Introduction to Multimodal Urban Transportation System

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Lecture-20
Public Transportation: Transit Stop Location

Welcome back friends. Now, in the last lecture of the series. We are going to look at how to locate a transit stop location, you may remember in the previous lectures.

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CONCEPTS COVERED

- Objective of bus stop
- Bus stop location determination

We stopped at understanding how to develop the capacity of various types of stations and in the previous lectures other than that, we have also looked at how stations play an important role in a public transportation system. Because they are essentially the points from where passengers board or disembark the metro lines or the bus lines or whatever public transportation you have.

So, in this lecture, what we are going to cover basically how to determine the location of a bus stop. I mean, we are calling it a bus stop, but most likely you can apply it for a metro stop as well maybe you should consider it more of a stop or a station on a rapid transit line. So, if it is a BRTs bus rapid transit line, then this kind of station location would apply to it. If it is a metro line, it would apply to it, it would not much apply to a regular bus route, but you can adapt this methodology to determine a bus stops for regular bus, city bus route as well. So that is what the topic is going to cover today.

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Bus Transportation

Objectives of bus stop

- Serve major centers, activity points, and transfer with other lines
- Achieve minimum passenger travel time
- Provide maximum area coverage
- Attract the maximum number of passengers
- Achieve minimum system cost
- Meet other requirements (e.g. economic development, population needs, etc.)

Just a quick recap of what are the objectives of a stop or a bus stop or any metro stop is, it is to serve the major centers, activity points and transfer with other lines. So, that is a location, which everybody needs to access in a timely and hassle-free fashion. So, that they can then get on the public transportation system, it must achieve minimum passenger travel time.

If you remember when we looked at the travel time components on a public transportation system, the travel time components consist of an access time as well as a time that is spent on the transit line. So, the location of the stations plays an important role in achieving minimum passenger travel time and it must provide maximum area coverage. So, there are a lot of residential complexes in an area then the bus stops or the transit stops must be spaced in such a manner that it is accommodating almost all those residential areas.

It may also be office areas. So, it must be such that it caters to most of them. So, it must maximize the coverage area and by doing so, it will attract maximum number of passengers and minimize the system cost. So, there is also a need for not only to look at the demand side of it, demand side looks at how many passengers you can attract, but you should also look at the supply side of it.

How many stations can you provide without increasing the cost of operations too much. A station will need a lot of infrastructure, a stop will not need so much infrastructure, but would still need some benches, shelter, etc. So, all of this incurs costs. So you should also look at minimizing the system costs in developing and or in locating where bus stops should be and also meet other requirements such as economic development, population needs, and so and so forth. So, these are the overall objectives of locating a stop or a station along the public transportation line.

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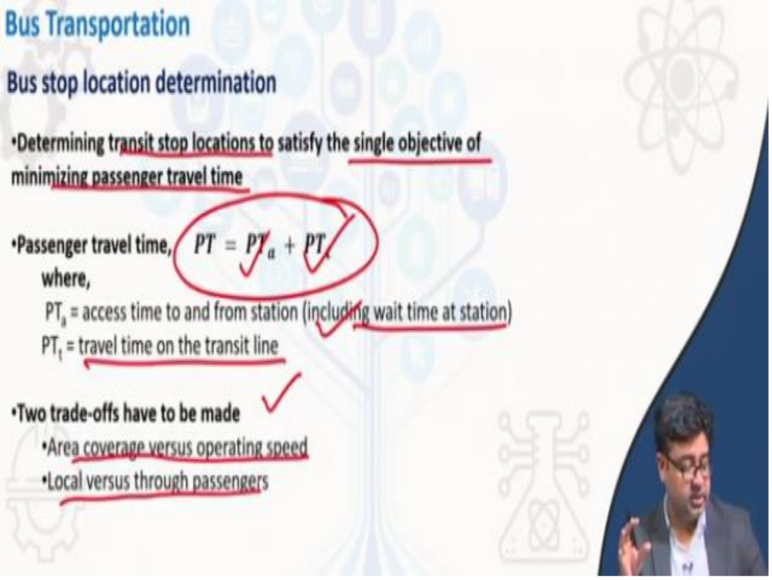

Bus Transportation

Bus stop location determination

- Determining transit stop locations to satisfy the single objective of minimizing passenger travel time
- Passenger travel time, $PT = PT_a + PT_t$
  where,
  PT_a = access time to and from station (including wait time at station)
  PT_t = travel time on the transit line
- Two trade-offs have to be made
  - Area coverage versus operating speed
  - Local versus through passengers

So, if you want to now for simplicity sake, although you must satisfy all those objectives that we talked about. But for simplicity sake of developing a mathematical relationship and equation, let us say that, we are going to determine a transit stop locations to satisfy just a single objective of minimizing the passenger travel time. So, that is only to minimize the passenger travel time and we are not considering any of these for the moment, for simplicity sake.

So, we already know that passenger travel time on a transit line consists of 2 components, the access time which includes the wait time at the station, and the actual travel time on the transit line. So, now to develop or to know where the station should be located, 2 trade-offs must be made. One is a trade-off between area coverage and operating speed, and we will see what that is and a trade-off between local passengers and through passengers. These 2 trade-offs will determine where you should locate your stations.

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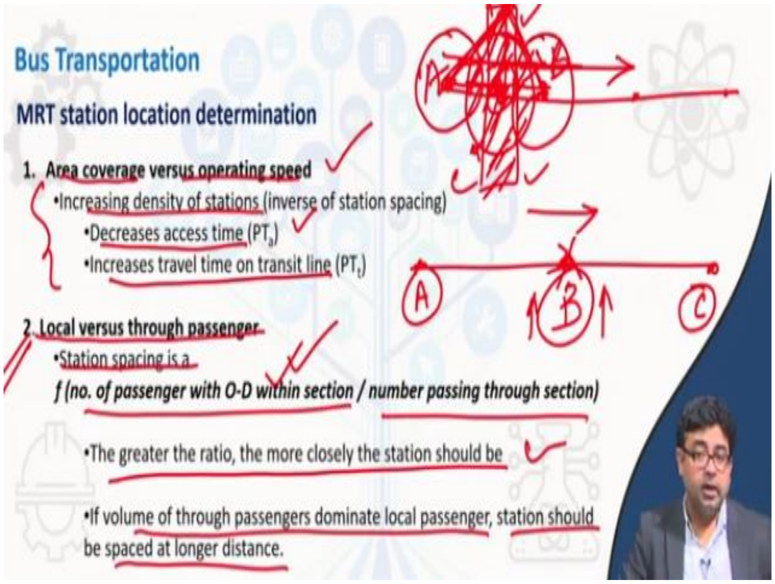

Bus Transportation

MRT station location determination

1. Area coverage versus operating speed
   - Increasing density of stations (inverse of station spacing)
     - Decreases access time (PT_a)
     - Increases travel time on transit line (PT_t)
2. Local versus through passenger
   - Station spacing is a
     f (no. of passenger with O-D within section / number passing through section)
     - The greater the ratio, the more closely the station should be
     - If volume of through passengers dominate local passenger, station should be spaced at longer distance.

So, let us look at each of those trade-offs. So, area coverage versus operating speed. So, if you think of a transit line, and you want to put your station locations, here, here, here, and here. So, for example, this station location is going to cover say for example, this much area, whereas this station location is going to cover this much area, that depends upon how dense the population is? Do you have enough street network there?

Do you have enough feeder routes? So, all of those determine the coverage area for a transit line. So, in this case what is happening, this much of an area is getting neglected. So, if any one of you living here or have their offices there, they are not well catered to access either any of these 2 stations because now it will be too far away from them. Hence, they would not get on the public transportation line and then they may just take their own private transportation.

So, that is the area coverage determination. So, how much area should a metro station cover that is one determinant. The other is operating speed; your operating speed is the speed of the transit vehicle. So, what is the trade-off that is being made here? If you increase the density of the stations, i.e. now to increase this area coverage, if you say increase the density that means density of stations means number of stations per kilometer.

So, to increase the density maybe you put another station here in the center you put another station in the center. Now, what happens is you have overlapping area coverage, which is now redundant. Now, this much area becomes redundant however, you increase the coverage, but what happens with the increase in coverage, it decreases the access time which is good. So, now people living here they can quickly go here.

Whereas the access time to these locations from those locations to those stations were large, so, it is doing one good, but it increases the travel time on the transit line. Now what happens is there is suddenly another station here. So, this BRTs or a metro line now, once it starts from this station, it must again stop here. So, there will be some lost time, or deceleration time, again it must accelerate, again it must stop here.

So, lost time, or deceleration time. So, now instead of it starting here, from point A to point B, where it could have nicely accelerated and gone here, it has to now make of it stop here at C where it is adding to a lost time. So, what is happening is making a trade-off between area coverage and increasing the density of stations, the actual speed of the transit line is going down.

So, how do you make that trade-off? So that there is a balance so there is enough coverage and also good speed or good travel time on the transit line. That is the first trade off that is made when you are trying to determine a location of a transit stop using this method meaning it is only fulfilling one of the objectives which is to minimize the total passenger travel time.

The second trade-off that is being made here is between local and through passengers. Now, if you consider a transit line and you are getting up on A and you want to get down at C, but there is an intermediate station here called B. At this station you are a through passenger, you have already boarded the transit line and it does not matter to you whether this location or whether this transit stop is there or not because you want to get down at C.

So, at this location you are a through passenger whereas, there are many people who want to maybe board at that station. So, for those people, they are local passengers at that station, they want the train to stop there. Whereas you who is on board the transit line and is a through passenger, you do not want the train to stop there because stopping of a train means for example, again increase in lost time in between the travel time on the line.

So, you may rather want the station train to go quickly to your destination to point C, you do not want to stop. So, how do you balance this now, you also want people to get on there, but you also want the travel time to be not reduced for people who are already on board. So, station spacing then becomes a function of number of passengers with origin destination within the section divided with the number of passengers who want to pass through the section.

So, if your origin and destination fall within the section, you are a local passenger whereas, if your origin and destination do not fall within that section, then you are a through passenger for that section. So, the greater the ratio, the more closely the station should be. So, there are a greater number of local passengers, that means more people want to board and disembark in that section. Then what you must do is you have to have the stations more closely spaced together.

If you think in your mind, when does the situation arise, a central business district may have 3 or 4 stations, which is only a section of the entire line, but within that section, many people want to board and alight the transit line at each of those, 3 or 4 stations. So, there are a lot of local passengers whereas there are very few through passengers who want to go and not want to get on and off at a CBD.

So, in CBD, you will see the station spacing very close to each other whereas if the ratio is the opposite, then you will have spaces which are far away from each other, which happens when you are at a sub urban location for example, the sub urban locations. The density is too less people usually do not want to board on and off at too many locations. So, you will see that the spacing is different. So, the volume of through passengers dominate the local passengers. Thus, stations should be spaced at a longer distance that is just the reverse of this. So, these 2 trade-offs are kept in mind when you are developing the station spacings using this method.

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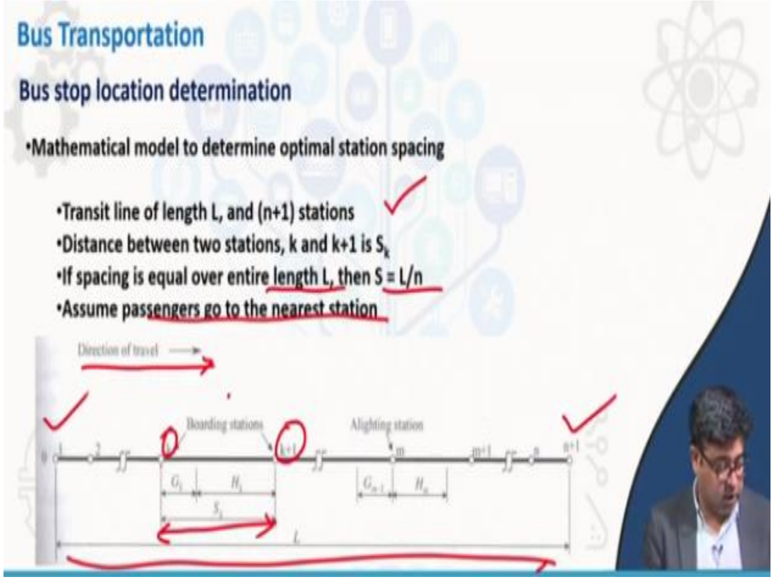

Bus Transportation

Bus stop location determination

- Mathematical model to determine optimal station spacing
  - Transit line of length L, and (n+1) stations
  - Distance between two stations, k and k+1 is S_k
  - If spacing is equal over entire length L, then $S = L/n$
  - Assume passengers go to the nearest station

Now, let us go ahead and see how this mathematical relationship is developed. I am going to show you the entire the derivation of the formula, but you most likely must use only the formula at the end. But understanding the derivation will make it easier to realize the concept of how to determine the spacing. So, if you consider a transit line of length L, which has n + 1 stations.

And distance between any 2 stations is k and k + 1, the spacing between them is S k and if the spacing is equal over the entire length L, then S is L divided by n. So, if you think of these are all equally spaced, then each spacing is L divided by n and assume that the passengers go to the nearest station that is a safe assumption to make, you would not want to access a station which is farther away from another station.

So, say for example, you are living somewhere here and this your direction of travel, you want to access the station that is closest to you, either k or k + 1 whichever is closest to you. You want to access that location. So that is an assumption that we make in developing the relationship. So, clear enough there are 2 stations, if you consider k as a boarding station and m as the alighting station.

So, what we want to develop is the spacing between them, if you know the spacing between them, then we can tell where to exactly locate them. So, spacing between these 2 will determine the location where it should be placed in a transit line.

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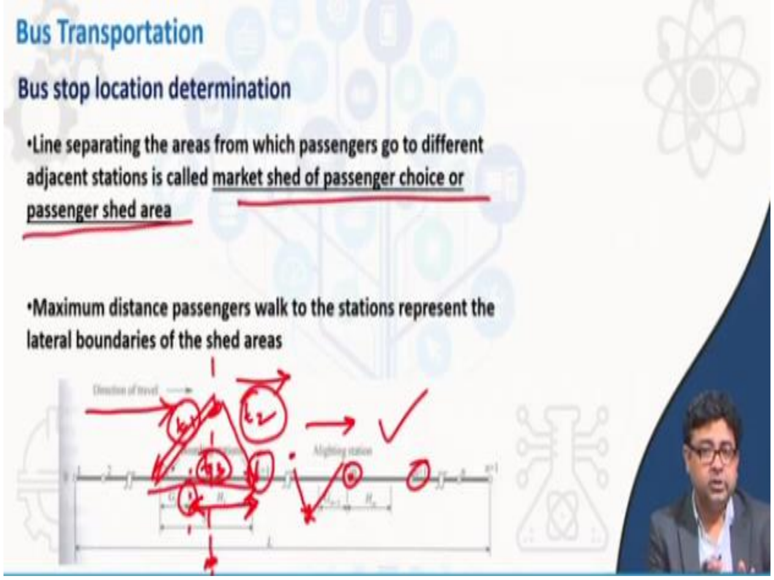

Bus Transportation

Bus stop location determination

- Line separating the areas from which passengers go to different adjacent stations is called market shed of passenger choice or passenger shed area
- Maximum distance passengers walk to the stations represent the lateral boundaries of the shed areas

So, now, what we need to do in the first step is to determine the market shed of passengers or which is called a passenger shed area. Passenger shed area is you see this line here, demarcating the spacing between the 2 stations k and k + 1 by what is called a G k and H k. So, this line is demarcating the spacing into 2. Now, the thinking is that the market shed should be half and half.

That line should be in between the 2 stations the market shed or that line whatever it means is that if you are staying anywhere here or here in the midpoint between 2 stations say this is the midpoint between 2 stations and we assume that is the market shed. However, we will see how the market shed has shifted to that side. If you were staying on this midpoint line, and your direction of travel is here.

So, you want to board at one of these 2 stations k or k + 1 and want to travel to m or m + 1. What would you intuitively do? Although you are in the middle of these 2 stations where your distance traveled time to this, and this may be equal. But what you want to do intuitively is you would want to travel to the station that is in the direction of travel. Although these 2 travel times t 1 and t 2 may be equal.

But you would want to travel to k + 1, because if you went to k, then again you must get on the transit line., so there will be this travel time and this t 3 that will be added on to your total travel time. Rather than that you would just want to go to k + 1 and then get on the transit line. So what is happening is, even though you are in the center of the market shed or the passenger shed area, you are more and more likely to go towards the station that is towards the direction of your travel.

So, what is happening is the shed area is increasing for you. So, this area, which is I am not saying area, but I am saying in terms of length, if you consider the perpendicular distance has to be equal. So, we can say the area in terms of the length H k. So, this H k is becoming greater and greater. So, a greater number of people who are in the center and a little bit off center are all going towards k + 1 and not going towards k because k is in the opposite direction of travel.

Hence, this market shed area is shifting towards the left or shifting toward in the opposite direction of travel. So just the opposite happens at the alighting station. At the alighting station, if you think of which station you want to get off, depending upon where your destination is, so if these are the 2 stations, and if your destination is here would you want to get off. Your train is coming from here, you would want to get off at this station and then travel back.

Or would you have rather got off at the earlier station and traveled to this location? tThat is the trade-off you are making. nNow it is the just the opposite. You want to get off at the earlier station and then walk towards your final destination rather than get off at the later station and walk back to your destination. So that determines the market shed line. So that is what is called the market shed area or the market shed line.

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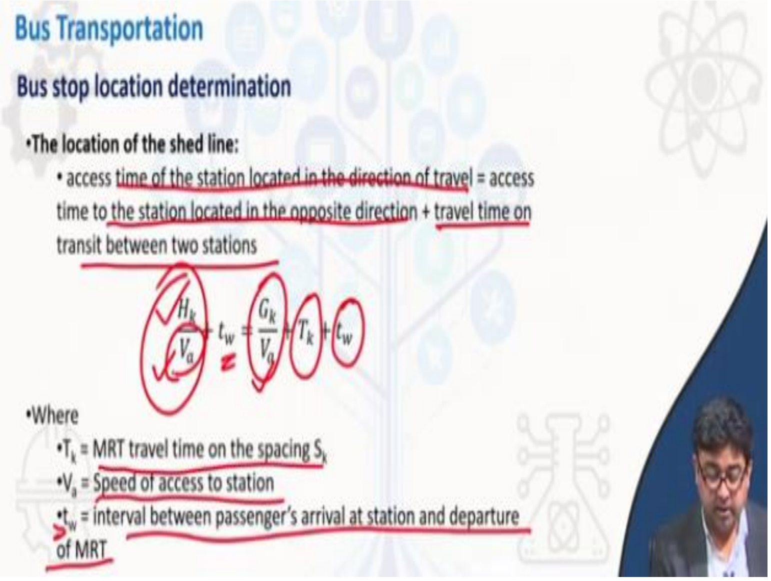

Bus Transportation

Bus stop location determination

- The location of the shed line:
  - access time of the station located in the direction of travel = access time to the station located in the opposite direction + travel time on transit between two stations

$$\frac{H_k}{V_a} + t_w = \frac{G_k}{V_a} + T_k + t_w$$

- Where
  - T_k = MRT travel time on the spacing S_k
  - V_a = Speed of access to station
  - t_w = interval between passenger's arrival at station and departure of MRT

If you remember that concept now, what is happening is the access time to the station located in the direction of travel k + 1 is equal to the access time located in the opposite direction plus the travel time on the transit between the 2 stations. You would rather take t 2, rather than taking t 1 + t 3. So, this t 3 which is the interval between passenger's arrival at the station and departure of the travel time which is the wait time at the previous transit stop.

So, if H k again is divided by Va, Va is the the speed of the access to the station. So, say you are walking to the station, or if you are bicycling to the station, your speed will be something else, that is called access speed. So, that is time, so distance by speed, time, plus if you add t w which is again you have to wait at that station for the train to arrive as well, is equal to now, if you had gone to G k, if you traveled this distance and gone back to the station in the opposite direction of travel, again some speed you would have gone it, but there would have been this element T k which is the travel time of the MRT or the Mass Rapid Transit on the spacing S k.

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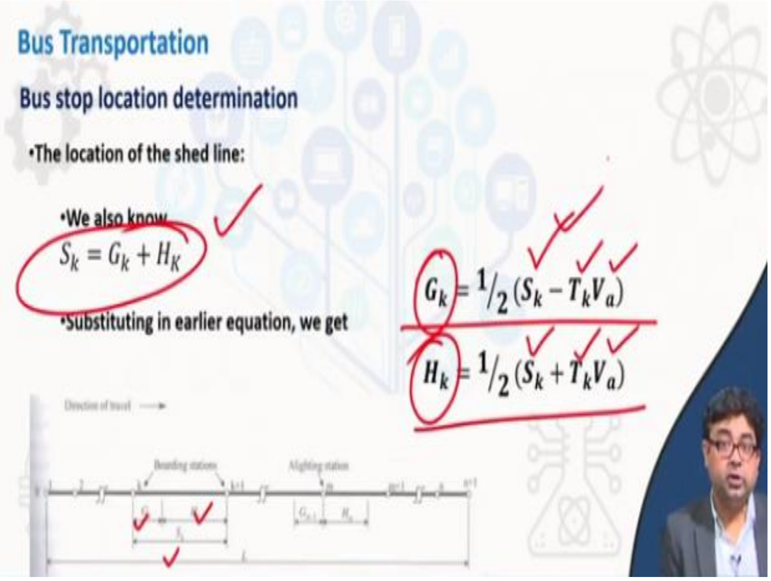

Bus Transportation

Bus stop location determination

- The location of the shed line:
  - We also know

    $S_k = G_k + H_K$
  - Substituting in earlier equation, we get

$$G_k = {}^1/_2(S_k - T_kV_a)$$

$$H_k = {}^1/_2(S_k + T_kV_a)$$

So, you must travel this extra distance now, because you have gone back to a transit line. So, when you equate these 2, what you start seeing is that you already know S k = G k + H k and if you substituting in the earlier equation, you can cut those 2. You will get is G k in terms of spacing and H k in terms of spacing and you already know the access speed and what is the on the MRT line. So, now you have got your market shed or your passenger shed areas in terms of spacing between the 2 stations.

$$G_k = \frac{1}{2}(S_k - T_kV_a)$$

$$H_k = \frac{1}{2}(S_k + T_kV_a)$$

$$S_k = G_k + H_k$$

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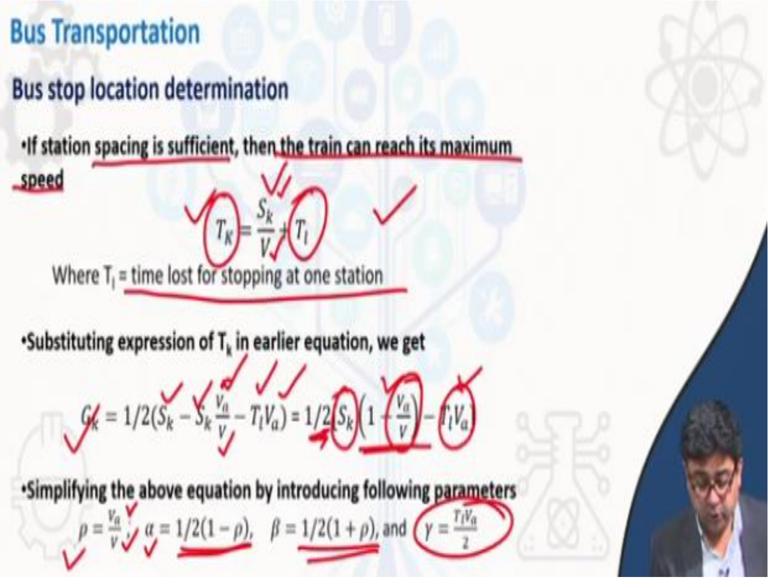

Bus Transportation

Bus stop location determination

- If station spacing is sufficient, then the train can reach its maximum speed

$$T_K = \frac{S_k}{V} + T_l$$

Where T_l = time lost for stopping at one station

- Substituting expression of T_k in earlier equation, we get

$$G_k = 1/2(S_k - S_k\frac{V_a}{V} - T_lV_a) = 1/2(S_k(1 - \frac{V_a}{V}) - T_lV_a)$$

- Simplifying the above equation by introducing following parameters

$$\rho = \frac{V_a}{V},\ \alpha = 1/2(1-\rho),\quad \beta = 1/2(1+\rho), \text{ and } \gamma = \frac{T_lV_a}{2}$$

Now moving ahead, if the station spacing is sufficient, then the train can reach its maximum speed. Remember, one of the trade-offs we are making is coverage area versus speed. So, if the spacing between the 2 stations is sufficient, that will allow the train to accelerate and reach its maximum speed, it can reach maximum speed. So, if T_k is the time taken to travel between the spacing S k with V as the speed, but there is always a T_l associated with it which is time lost for stopping at one station.

$$T_k = \frac{S_k}{V} + T_l$$

So if you write Tk again in terms of Sk, i.e. in terms of spacing, and substitute this equation in the previous equation in these 2 equations, what we get is Gk in terms of Sk, Va by V, a is access and V is speed on the transit line, travel time lost and access speed. So, we are only getting it in terms of S k and then if we convert all of this into some constants, say we say Va by V is rho, this is equal to rho.

$$G_k = \frac{1}{2}\left(S_k - \frac{S_kV_a}{V} - T_lV_a\right) = \frac{1}{2}(S_k\left(1 - \frac{V_a}{v}\right) - T_lV_a)$$

And then we say alpha is 1 / 2 times (1 – rho). So, this is (1 – rho) and this is 1 / 2. So, if we say thatas alpha, and beta is 1 / 2 times (1 + rho) and gamma and if we convert this Tl times Va / 2 turn into gamma. So, if you just simplify this equation by converting these into some constants.

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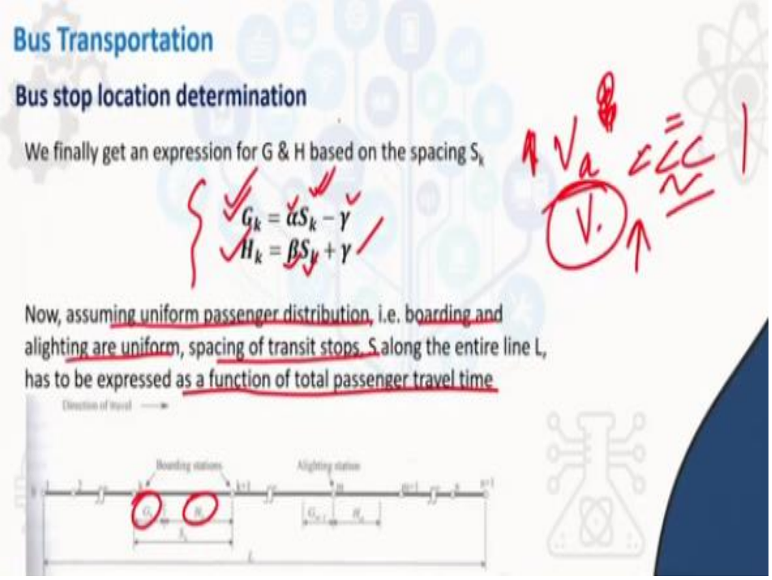

Bus Transportation

Bus stop location determination

We finally get an expression for G & H based on the spacing S_k

$$G_k = \alpha S_k - \gamma$$
$$H_k = \beta S_k + \gamma$$

Now, assuming uniform passenger distribution, i.e. boarding and alighting are uniform, spacing of transit stops, S along the entire line L, has to be expressed as a function of total passenger travel time

What we get is your passenger shed areas in terms of spacing and all the other terms are constant. This tells you Gk and Hk, Gk again, remember G k and H k these are the market shed lines or passengers shed lines that we are trying to determine, which will allow you to know the spacing between 2 stations. Now, what this tells you is G k and H k are governed by alpha or beta and alpha beta in turn are governed by rho.

$G_k = \alpha S_k - \gamma$

$H_k = \beta S_k + \gamma$

And rho is nothing but V a / V. So, what this is telling you is, when V a / V becomes very less, becomes, very less meaning this is too high, and this is too low. The speed of the metro line is very large, much larger than the access speeds to the metro line that means access speed meaning everybody is walking, whereas the metro is going 60 miles per hour whereas your walking speed is may be 4 meter per second or 5 meter per second.

So, at that point, the market shed line comes to the center and Gk and Hk becomes equal. Whereas, if your access speed increases, if this now starts increasing and this becomes very closer to one, then what happens is, the market shed line starts moving towards the station in opposite direction, then the station in the direction of travel gets a lot of people accessing that station and the previous station becomes almost redundant.

Nobody is taking that station, so that is the time when you can remove that station. So, if the access speed increase, that is why people want more feeder buses or feeder systems or auto rickshaws to provide access. So, that will increase the speed of the people accessing the station. And by that you can almost sometimes remove a station on the transit line which will then increase the travel time or increase the speed and reduce the travel time on the line.

Now that we know the spacing between or we know the market passenger shed line, if you assume uniform passenger distribution that is boarding and alighting a uniform spacing of uniform along the spacing of transit stops for the entire line. Then, you can determine these you can determine the G k and H k as a function of total passenger travel time

Because we are trying to minimize the total passenger travel time. That is the objective and hence we want to know how to space the stations. Now we know the passengers shed lines in terms of spacing. Now we want to know the spacing in terms of minimizing the passenger travel. So, if we are now assuming uniform passenger distribution.

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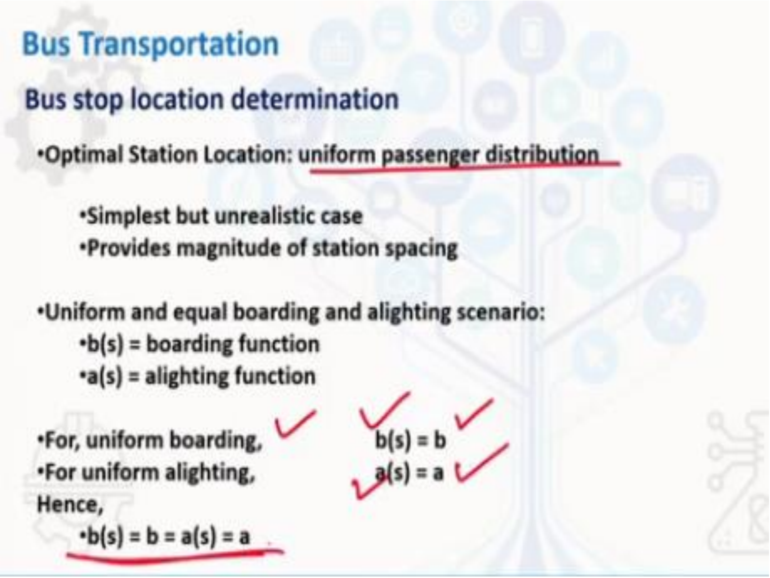

Bus Transportation

Bus stop location determination

- Optimal Station Location: uniform passenger distribution
  - Simplest but unrealistic case
  - Provides magnitude of station spacing
- Uniform and equal boarding and alighting scenario:
  - b(s) = boarding function
  - a(s) = alighting function
- For uniform boarding, b(s) = b
- For uniform alighting, a(s) = a

Hence,
  - b(s) = b = a(s) = a

That is a very unrealistic assumption to make, because you will never have uniform passenger distribution throughout your transit line, you will not have the same number of people boarding and alighting at every stop, but again to make it simplistic for this mathematical expression to be developed, we are assuming that kind of a uniform passenger distribution. So, for uniform boarding, if it is a function b of s = b and uniform alighting a of s = a and then all are equal.

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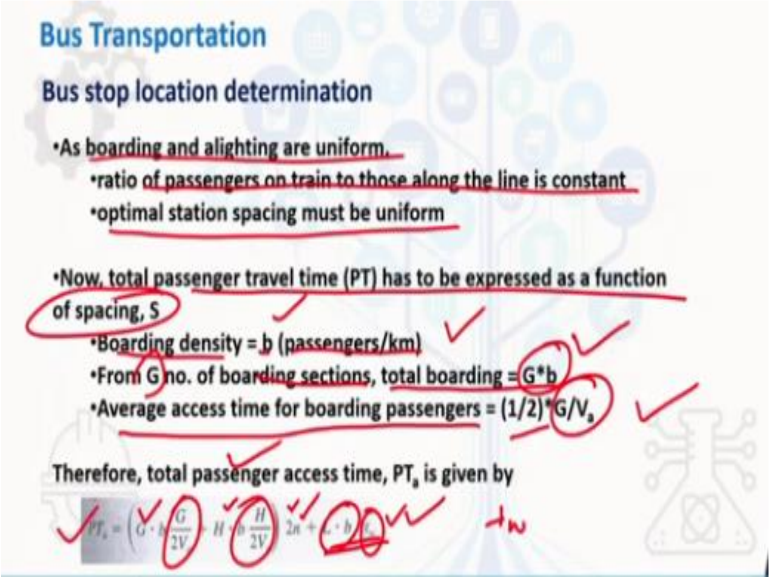

Bus Transportation

Bus stop location determination

- As boarding and alighting are uniform,
  - ratio of passengers on train to those along the line is constant
  - optimal station spacing must be uniform
- Now, total passenger travel time (PT) has to be expressed as a function of spacing, S
  - Boarding density = b (passengers/km)
  - From G no. of boarding sections, total boarding = G*b
  - Average access time for boarding passengers = (1/2)*G/V_a

Therefore, total passenger access time, PT_a is given by

$$PT_a = \left(G \cdot b \frac{G}{2V} + H \cdot b \frac{H}{2V}\right) 2n + L \cdot b \cdot t_c$$

t_w

So, if you assume that boarding and alighting are uniform, ratio of passengers on a train to those along the line is constant, i.e. ratio of passengers on train to those along the line or waiting on the platform are almost constant, and so optimal station spacing must be uniform. So, the station spacing must be uniform. We are trying to calculate the station spacing, but in this case whatever station spacing we calculate would be uniform throughout the line.

So, that is a very over simplistic way of developing it, but at least you understand what the elements are in developing this spacing of the station. Now, the total passenger travel time as you know consists of 2 parts access time and travel time on the line. So, that must be now developed in terms of spacing. So, let us go ahead and look how that is done. So, the boarding densities b already we looked at passengers per kilometer.

And there are G number of boarding sections, we looked at G k and H k. So, consider there are G number of such boarding sections. So, total boarding would be G times b and the average access time for the boarding of passenger’s access time. We already know G / V a. So, if you say it is an average, so we just divided by 2. So, now the total passenger access time. So, passenger access time for all the passengers who wants to board, or alight also includes your egress time essentially.

So, it also includes the time that will take you to reach your destination from the station where you disembark from the metro line or bus line. So, if you already know that this many people are boarding from G stations, that will be then that many people also boarding from H station. And you already know the average access speed. For those sections, you multiply it by 2 because just like I said, you also have another set of m sections, m and m + 1 where you alike so, the similar thing is going to happen there.

So, we multiply it by 2 and there are 'n' such sections. So, you multiply that by n and then there will be the waiting time for at each of those the entire length of the section L. So, all these people must wait for a certain amount of time t w. So, that time plus the access time comprises of PT a.

$$PT_a = \left(G * \frac{bG}{2V_a} + H * \frac{bH}{2V_a}\right) 2n + L * b * t_w$$

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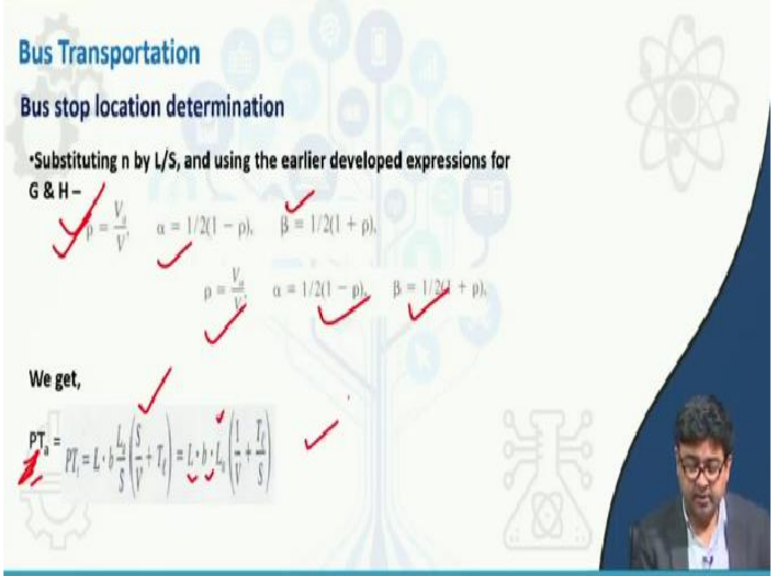

Bus Transportation

Bus stop location determination

•Substituting n by L/S, and using the earlier developed expressions for G & H –

$\rho = \frac{V_a}{V'}$, $\alpha = 1/2(1 - \rho)$, $\beta = 1/2(1 + \rho)$,

$\rho = \frac{V_a}{V}$, $\alpha = 1/2(1 - \rho)$, $\beta = 1/2(1 + \rho)$,

We get,

$PT_a = PT_1 = L \cdot b \frac{L_1}{S}\left(\frac{S}{V} + T_e\right) = L \cdot b \cdot L_1\left(\frac{1}{V} + \frac{T_e}{S}\right)$

So, now we know PTa and again if you substitute those old constants that we had already developed previously into this equation, what you will get here is PT in terms of spacing. Again, remember we have to have PTa in terms of spacing. So, we have to convert everything in terms of spacing and so that we are eventually looking to space the stations, or we are eventually looking to space where stations along the transit line around the metro line could be located.

So, now again by replacing many of those terms here, you through those constants that we had developed, you would get PT a = L times b times L a into 1 / V + T l / S. So, all of these are simple terms to remember simple terms to understand.

$$PT_a = L * \frac{bL_a}{S}\left(\frac{S}{V} + T_l\right) = L * b * L_a\left(\frac{1}{V} + \frac{T_l}{S}\right)$$

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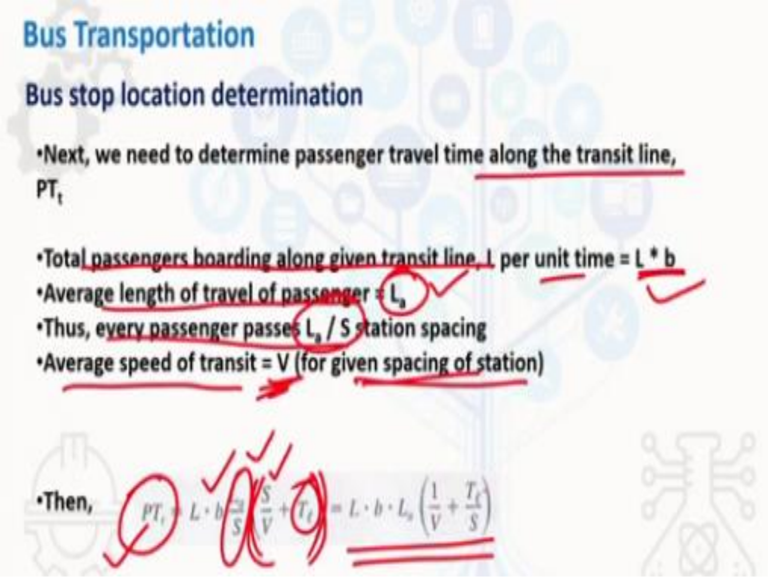

Bus Transportation

Bus stop location determination

- Next, we need to determine passenger travel time along the transit line, PT_t
- Total passengers boarding along given transit line, L per unit time = L * b
- Average length of travel of passenger = L_a
- Thus, every passenger passes L_a / S station spacing
- Average speed of transit = V (for given spacing of station)
- Then, $PT_t = L \cdot b \frac{L_a}{S}\left(\frac{S}{V} + T_t\right) = L \cdot b \cdot L_a\left(\frac{1}{V} + \frac{T_t}{S}\right)$

And the other travel time that we now must calculate is their travel time along the transit line; because total travel time is equal to access time plus travel time along transit line. Now, travel time along the transit line will be if the total passengers boarding along the transit line L per unit times L times b average length of travel for each passenger. So, each passenger will not travel the entire section of the transit line, they may be only traveling a part of that length of the transit line. So, if you consider average to be L a, then every passenger passes L a / S station spacing.

So, if you consider different stations spacings. So, they will cross only La by S station spacings and they will not travel the entire spacing of the transit line of the stations. And if the average speed on the transit line is V for given spacing, then the passenger travel time on the transit line equals L times b L a / S it is only going to L times b times L a / S multiplied the whole thing by speed by velocity spacing by velocity for whatever given spacing.

What is the speed plus T l, T l is the stop and restart every time there is a station, so lost time. So, if you use this term, then what you get is the passenger travel time on the transit line as L times b into L a times 1 / V + T l / S.

$$PT_l = L * \frac{bL_a}{S}\left(\frac{S}{V} + T_l\right) = L * b * L_a\left(\frac{1}{V} + \frac{T_l}{S}\right)$$

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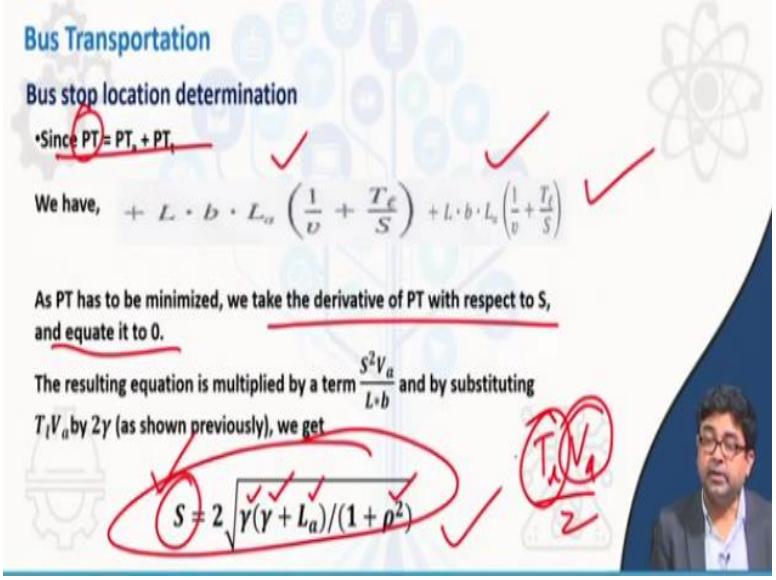

Bus Transportation

Bus stop location determination

- Since PT = $PT_a + PT_t$

We have, $+ L \cdot b \cdot L_a\left(\frac{1}{v} + \frac{T_\ell}{S}\right) + L \cdot b \cdot L_a\left(\frac{1}{v} + \frac{T_l}{S}\right)$

As PT has to be minimized, we take the derivative of PT with respect to S, and equate it to 0.

The resulting equation is multiplied by a term $\frac{S^2 V_a}{L \cdot b}$ and by substituting $T_l V_a$ by 2γ (as shown previously), we get

$$S = 2\sqrt{\gamma(\gamma + L_a)/(1 + \rho^2)}$$

$\frac{T_l V_a}{2}$

So now if you add both of those terms, since PT = PT a + PT t, you add those 2 terms, you get this. And eventually what you must do is since you must minimize the travel time if you just do a derivative of PT with respect to S and equate it to 0. You are going to get S in terms of rho and gamma and rho and gamma as you already have seen. Rho and gamma are in terms of let us see where we have developed gamma, rho and gamma are in terms of T l V a.

$$PT = PT_a + PT_t$$

$$S = 2\sqrt{\gamma(\gamma + L_a)/(1 + \rho^2)}$$

So, you already know all these values, what is the lost time, what is the access speed and so on and so forth. So, Now, we have developed the spacing between stations in terms of certain metrics that you can calculate on the field. If you calculate those metrics, you can determine the spacing. However, you can see that the magnitude of the spacing is what you can estimate using this equation not the exact spacing, because remember, we had so many assumptions that we had to put in there.

And beginning of the problem what we said was, this was only solving one objective not the all the other objectives. So, this is a simplistic view of understanding the spacing between 2 stations. However, it gives the magnitude of the spacing and not maybe the exact distance between 2 stations, but it gives you the magnitude of the spacing. So, what it tells you that the magnitude spacing will be higher, if people travel longer distances, La is the distance traveled by each person. So, if people travel longer distances, the spacing should be longer, gamma is T l into V a / 2. So, if the loss times are greater, then the spacing is greater if the access speed is greater, the spacing can be greater. So, it gives you a relationship between different parameters that you can measure on the field and it gives you a value of or a magnitude of spacing between the 2 stations.

I hope you have followed through the derivation part. Eventually, you will only need to use this formula or this formula to calculate what is the magnitude of spacing, but once you understand the derivation of it, it helps you in understanding in real life situations, how do you develop the spacing between the stations on your Rapid Transit line.

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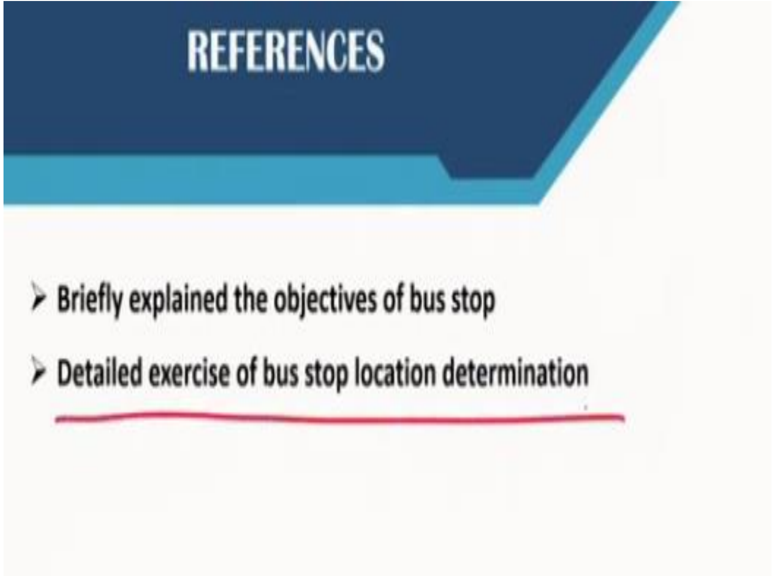

REFERENCES

- Briefly explained the objectives of bus stop
- Detailed exercise of bus stop location determination

So, I hope you have followed through whatever we have explained to you today, basically what we have done is explained the bus stop location determination.

(**Refer Slide Time: 35:08)**

- Book: Urban Transit – Operations, Planning and Econo
by Vukan R. Vuchic
- Book: Urban Transportation by Victor Ponnuswamy

THANK YOU !

And sorry this slide is mixed up. But again, all of this is taken from the textbook of Vuchic and you have access to it. There is another textbook, which is an Indian textbook, which also tells you to solve some problems in understanding the spacing of transit stations along the Mass Rapid Transit line. Thank you very much for your attention.