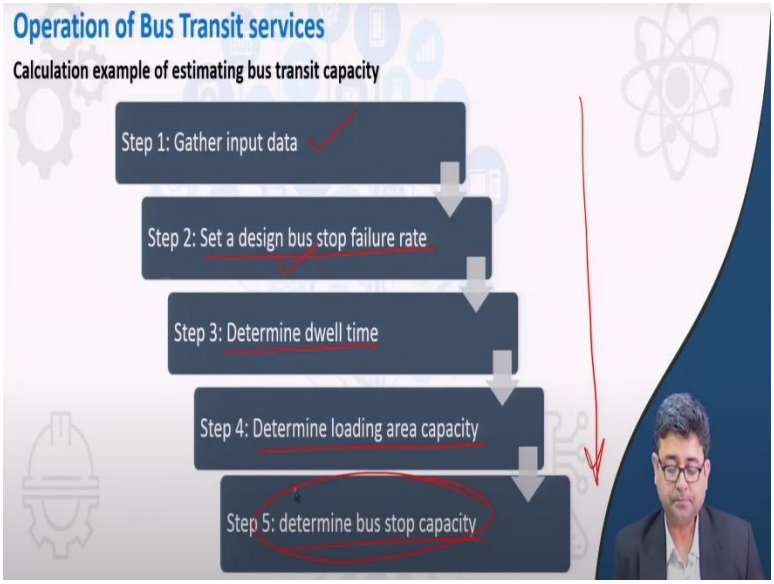



Bus interference - if there are a number of buses scheduled exceeds half of the facility's maximum capacity. So, if it is exceeding half of the facilities maximum capacity, buses will

begin to interfere with each other. So, bus stop failure, passing / leapfrogging activities - 2 buses trying to race against each other.

That is when you know that the bus transport network is not functioning well because they should not compete against each other. They should be helping or working in parallel to each other so that efficiency is increased. So, what happens to the bus speed. The bus speed average starts going down when the bus lane's v / c ratio starts going up. The greater number of buses than the capacity it can hold in that facility keeps on increasing, the bus speeds goes on reducing. So, you should never have too much bus bunching going on in your system.

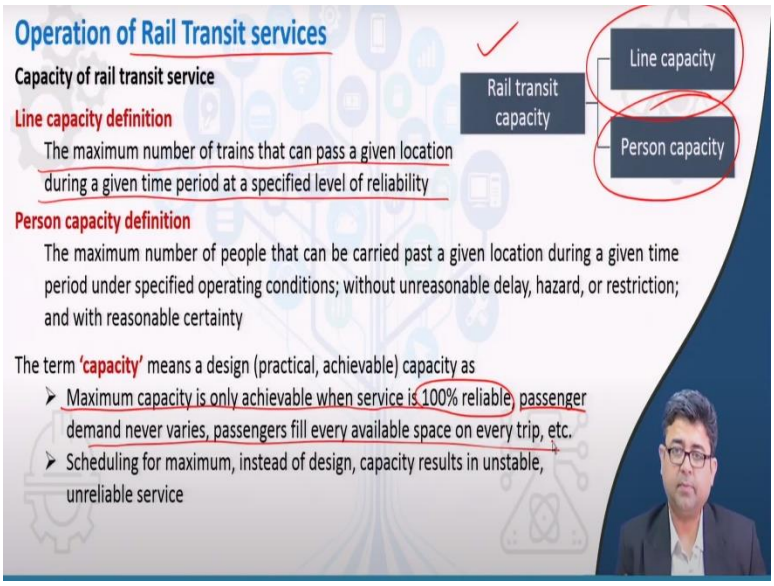
**(Refer Slide Time 18:30)**




So, these are the generic steps that are usually done to estimate the bus transit capacity you design. You get all the background data, social economic data, demographic data from your city. You set a design bus stop failure rate. And then against that design rate you start determining the dwell time determine loading area capacity and determine the bus stop capacity.

You have understood that the loading area is the lowest denomination, then it is the bus stop capacity, then it is bus stop facility's capacity. So here we have stopped at the bus stop capacity level.

**(Refer Slide Time 19:16)**

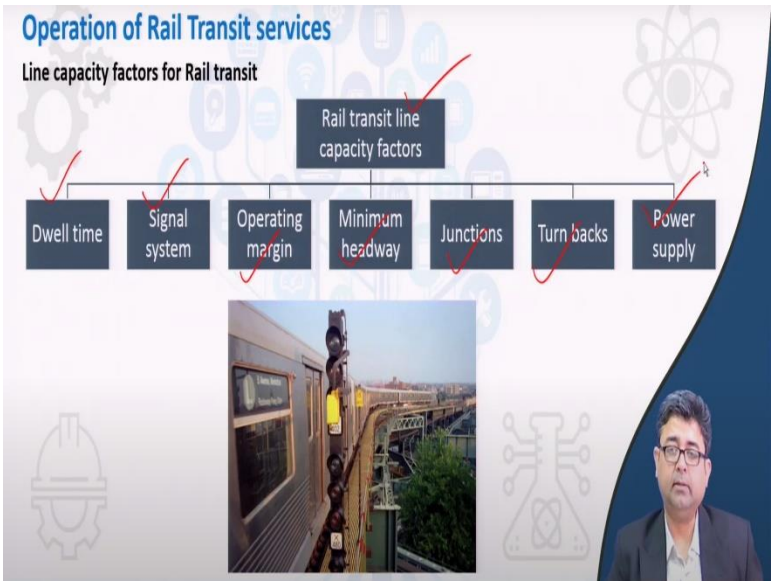



So next, if you start looking at the rail transit services, and their capacity calculations. The principles are very similar to bus a stop transit capacity. There are few other factors that come into play when you are trying to calculate rail transit capacity. Rail transit capacity depends upon 2 different things - the line capacity and again the person capacity. You know how to measure the person capacity in terms of bus transportation systems.

But we never talked about line capacity in bus transport system. So, let us look at what is line capacity here? Line capacity is the number of trains that can pass a given location during a given time period at a specified level of reliability. So, the definition is also very much similar. There we had bus capacity or vehicle capacity here we have line capacity. Person capacity is similar to what we have in the bus transport arena as well.

Again, here also we have reliability. So maximum capacity is only achievable when service is hundred percent reliable and passenger demand never varies. This was the situation for bus transport as well. So, when you talk about bus and rail transport, the basics are very similar when it comes to measuring the capacity. There are few other elements that we look at in rail which are different from the bus and we will give you an idea of it.

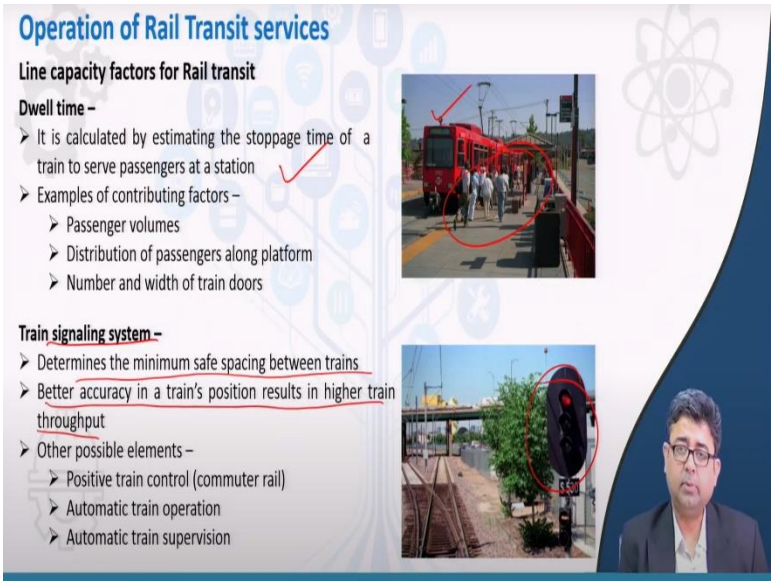
**(Refer Slide Time 20:53)**




So again, dwell time is very similar. Signal system plays an important role even for bus transport the signaling on the urban roads plays an important role. But for rails they have dedicated signals which also play a role in understanding the capacity of the rail transport system. Operating margin is something that is similar to headway in the bus situation.

Junctions here plays a role; looking back, this is something that did not play a role in bus calculations, so we will take a look at that; and also power supply, which again buses do not have to be plugged in, unless they are now new electric buses that are coming in off late. So, they will be affected by power supply.

**(Refer Slide Time 21:43)**

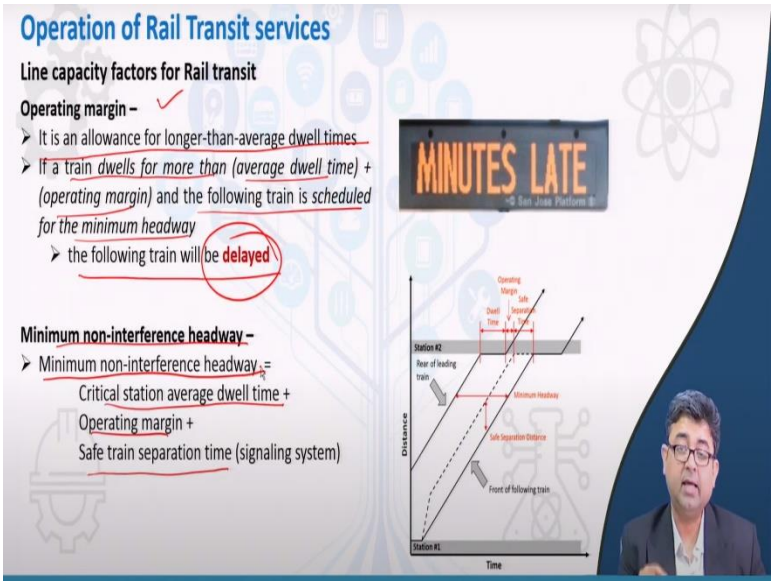


Dwell time is calculated as the amount of time that transit vehicle waits at a stop to allow the passenger to board or disembark. Train signaling system determines the minimum safe spacing between the trains. So, better accuracy in a trains position results in higher train throughput. Now train signaling systems are very important because not only in the capacity point of view but also in the safety point of view.

These are possible elements. These kind of signaling system when they are trying to improve the capacity, they will however always keep in mind that they will not interfere with the safety of the system in order to increase capacity. So, capacity will always be secondary and safety will always be primary when it comes to train signaling systems. Although you would want to have signals to give minimum red time and more green time so that more trains can come.

But that may reduce the safety of the train systems. So that is something to keep in mind when you are trying to design your train services or train public transport services in your urban area. I am not getting into intercity rail yet, this is just to take this into consideration for metro rail services, for example or maybe light rail services that maybe available in your city.

**(Refer Slide Time 23:26)**




Operating margin is something that rail systems always worry about. So, it is an allowance for longer than average dwell times. So usually what happens is sometimes the train waits at a station for longer period of time because there are multiple cars in a train system and to load and unload passenger it may take longer than an average dwell time. So, if a train dwells more than

the average dwell time plus the operation margin and the following train is scheduled for a minimum headway, then the next train will be delayed.

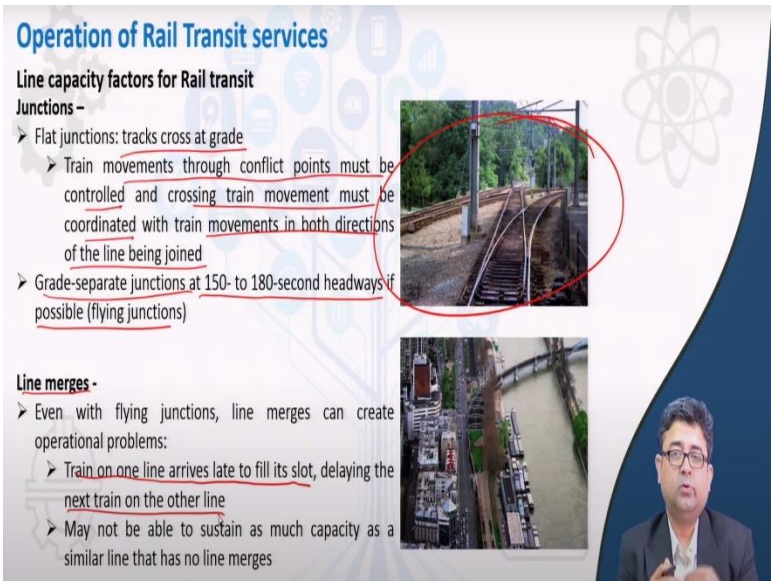
There is always an operating margin that is given to all the train services as buffer. So this operating margin can be looked as a buffer that if you want to wait in a station for 2 more seconds you can do so. However, you have to leave within the next half a second because otherwise if you cross the buffer margin then the next train that is following you might be delayed.

So operating margin is always kept in mind very carefully when you are calculating how much dwell time each train has at a station. Minimum non-interference headways are equal to the critical station average dwell time plus the operating margin plus the safe train separating track. Again, there is always a minimum headway that has to be kept in case of rail transit.

We notice that we always try to minimize the headway as much as possible because it is easier in the cases of the buses to control the headway. But when you are on rails you have to maintain a minimum headway. And you should not tinker with that minimum headway because the trains are at usually at higher speed, then it becomes very difficult for you to decelerate in time and it may cause a collision with the train ahead of you.

So always maintain a minimum headway keep that in mind even when you are designing for maximum capacity. Capacity should not come as in the way of lower safety. Higher capacity should not come in the way of lowering safety.

**(Refer Slide Time 26:15)**



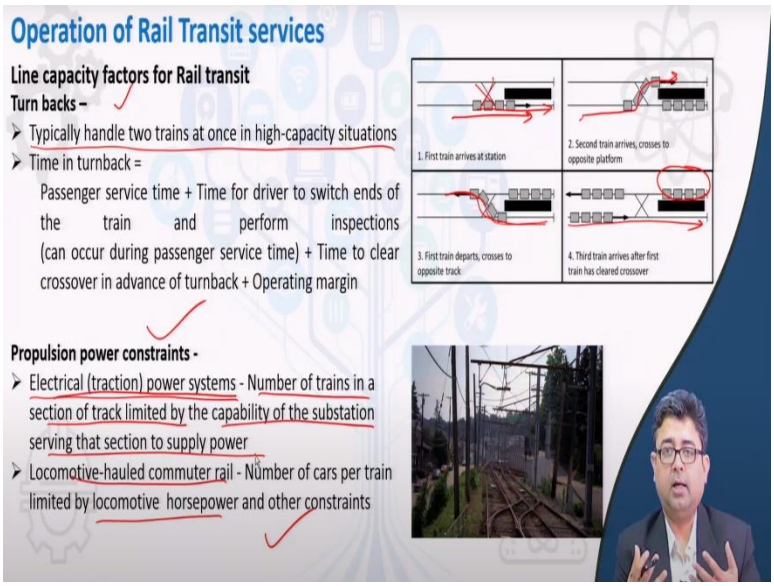

An important thing in the case of trains are junctions. These pictures are of course of an intercity rail system. But even in metro rails you would of have seen that there are junction areas where the trains have to turn around or there are multiple train lines that combine at one rail station so that becomes a junction. So, what happens is that the tracks cross at grade.

When the tracks start crossing at grade that is when some delay is incurred to the movements of the train. So, the train movements through conflict points must be controlled and the train crossing movement must be coordinated with the train movements in both the directions of the line being joined. So always 150 to 180 second headways if possible are given at grade separated junction.

So again, this adds to your delay and has to be taken into consideration when you are calculating your headways as well as your capacities. Similarly, there may be a line merging at junctions where train on one line arrives late. So, to fill its slot, delaying the next train on the line, if usually they have rights of way. So rights of way does 2 things. Right of way allows you no interference to the other traffic.

So, you can provide reliable travel time. But if anything goes wrong, you now have your dedicated right of way, so, you cannot fix it very quickly. So smaller delays add up, making a larger delay as well. So, dedicated right of way always is something that has both advantages and disadvantages.

**(Refer Slide Time 28:20)**




Turn backs are usually provided at railway station so that they can handle 2 trains at once in high capacity situations. So, you see if the first trains arrive and go on this side of the platform. The second train arriving can go at the other side that is why you provide this kind of railway crossing or turn backs. If the train which came here had to go back then it can again depart from that station independent of this train which is now sitting at this platform and the other new train can come and use this platform.

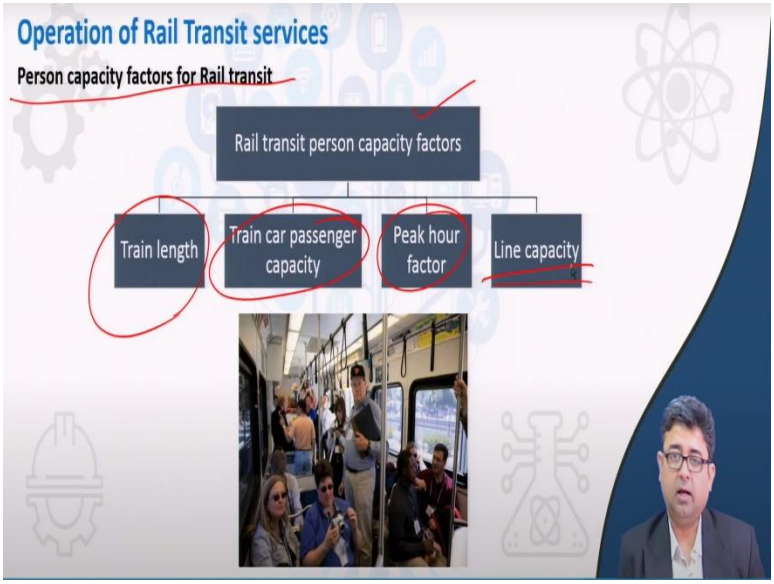
So, these turn backs are very important feature of any rail transit system and they help improve the capacity of the rail, or of the rail transit, or the rail transit system. And of course, then you have power constraints, electrical traction power system, locomotive hauled commuter rail. So, more the number of cars per train, it is limited by the locomotive horsepower. This is when long distance or regional railway are designed.

Whereas electric traction power systems of your metro rails in a section of the track maybe limited by the capability of the substation serving that station that supplies power. So, you have to take in to account the actual substation capacity that you are utilizing for your trains.

So, when people say that why don't you add another car to the metro rail that arrives during peak hours. So usually you do not realize that another car or boggie for example will need additional

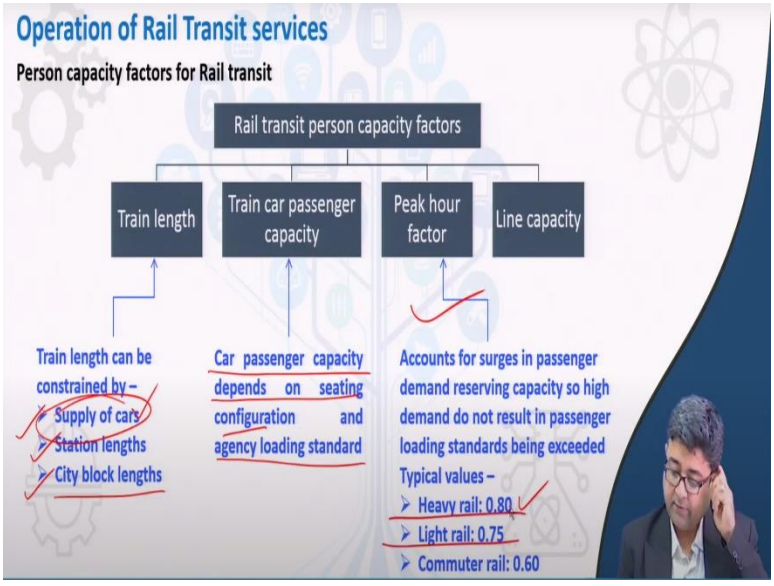
power and if you are already running at maximum power from the substation from which we are deriving power, we may not be able to add another car or a boggie to the rail.

**(Refer Slide Time 30:35)**




If you want to calculate person capacity, you have to know the train length of course, the number of bogies you have or the number of cars you have in the train, the train car passenger capacity each car, how many seating are there, if you are allowed standing passengers should be considered. Then you always have a peak hour factor and of course the line capacity whether you have double line or single line and even with the single line how much headway can you have between 2 consecutive trains.

**(Refer Slide Time 31:21)**

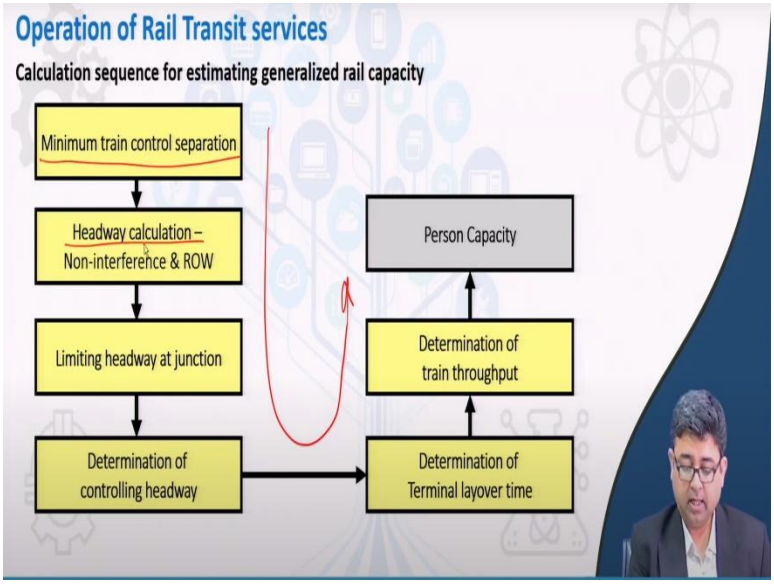


Train length -- you understand; supply of cars, station lengths, city block length. Supply of cars will depend upon how big your city blocks are. If your city blocks are too close to each other then, passengers may get on and off very frequently and you may not need too many cars in your metro railways whereas your full city blocks are longer and the people may not get on and off then you may need more cars or more seating capacity in your train.

Car passenger capacity are depending on seating configuration and agency loading standards. So you cannot over load a car arbitrarily; there are some loading standards that you have to follow. When the car is full and when a metro rail is at capacity they would not stop at a station. They would just come, and the doors would not open at the station, and train would go away because that particular car has reached the capacity and you cannot load anymore.

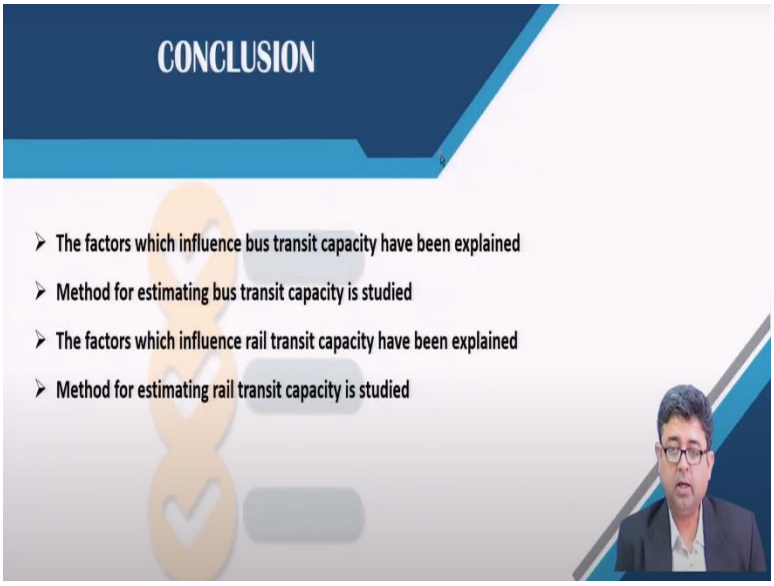
Peak hour factors are obviously for light rail, for heavy rail these are the factors that are already in use.

**(Refer Slide Time 32:39)**




We have looked at line capacity and then this is something of a generalized rail capacity measurement step. You always maintain a minimum train control separation between 2 headway calculation for safety junction at the headways you must limit them. Determining the controlling the headway again, determining terminal layover time and then throughput to understand what the person capacity of a rail is.

**(Refer Slide Time 33:13)**




What we will do in the next lecture is to give you 2 or 3 examples of solved problems which will allow you to understand how these capacity and speed of public transportation systems can be measured and calculated, and that will help you in designing your public transportation system for your city. So, in conclusion in today's lectures we have looked at the factors which influence bus transit capacity and also looked at the methods for estimating the bus transit capacity. Similarly, we look at trail transit capacity, the factors, and how to estimate the rail transit capacity. Thank you once again for your attention.