

The following content is provided under a Creative Commons license. Your support will help MIT OpenCourseWare continue to offer high quality educational resources for free. To make a donation or to view additional materials from hundreds of MIT courses, visit MIT OpenCourseWare at ocw.mit.edu.

**GABRIEL
SANCHEZ-
MARTINEZ:**

So now we resume after our hiatus in the introductory theme, because of the snow day. We resume the introductory theme, right? And this is the second of three introductory lectures. And today we deal with the modal characteristics and role. So we talk about the different modes of public transportation and their characteristics and what role they play.

We're looking at the range of modes and services, the descriptions of each mode. And we'll do some comparisons in terms of how they perform. So what are the roles for each mode? When we think about the different modes that can be used for transportation, we can think in different dimensions. And one of them is going from low density to high density.

That is from very sparse OD matrices where origins and destinations are both scattered in a geographical area to a situation where, along a particular corridor, there are concentrated origin destination pairs and many people wanting to travel along the corridor. Obviously this happens more in cities than it happens in rural areas. And we also see that we can think about it in that same dimension from having low vehicle capacity being necessary to requiring high vehicle capacity.

And by capacity, I mean the capacity of a vehicle to hold passengers inside, right? So in that direction, we have private modes on the top. And we have public modes, so-called public at the bottom. So we all know what the auto is. It's a private mode that is often used a single person, sometimes by a family. And yeah, so very low density of the payer being served.

Then you go to carpool where people are more in that same vehicle. And there might be multiple stops along the way. And vanpool, slightly larger vehicle. This is often private. So it could be arrangements between co-workers requiring capacity higher than a normal car. So they get a van. And maybe one of them drives it or maybe they hire a driver.

So then in the public side we have taxi. And I'm using the term here generally. So you can think of this as one of the newer forms of taxi of transportation that were companies like Uber and Lyft. So you might hail a cab just for yourself. And that's the extreme. Or you might use

the pool servicing, the pool services offered by those companies, or you might share a taxi.

So you start increasing the utilization of that vehicle. Then we have publicos. Publicos are-- they can be cars or vans. They're operated by a private driver often in an association. And they usually drive these vehicles along more semi-flexible, semi-fixed corridors. So people more or less know the routes they serve. They have some flexibility. So they can say, well, can you take me, you know, around the corner. And they'll do that.

So it's the mode that is sort of right before formalized public transportation. Then we have fixed route bus. That's the route one and the buses here in Boston and in many places, traditional bus service. BRT, which is bus rapid transit, which is a mode where buses are being used to deliver transit that is generally delivered via rail services, light rail services in particular. We'll look at some examples later in this lecture.

And then we have light rail like Boston's Green Line and heavy rail, which is the traditional subway or Metro system, right? In the middle sometimes subscription bus. So the car services that are sometimes-- it's oft-- like a normal sized bus. It could be paid for by a company to get its employees to the site, right? So it's somewhere in the middle. Because it's not public. So not everybody can use it. But it's not private. Because somebody else, so there's a third party who is providing the service.

So along that same direction of increasing vehicle capacity and passenger flows. We can also look at what happens to the operating arrangements. And we have three operating arrangements listed here, three classes. What happens to drivers? What happens to right-of-way? What happens to routing and scheduling? So how much does it cost to have drivers operating a private car?

If it's just you, you don't think about the cost, although you could assume some cost for your value of time. But you're not paying someone to drive you often. As you move to van, as I said earlier, if it's an arrangement where you or one of your friends is the one driving the van that's free as well. Or if you hire a driver, then it becomes a low cost salary or payment for that driving service.

Then we have mini bus and bus. So depending on the size of the system and how big the vehicles are and the context of how that driver gets hired, it could be low cost. But as [INAUDIBLE] and labor unions, then the cost starts increasing, right? So you have higher

salaries, and especially as you move towards light rail and heavy rail, much higher salaries for drivers.

However, when we get to heavy rail, especially the more modern, the most advanced systems of heavy rail, a lot of these are driverless. They operate automatically. And they might have attendants inside of them. But they don't necessarily need to have attendants. So you could think in the extreme, this is coming back down to, well, it's a robot driving the vehicle. And I don't have to pay for a driver.

In terms of right-of-way, we start with shared right-of-way, so cars, vans, minibuses, and buses typically share the road with other cars, right? So they're sharing the space. And they're stuck in traffic, if there is traffic. For bus, light rail, you have a mix. Some of these systems can operate only in a shared right-of-way or only in dedicated corridors or a mix of both.

So light rail systems, for example, often have shared-- often have dedicated right-of-ways, but when they hit intersections, they have to wait like all the other cars to cross the intersection, not always, but often. And then there's dedicated right-of-ways, which is more typical for Metro systems where it's a tunnel or it's a grade or it's up and over, yeah, like an elevated section.

But it's dedicated to this Metro system. So you have a question, [AUDIENCE], yeah?

AUDIENCE: Yeah, now, light rail. What would you call light rail on certain segments that needs-- that has its own complete right-of-way it's grade separated? Because they have that-- these big systems where they're partially light rail and they're partially segregated, and even that heavy rail that even has occasional crossing [INAUDIBLE]

GABRIEL That's right, yeah, yeah.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE]

GABRIEL Absolutely. And that's a great question. So the question is why, or how do we label some
**SANCHEZ-
MARTINEZ:** services that share characteristics that I'm describing. I'm seeing Metro as this way and light rail as this way. But there are, in fact, systems that combines some of these characteristics. So I'm talking about the stereotypical descriptions of each system.

And one of the points of this lecture is, in fact, that it's blurry. All these lines are blurry. And you

can combine different characteristics. So, yeah. But it's still useful as a framework to think about all the different modes and their typical or stereotypical characteristics. Right, so, routing and scheduling, so if you're in your own car, it's fully flexible, right? You decide where the car is, when it leaves, when it ends, its trip.

As you move towards minibus and you're sharing the ride with other people, it might have either fixed routes or fully flexible or somewhere in between, like the Publicos that I described where there is a semi-fixed route but with some flexibility to deviate from those to accommodate certain passenger's destinations. And then as we move to the most formal systems, it's a picked through-- it's a published service plan with stops at certain places and people know where to go take it. Any questions on the terms of services?

AUDIENCE: Yeah. [INAUDIBLE]

GABRIEL [INAUDIBLE], yes?

SANCHEZ-
MARTINEZ:

AUDIENCE: On Publicos.

GABRIEL Yes.

SANCHEZ-
MARTINEZ:

AUDIENCE: Typically the flexibility would be, would be with the alighting.

GABRIEL Yes.

SANCHEZ-
MARTINEZ:

AUDIENCE: You would have to know where to board.

GABRIEL That's right.

SANCHEZ-
MARTINEZ:

AUDIENCE: But they could drop you off anyplace.

GABRIEL Yes. Sometimes you can call the companies. And they can communicate and say, arrange for

SANCHEZ- a pickup. But most typically, yeah, you have more flexibility on the alighting side. All right.

MARTINEZ: Other categories. Let's talk about rights-of-way. We started talking about that. So degree of segregation. We can think about three different levels, surface with mixed traffic.

This is typical for buses or light rail that has no preferential treatment. Then we go to longitudinal separation with at-grade crossing. Well, the Green Line here in Boston is mostly like that, several benches are like that. So they run on their own track. When they hit an intersection, they have to wait for the red light with other cars. Some sections of the Green Line are actually surface with mixed traffic. I'm thinking about the last end of the E line. And then full separation, right? So that could be at-grade tunnel, elevated.

Technologies. Let's talk about technologies. Support, which is referring to contact between the vehicle on the surface, what counters the force of gravity essentially for these vehicles. We have rubber tire on concrete for buses. That's typically what it is. Some trains have that. If you go through the Metro system in Paris, for example, you'll see rubber tire on concrete for their Metro.

That has a benefit over steel wheel on steel rail in terms of the grip, and, therefore, acceleration and braking distances. They can be shorter. Steel wheel and steel rail is more common for rail systems. And the maintenance cost is lower. And they last longer. But they have a lower coefficient of friction. So braking distances are longer. And the capacity to climb very steep grades is reduced. You have a question?

AUDIENCE: Yeah, do you think Paris [INAUDIBLE]

GABRIEL I don't know.

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL Yeah, I don't know why they chose that.

SANCHEZ-
MARTINEZ:

AUDIENCE: I have an answer.

GABRIEL Yeah?

**SANCHEZ-
MARTINEZ:**

AUDIENCE: The Michelin, the company, when they were rebuilding the Metro after World War II put a lot of pressure on their jeeps [? for climbing ?]

GABRIEL That sounds more likely.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE] of a conspiracy theory but [INAUDIBLE]

GABRIEL Not a conspiracy but, yeah, the local industry being favored in the construction of a system.

**SANCHEZ-
MARTINEZ:** That makes a lot of sense, right? So, I'll buy that. Right, so other support systems. Let's get some ideas. Besides these very traditional rubber on concrete or rubber and asphalt, steel wheel on steel rail. What other forms of support exist? Some of them are fancy, some of them are less common. Let's start over here with

AUDIENCE: Magnetic levitation.

GABRIEL Magnetic levitation, so Maglev, right? You can think about some of the Japanese systems that do that. For a very high speed rail, you want to reduce friction. So use magnetic levitation to reduce friction. Over here.

AUDIENCE: No contact [INAUDIBLE]

GABRIEL Yeah, well, not a real system yet. It can't take turns. But yeah, so air. It's some other form of levitation, right, well, based on air pressure, and yeah. Any other ideas?

**SANCHEZ-
MARTINEZ:**

AUDIENCE: Small airplanes [INAUDIBLE].

GABRIEL Yeah. We're not-- well, in this course, that is right. It's a form of public transportation. In this course we are excluding some forms of public transit. We're excluding airplanes. You could argue that elevators are a form of public transportation. They go up and down along a track. And you have stops that you call. But we're also excluding them. So, yes. I'm thinking more traditionally but somewhat different forms of support.

AUDIENCE: Cable cars.

GABRIEL Cable cars, yes, or gondolas, right? So suspended cabs that are taken over the air, yeah.

SANCHEZ- Yeah.

MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL Right, there's funiculars, which are [INAUDIBLE] and are, sort of, they look like little a rail car.

SANCHEZ- But they climb very steep grades. Yes.

MARTINEZ:

AUDIENCE: Ferries.

GABRIEL Ferries. So if you go to Translink in Vancouver, ferries are part of their transit system, yeah.

SANCHEZ- So, OK, I think that covers some ideas. Let's talk about guidance now. And when I say

MARTINEZ: guidance, I mean lateral control. What steers the vehicle? So, traditionally steered by the driver, right? That's bus. For rail, obviously the vehicle is guided by the track. And then there are other forms of steering. Any ideas of what they could be? **AUDIENCE?**

AUDIENCE: I mean, this is also a little bit, maybe, little bit into the future but self-driving vehicles.

GABRIEL Yes, so you have a robot with a Servo that's steering the thing, yeah. We have an example in

SANCHEZ- this lecture of real systems that already do that, yeah.

MARTINEZ:

AUDIENCE: There's [INAUDIBLE]

GABRIEL That's right. We have a picture of that. And so great. All right, great, so, yeah, examples of

SANCHEZ- that. Now let's talk about energy and propulsion. So for bus, the most traditional thing is to

MARTINEZ: have a diesel internal combustion engine. It used to be the conventional engine. Now they've really improved with fuel injection and other technologies. They've made them clean diesel. So they control the exhaust.

And these engines can shut down and start very cleanly without wasting of fuel. So, they reduce pollution and noise. There's compressed natural gas and abbreviated CNG. A lot of the fleet here in Boston, bus fleet, is CNG. And they're pretty loud. And they have a CNG logo in the back. So you'll notice when you see them. Those are-- they require special maintenance and refueling facilities, of course.

And, at least in North America, CNG was popular for a while. But now agencies are switching back to diesel, and in particular, clean diesel and hybrid electric with diesel. So fully electric buses exist. And they're getting better. Battery energy storage is getting better. So we have fully electric buses that can service-- that can provide service for many hours without recharge in between. So that's great.

And as I mentioned, hybrid diesel electric. That's very common. I think it's being the preferred bus mode now, so preferred energy system or propulsion system for buses. So often how this works is that you have a diesel--a clean diesel engine, that powers an electric generator, which stores electric energy. And then on each wheel, you have electric motors.

So, in fact, the propulsion directly is electric. And you're only using the motor to generate electricity. So you can get a lot of fuel efficiency from that, especially because all of these buses stops so often. Right? They have very-- a lot of stop and go. And so sometimes you can just kill the engine when the bus is stopped. All right, what about control?

So we talked about guidance, which is lateral control. What about longitudinal control? So how do you control when you stop? How do you accelerate how quickly you go or brake? So we have manual or visual. So buses are typically driven by a person who has a brake and a accelerator. And they control everything manually and on site.

There is also manual with signals. This is more typically for rail. You have signals that might set a limit, a speed limit on the vehicle and protect trains from crashing into each other. And then there's fully automatic. So you have a robot controlling the longitudinal movement of the vehicle. Questions on these technologies? We'll see some examples. [AUDIENCE]?

AUDIENCE: In terms of automatic [INAUDIBLE] as well?

GABRIEL Yeah.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE] the bus exactly where it is.

GABRIEL Yeah.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE]

GABRIEL SANCHEZ-MARTINEZ: That's right, yeah. OK, so we talked about automatic train protection. Here's how it works. This is the classical block system for rails. And here's how we control the longitudinal movement in a system like the red line. So this is the fixed block system. What you do is that you divide the track into sections. And the goal of the system is to prevent trains from colliding into each other.

So let's suppose that there's a train right here and in maroon. And it's occupying a section of track. The track knows that a train is occupying that segment. And to prevent a collision, it blocks trains from entering the previous segment. OK? And how does it do that? It does that by setting the speed limit on the segment to [INAUDIBLE] upstream to 0.

So if a train were to enter that segment, it would be braked automatically. And then the speed limit gets increased as you go farther upstream. So a train can move along the track. But if it gets too close to the piece of track to being occupied, it will have to slow down or brake. Have you been on a train here or elsewhere where you're braked all of a sudden in the middle of the track between stations?

Yeah, and then normally you hear the brakes going off. And then it starts again. So what happens in those cases is that the driver exceeded the speed limit. And the automatic train protection system kicked in. It brakes, it brings the train to a halt. And the driver won't be able to start the train again until the pressure on the brake system is released. Questions?

AUDIENCE: Do you know that the DC Metro does not have this? Because I used to never ride the front or the back car. Because they were notorious for hitting each other, at least like 10 years ago.

GABRIEL SANCHEZ-MARTINEZ: Yeah, they have that. So if-- they have a system to prevent collisions.

AUDIENCE: [INAUDIBLE]

GABRIEL SANCHEZ-MARTINEZ: If it thinks-- if it's not maintained properly, then things can happen. Or it could be that they haven't enabled it in some sections of the track. I don't know the details.

AUDIENCE: [INAUDIBLE] because there were a lot of people that died [INAUDIBLE]

GABRIEL Yeah.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: There was like--

GABRIEL Yeah, so--

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE] years ago the DC Metro [INAUDIBLE]

**GABRIEL
SANCHEZ-
MARTINEZ:** All right, so, one of the things with block systems like this is that they constrain the capacity of the line. If we look at the red line, in particular, this is the line that puts a constraint on the frequency of service. Approximately three minutes. You can't run service more often than that. And the red line, because of this, the way the blocks were assigned. So what happens?

As you're moving from Kendall to Charles MGH, and particularly in the segments from MGH to Park, this segment right here is downhill, right? You're going from elevated downhill to subway. So you're also going downhill on steel wheel on steel rail. And the track may be wet. Because it was outside. So there's a concern that the braking distance might be quite long.

And to be very safe and conservative, what happens is that trains are not allowed to enter Park Street until the train ahead departs Downtown Crossing. So you need to clear the platform of Downtown Crossing. And only then can you start moving into Park Street. So that might cause trains to be held up at Charles actually. So, yeah.

So if we look at the time that it takes the train to close in, that is from the beginning when the head of the train hits the circuit just after Charles MGH to the time it actually gets to Park Street and opens its doors, the dwell time at Park Street serving passengers, allowing passengers to get off and to board. And then you have the running time between Park Street and Downtown Crossing.

And finally the time it requires a train to close its doors and exit and for the tail of the train to clear the circuit so that it's no longer occupying the circuit. That's about three minutes. You can't run service more often than not. So you would have to change the blocking, the sign of this segment to the red line if you wanted to increase the frequency.

More modern systems are indications based train control systems. And what happens in those cases is that the blocks are not fixed. They move between vehicles. A computer will look at the speeds and the distances between trains and generate virtual blocks that are quite short. And they can control with finer precision how the speed limits that a train has that are being applied for safety.

Often, these are in systems that are automatically controlled. So you have the moving block system, which increases the capacity. And you have a computer also regulating the speed, which eliminates driver variability and further increases the capacity of the system. Any questions on blocking?

AUDIENCE: What are some examples of systems that are the most modern?

GABRIEL
SANCHEZ-
MARTINEZ: I will give some examples next slide actually. So great segue. So levels of automated protection. So we start with basic. The Green Line has no [INAUDIBLE]. Right? So, and that's why a few years ago, somebody was-- well, said the person was texting. But then they said there was a medical problem. I'm not sure. So--

AUDIENCE: That's quite a medical problem.

GABRIEL
SANCHEZ-
MARTINEZ: So, yeah. So a train rear-ended another one. It wasn't too bad. I don't think anybody was killed. But, yeah, so there are advisory signals along the track that say, you should go or you should not go. Or you should go slowly. But it's up to the driver to regulate that speed.

AUDIENCE: On the Green Line as well one of the provisions is on the wayside, the signal [INAUDIBLE] are so old that if you get your red signal and it is not changing and you wait 60 seconds, you can proceed through.

GABRIEL
SANCHEZ-
MARTINEZ: Right, and you have to proceed slowly. But, yeah. Right. So they allow trains to sometimes to both two trains to birth on a platform in some cases, although they're not really liking that anymore. But they used it a little bit more. Right, so--

AUDIENCE: And in Chicago, though, that train's [INAUDIBLE] you can call to get clearance to pull past the red signal [INAUDIBLE].

GABRIEL
SANCHEZ-
MARTINEZ: That's true for most systems. You can override. And with a very slow speed you can take control and manually-- and you need that, because sometimes these systems fail. And they all go red. So you still have to move the trains. And you need this override system. But it won't

allow quick movement.

AUDIENCE: That's how we had runaway train on Red Line.

GABRIEL Yep. OK. The next level of automation is manually setting the speed below the maximum level.

SANCHEZ-
MARTINEZ: That's the Red Line, what he just described. In-cab signals, the speed limit of the block that the train is occupying is sent to the cab so that the driver knows what the speed limit is. It's up to the driver to determine what the speed is. But if the driver exceeds that speed, the automatic train protection system kicks in and brakes the train to a halt. All right?

Then we have manual setting of dwell times only. So the train drives itself between stations. The driver decides on the door opening and door closing manually and, therefore, controls how long the doors are open for. So it's a more advanced system from the '70s and '80s. And then we have semi-automated so we have automatic train supervision or automatic train regulation.

A good example of this is Tren Urbano in San Juan, Puerto Rico and the London Underground central line. So here the train can drive itself automatically between stations. The driver only pushes a button to tell the train go to the next station essentially. In Tren Urbano's case, and I imagine this is true in all system. The drivers are required to manually operate for small fraction of their [INAUDIBLE] to manually control trains if there is a failure of the system Eli?

AUDIENCE: But they don't control dwell times in these?

GABRIEL They can but often not. Often the dwell times are also regulated.

SANCHEZ-
MARTINEZ:

AUDIENCE: They definitely control them on the Central Line.

GABRIEL Yeah, so--

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE] Warning for the people on the platform.

GABRIEL Yeah.

SANCHEZ-

MARTINEZ:

AUDIENCE: --people on the platform.

GABRIEL So you have this button that you push, the driver, to sort of authorize the movement forward.

SANCHEZ- So you can, right, you can not press it and thereby extend the dwell time. But the speed

MARTINEZ: between the stations and everything else is the parking of the train at the platform and the opening of the doors. It all happens automatically. Then you have full automation.

And this comes often with a communications based train control. So you could drive this without any driver inside. Shut-- airport trains are often like this. But we're seeing this in Metro systems as well. In some systems, they still have attendants or they still have a driver just in case or for political reasons. But these systems can drive themselves.

You often need platform screen doors. That's one of the concerns with fully automatic systems. It allows people to go into the track and the computer won't see them, right? So it has to be a more controlled system. Line 14 in Paris is another example of that. Yeah, and then you can [INAUDIBLE] capacity through a moving block system. And here's an example of the C Line in New York City. Questions?

AUDIENCE: You said [INAUDIBLE] people [INAUDIBLE]

GABRIEL Yeah, so these systems have platform screen doors and they don't have a driver, right? So

SANCHEZ- you go in and they move between stations. But you also have lots of Metro systems in cities

MARTINEZ: that work like that. As of 2013, there were 48 fully automated Metro lines in 32 cities over the world that didn't require a driver to operate. And that number is going up.

OK. Let's talk about bus. What is a bus? And [INAUDIBLE] we're talking about the stereotypical-- this is the what is a bus, what is a train lecture. So this is the stereotypical description of what a bus is. But of course, the boundaries between these modes are blurry. So stereotypical definitions are of vehicle operating individually with rubber tires with manual lateral and manual longitudinal control, so a driver has full control.

Sizes. They can be small like a minibus can carry 10 to 20 passengers. And you could go up to bi-articulated carrying as much as a light rail system, a light rail train, so up to 250 passengers. If you at systems like Curitiba in Brazil. Vehicle design, you can have high floor design or low floor design. Can somebody suggest what the difference is and what the benefit of low floor is? Eli?

AUDIENCE: Low floor is better for wheelchair accessibility.

GABRIEL Uh-huh, there's another benefit. So one of the benefits of low floor is wheelchair accessibility.

SANCHEZ- Another benefit?

MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL Sorry?

SANCHEZ-

MARTINEZ:

AUDIENCE: The boarding time is lower.

GABRIEL Shorter dwell times, right? These people are not climbing stairs to get on the vehicle or off the vehicle. You can speed up the process and increase capacity. Another idea?

SANCHEZ-

MARTINEZ:

AUDIENCE: The ride is more stable?

GABRIEL Sorry?

SANCHEZ-

MARTINEZ:

AUDIENCE: The ride is more stable.

GABRIEL I'm not sure that's the case. I don't think that has a large impact on-- yeah, on-- I don't think vehicle design in terms of high floor or low floor increases stability that much, not anyway for the speeds at which these buses go. It's not much of a critical consideration. OK, right-of-way. So all options are available. You could be on the street sharing your lane with cars. Or you could have a dedicated bus lane with no signals and preferential treatment if you have some signals. So everything goes.

In terms of guidance, often it is manual. But sometimes you have the systems to automatically guide the bus. And we'll see two examples of that later in this lecture. Propulsion. All options are available. You have electric. You have diesel. You have hybrid, everything. And in terms of fare payment, another key decision if you're thinking of a new bus system in your city is, do you have the people paying the fare as they get on the vehicle or do you want that to-- do you

want that payment to happen outside?

So are you going to make some stations where people pay their fare and then board without having to interact with a fare box? The benefit of the latter is that you speed up the dwell times. But of course, you need to spend more on fare gates or some other means of paying a fare.

AUDIENCE: Is there a benefit to high floor for urban buses?

GABRIEL There--

SANCHEZ-

MARTINEZ:

AUDIENCE: Not intercity coaches.

GABRIEL So they are cheaper. Because it's easier. You have more space to, right, to put all the
SANCHEZ- mechanical parts of the bus. And I'll actually show you in some BRT systems, like, Curitiba, it
MARTINEZ: is very high floor.

AUDIENCE: Yeah. [INAUDIBLE]

GABRIEL And that's a very high capacity. So, yeah. So this is a bus. This is a traditional 40 foot bus that
SANCHEZ- seats 39 people. It has capacity for 56 people if you count standees. You can crush a few
MARTINEZ: more people in. Here's a double deck, capacity for 70 to 80 people. The upper deck is for sitting only. If they see you standing, the driver will announce that you have to sit down for safety though.

Articulated bus in Bogota. So now you're getting a bigger size. You have two sections much like the light rail, the Green Line vehicle here in Boston. But this is a bus. And bi-articulated so you can keep adding sections. This is the example that I mentioned where it's a high floor bus. Notice how high the doors are. And obviously no one's going to jump from the street up or down.

These are [INAUDIBLE] at specific stations. Here's the photo. These are the stations. You can see other gates so people have to enter the stations and pay their fare as they go in. And, sorry, and then there are these little platforms that stick out. The bus stops right in front of those. And the doors open wide much like a Metro door will open very quickly to allow level boarding.

So this [INAUDIBLE] of BRT, bus rapid transit, with all the features of bus rapid transit. So you have [INAUDIBLE] link, fare collection. You have very wide doors. So it behaves like a rail system. But it's buses that are serving it. Were there some questions? I saw some hands. Perhaps I answered them. OK.

Now a minibus, a very small minibus. So, if there were a cute bus, perhaps this is it, right? So this is in Avignon, France. It says free service one bus every six minutes from 7:30 to 7:30 from Monday to Saturday. So this probably sits 10 people about. So here's [INAUDIBLE] Cambridgeshire busway in the UK.

This is automatically guided. So the bus has the mechanical arm that sticks in front of the wheels or behind the wheels with a curb. And it sort of holds laterally against the, these edges of concrete. And so if that guideway turn, the steering wheel will also turn. That make sense? The benefit of this is that you can run quick. You can sort of operate at high speed through narrow sections. This is more useful in tunnels.

So, for example, the Silver Line here in Boston could operate much faster if it had that system to guide it. OK. Here's another system for guidance. Can somebody tell me how this works? It goes back to what Emily said earlier.

AUDIENCE: [INAUDIBLE]

GABRIEL What?

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE]

GABRIEL Do you notice these lines on the floor? So there's a camera looking down right in front. And
SANCHEZ- it's-- this camera is program to automatically steer the bus such that it remains along that line.
MARTINEZ: So the lateral control of the bus in [INAUDIBLE] it runs in France. It is fully automatic. Eli?

AUDIENCE: What's the advantage of that? Like [INAUDIBLE] dedicated [INAUDIBLE]

GABRIEL You can [INAUDIBLE] this is a pretty narrow section if we're going both ways. So [INAUDIBLE]
SANCHEZ- computers are better at controlling things, so-- and we could highlight other features like this
MARTINEZ: sign here saying when the buses are coming. And so this is a nicer bus system with elements

of the BRT.

That's another comment I want [INAUDIBLE] BRT. BRT is-- the full BRT is much like [INAUDIBLE] example I showed you, but especially in North America and actually all over the world, agencies are taking elements of BRT and applying somewhat selectively. Sometimes they call it BRT even so they take the branding of BRT into it. Hopefully, it's more than just the branding and they've taken other [INAUDIBLE]

AUDIENCE: [INAUDIBLE] what happens when the lines get dirty or there's snow?

**GABRIEL
SANCHEZ-** Yeah, yeah, I don't know. I imagine you have to clean and repaint the lines often. Or you have to take control. Yeah.

MARTINEZ:

AUDIENCE: --radar.

AUDIENCE: Other places where they put actually like coils in the ground and then touch that.

**GABRIEL
SANCHEZ-
MARTINEZ:** Yeah. Yeah. OK. Let's talk about light rail. So stereotypical description of light rail. Vehicles operating individually or in short trains with electric motors and overhead power collectors, steel wheel on steel rail with manual or automatic signal control. So if you were a consultant and you were thinking about [INAUDIBLE] about what, how you were deciding on the key aspects of a new system, you could think about vehicle design.

Are you going to make it high floor or low floor? So some vehicles here in the Green Line are-- we have both on the Green Line. I don't know if you've noticed. The older ones are high floor. You have to go upstairs to enter the vehicle. And the more-- the newer ones are low floor. You could have articulated or rigid body vehicles. Right-of-way, we have an option just for bus. And you also have a fully automated to manually [INAUDIBLE] or things in between.

And here are some examples. We have-- this is in Utah, so the TRAX, T-R- A-X. And this one goes through, I believe this is an intersection where cars can cross. So it's sharing some aspects of its right of way. Here's the Metro Blue Line in Minneapolis. Both of these take power electrically from overhead catenaries as you see here.

But the third, well, no, not the third. Here we also have catenaries. That's Here is the fourth example I have of light rail it has no catenaries. So this is a more modern system for powering light rail that actually stereotypical description. So does somebody know how this works?

AUDIENCE: [INAUDIBLE] it has-- you can see three lines.

GABRIEL There are three lines. So these two are for guidance.

SANCHEZ-
MARTINEZ:

AUDIENCE: Yeah.

GABRIEL And there's one in the middle.

SANCHEZ-
MARTINEZ:

AUDIENCE: Then one is for power.

GABRIEL That's the third rail. So how do you prevent people from electrocuting themselves when they walk. Because typically in Metro systems a third rail, it's [INAUDIBLE] Yeah. Huh?

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE] induction maybe?

GABRIEL No, it's contact.

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL Nope. It has to be--

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL [INAUDIBLE]

SANCHEZ-
MARTINEZ:

AUDIENCE: It's in short insulated sections that are only active when the vehicle is going.

GABRIEL And they're electronically controlled. So the head and the tail of the train emits some signals

SANCHEZ- that say, I'm over you. Open, like, turn the turn the section on. And only the section that is
MARTINEZ: under the vehicle is powered. The rest of it is disconnected. So it's prettier. Because you don't have these overhead catenaries that are somewhat unsightly taking space. Over in the back? Sorry. This is in Bordeaux in France.

AUDIENCE: So is it also cheaper because it's in the ground [INAUDIBLE]

GABRIEL I don't-- I can imagine that it's more expensive actually. But I can't say for sure. It's getting--
SANCHEZ- you know, when this started it was a new thing and there were issues with [INAUDIBLE] and
MARTINEZ: other things. It's getting more widespread. And I think they've solved a lot of [INAUDIBLE] It's becoming more common, so I imagine that the cost will go down with that.

AUDIENCE: Back in the '50s and before New York and DC wouldn't allow overhead so they actually had clouds that if they had conduits in the ground, they had to have [INAUDIBLE]

GABRIEL Yeah, underground, yeah. All right. Stereotypical description of heavy rail. Vehicles operating
SANCHEZ- in trains with electric motors on fully separated right of way with manual signal or automatic
MARTINEZ: longitudinal control, level boarding and off-vehicle fare payment. So Metro, right? If you were designing a Metro system, what would be your key decisions?

You would think about train length. How long will my train be? It can't be longer than your platform. So your station assigned has to go with this. If you have old stations and you're having a capacity problem, you can't just buy longer trains. Some system allow for the last car to remain, at least the last door of the last car to remain in the tunnel. In London you see that. So a [INAUDIBLE] station saying, if you're in the rear of the car, move to the front, because we're entering a shorter segment. So that's one of them.

The other things that could limit the length are turning radius radii, but that's not usually a problem with Metro. Because Metro doesn't usually have very tight curves. OK. Right of way. So you could have it at-grade. If you have it at-grade that means that if you want cars to cross under or over, you have to do a tunnel or an overpass.

Elevated, [INAUDIBLE] you were making the overpass kind of over a long stretch for the train and allowing-- keeping your streets as they are and a tunnel [INAUDIBLE] well [INAUDIBLE]. The Tren Urbano in Puerto Rico has all three types of right of ways. Station spacing is another consideration. If you space stations out-- if you have longer distance between stations that means you can cover a longer distance faster.

But that means that people have to walk longer to their final origin or their, sorry, their first-- the real origin or their real destination. And their at both ends of the trip. And then operating arrangements. We talked about the different blocking systems and control systems. Do you want this to be driven by a human or will a computer be taking over? So questions about this? Yeah?

AUDIENCE: So the difference between heavy and light rail is it as simple as just heavy and light rail or--

**GABRIEL
SANCHEZ-** No, it has nothing to do with whether-- with the weight of the vehicle for sure. So, but again, and stereotypes--

MARTINEZ:

AUDIENCE: Well, not of the vehicle but [INAUDIBLE] the type of vehicle.

**GABRIEL
SANCHEZ-** Yeah, [INAUDIBLE] no. But stereotypically yes because you have streetcars, which are the track is kind of embedded--

MARTINEZ:

AUDIENCE: Yeah.

**GABRIEL
SANCHEZ-** --on the-- and narrower kind of on the ground. And then these heavy rail systems tend to have a third rail and sort of wider gauge. It's for higher capacity. So here's an example. This is-- is this Beijing or Shanghai?

MARTINEZ:

AUDIENCE: Beijing [INAUDIBLE]

**GABRIEL
SANCHEZ-** Yeah. Yeah, Beijing. Line 4 in Beijing. And you can see here, so platform screen doors. So these will only open when a train is there. And it protects people from being pushed into the track, which could happen by accident or a person trying to commit suicide, which is actually a big problem for Metro operators. Yeah?

MARTINEZ:

AUDIENCE: [INAUDIBLE] you mentioned, do they control the door of the last car [INAUDIBLE] so--

GABRIEL Yes.

SANCHEZ-

MARTINEZ:

AUDIENCE: --they open--

GABRIEL They don't open the door that is not-- yeah, yeah. Only open doors that are right in front of a
SANCHEZ-
MARTINEZ: platform screen door if that makes sense. And it's hard to align the train very well. So you often have these, with a computer controlling the train, to stop precisely where the doors are.

AUDIENCE: Do you know a system of how they choose the doors, which one will be open them?

GABRIEL Yeah, I mean it's just based on-- the train will stop so that its first door aligns with the first
SANCHEZ-
MARTINEZ: platform screen door. And everything else just follows.

AUDIENCE: [INAUDIBLE]

GABRIEL Huh?

SANCHEZ-
MARTINEZ:

AUDIENCE: I think he means with the control system back here.

GABRIEL [INAUDIBLE] what communication happens exactly? I don't know the details of each system. It
SANCHEZ-
MARTINEZ: might be a little [INAUDIBLE] yeah. This is [INAUDIBLE]. This is an elevated section. You see the third rail right here carrying the power. Power. Let's have a quick aside and talk about power. There are two electric sort of categories of [INAUDIBLE] rail is most likely [INAUDIBLE] volt direct current power.

And systems that are longer [INAUDIBLE] alternating current at 25 kilovolts, so much higher voltage. Any ideas about the trade-offs between these two or when would you use one over the other?

AUDIENCE: Third rail at low speeds?

GABRIEL Maybe. But more than lower speeds, it's shorter distances. So why?

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL Yeah?

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL So, if you're-- yeah, so if you're in a tunnel, the tunnel construction will be more expensive if
SANCHEZ- you have to fit in a catenary and space for the pick-up, right? What else? [INAUDIBLE]?
MARTINEZ:

AUDIENCE: I think a lot of it has to do with where you have to build substations and how power is transmitted.

GABRIEL And that is-- that is the key difference. Yeah, so--
SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE] power is a lot easier to transfer [INAUDIBLE]

GABRIEL Right.
SANCHEZ-
MARTINEZ:

AUDIENCE: --distances but the cost--it probably cost more to--

GABRIEL To maintain the system. Right. OK, so AC power, well, you can change the voltage on the
SANCHEZ- current, right? So you can make it very high voltage. And that means that it's easy and
MARTINEZ: cheaper to transmit over longer distances. So whenever you have intercity trains, almost always they will be overhead high voltage AC. For subways, shorter distances, tunnels, you don't want to have transformers everywhere.

And the other problem with high voltage is that it arcs more easily between two pieces of metal. So in a subway sys-- in a subway train like this, you don't have much space between underneath the train to fit things in with proper electrical isolation. So if it's an intercity train, it's higher floor. You have more space. But if it's a Metro system, often you have less space.

So if it's DC inside the train and you don't need transformers [INAUDIBLE] at very short intervals in your system. Yeah, so that was a short parenthesis. Commuter rail is another kind of rail system. So the stereotypical description. Vehicles operating in trains with long station spacing. This frequently. Serving long trips into the central city. There's usually a large balance between peak hour and off-peak service.

So commuter rail to bring people into work in the morning and out of work [INAUDIBLE] in [INAUDIBLE] afternoon. So you often have service every hour or every two hours in the middle of the day. It's on the sign for frequent service. Your key decision-- the decisions are fare collection strategies. Are you going to put gates on the whole system as if it were a Metro system? Are you going to have paper tickets?

Some systems are moving towards mobile phone ticketing where you buy something that flashes in colors and proves that you've bought a valid pass. So different strategies for fare collection. Line length, how long-- how far out from the city center are you going to lay track and provide service? Are you going to through route in the CBD? That is, is the train going to only get to the CBD and turn back? Or are you going to cross the city and provide service on the other side having crossed the [INAUDIBLE]?

That's pretty critical actually. Because it's commuter rail is very directional. So if you don't have a place near the city to store your trains after you have inbound service, you'd have to then take them out. So you're running trips that cost you money to operate, and we're not serving many trips. So if you have through routing and you have a yard close to the city center, it might make more sense.

Station spacing is another issue and extent of parking capacity. Why parking? Because commuter rail is often accessed with a park and ride service, right? So you're usually-- you drive to a commuter rail station. You park there. And then you take the commuter rail. Questions on commuter rail? OK. Some examples.

[INAUDIBLE] this [INAUDIBLE] diesel. So in some sections it runs on diesel. As it gets closer to the city center, it uses electric power. Here's Mumbai. This one has a catenary. So it's taking power from these catenaries. This is GO Transit in Toronto. This is typical of commuter rail having two levels, two decks, fit more people in.

OK. So what are the traditional service concepts? Bus on shared right of way. Street car or let's say light rail on a shared right-of-way. Heavy rail on exclusive right of way. And then commuter or regional rail on something that is semi-exclusive or exclusive right of way. Sometimes commuter rail shares the segments with freight. So-- and that's it's semi-exclusive.

Newer service concepts, BRT. So we're looking at using buses to operate something that is more akin to light rail or even to lighter heavy rail, if you want. So including exclusive lanes and or transit signal priority where the signals turn green when one of these vehicles approaches

to not delay the vehicle [INAUDIBLE]. And then light rail on exclusive right-of-way, which makes it more like heavy rail if you look at the stereotypical descriptions that we had here.

OK. And what else is happening? Increasing diversity. Driver arrangements. Instead of having people hiring part-timers to cover the peaks or having 10-hour days but not five days a week. And then payment by vehicle type so you pay as much for [INAUDIBLE] for a heavy rail car as you would for a bus. So let's go back to part-timers and 10-hour days. Why are these [INAUDIBLE] help increase the efficiency, [INAUDIBLE] efficiency, of a bus or a rail system? Why is that necessary?

AUDIENCE: Like as people that just work in a peak period where you need more-- if you're operating more of your fleet but if you don't actually need them for the whole day.

GABRIEL OK. So that would be for part-timers, right?

SANCHEZ-

MARTINEZ:

AUDIENCE: Yeah, part-timers.

GABRIEL Yeah, so you might need more to run more service only at the peaks. And the peaks are not long enough. They're also not-- they're also not spaced-- they're kind of spaced eight hours apart aren't they? So an eight-hour day doesn't really work to cover both peaks. So that's why you can do that by hiring part-timers or by extending the day to get 10 hours and cover both peaks.

OK. Routing and scheduling. So fixed, flexible, advanced booking. Yeah, so vehicle types. We have all these minibuses, articulated buses, rail cars, bi-level rail cars, low floor. We saw some examples. Control options. Traditionally it was fixed block. But now we have moving block. And we have fancier systems [INAUDIBLE] collisions and to actually control the system to run faster and more even headway.

And you have dual mode operations. So bus systems or light rail systems that work more like buses but also more like rails in some segments. So in some cases, this dual mode has more to do with power. So it could be a bus that runs electric in a tunnel section but runs diesel [INAUDIBLE] tunnel section like the Silver Line here in Boston.

It could be having some sort of [INAUDIBLE] system that operates on streets as a normal bus

would but then enters a corridor where it's fully dedicated to the bus system. So it's operating in both manners. Yeah?

AUDIENCE: Why [INAUDIBLE] I think [INAUDIBLE]

GABRIEL I'm not sure I follow. I can't hear you very well. But--

SANCHEZ-

MARTINEZ:

AUDIENCE: Oh, sorry.

GABRIEL If you're asking about why not run diesel in the tunnel? It's for exhausts.

SANCHEZ-

MARTINEZ:

AUDIENCE: Yeah.

GABRIEL Yeah, so there might be regulations. You don't want diesel exhaust in the tunnels. So it's for health reasons. A lot of the newer buses, like hybrid buses that are diesel electric, because obviously if you've got a fully electric bus, there's no issue. If you've got a diesel electric, some of them have a [INAUDIBLE] If you're entering the tunnel you can tell it to only use electric. And it's [INAUDIBLE] slower it will. But it'll run only on electric. And then get-- you turn that off when you exit the station to keep generating electricity. Questions on these?

OK. Rail versus bus. So rail has higher capacity. Bus has a lower capital costs. It's cheaper to buy a bus than to buy a rail or to build rail. Buses, you buy the vehicle and the streets are already there. So you're not having to build stations. The unit operating costs are lower for rail. So if you look at the average, and we'll look at some of these costs, unit cost by say, by trip, by passenger trip.

Because so many people ride rail, it's cheaper per ride to provide rail than to provide bus. Bus, however, can cover a wider network because it's more flexible. Rail tends to better service quality. Because it doesn't have traffic. And it has a dedicated right of way. So, yeah. And it has a stronger land-use influence. Because the stations are in map. And you sort of know the rail map of the city much faster than you learn about its bus network.

So there's a bias that people have towards taking rail over taking bus, even if rationally taking a bus would be faster. You may not even be aware of all of your bus options. And fewer

negative externalities. That's because electricity that powers these is often generated outside of the city and brought in. So the air pollution cost by the consumption of electricity for rail is not-- is not an externality that is internalized in the city often, if that makes sense.

So, right. So bus is much more flexible. And you can operate it on any road [INAUDIBLE] or on a guided right-of-way or a designated right-of-way. And it's more prone to being used in [INAUDIBLE] mode nature, right? So just the flexibility. Let's look at the-- going back to the APTA Fact Book of 2011. And these are numbers for 2011. Because they always do these reports for two years before the report comes out.

So how much was spent in bus service in the US? So 18, this is in millions, so 18,000 million, actually billion heavy rails less and light rail even less. And then commuter rail is more expensive. Paratransit is a form of transit that is provided to handicapped people. And it's-- you reserve it. You say, I need to be picked up here and taken there. And you get a window, maybe a three-hour window, so it'll schedule a pickup and take you to provide service for you. So, because it's so dedicated, it's expensive to run.

OK, in terms of-- that's in terms of operating expenses. How many trips are served? So bus also provides more than heavy rail, because there are more bus systems all over the US. Heavy rail, but you can see if you compare the operating expenses with annual unlinked passenger trips that it's more efficient per passenger, right? And then light rail and commuter rail and paratransit are much smaller contributors to this.

Let's go down to these pale yellow ones. Here we are dividing operating expense by revenue vehicle hour or revenue vehicle mile on length of trip. So we got some unit costs, right? So you see the unit costs for bus, \$3.40 per bus ride. For heavy rail \$1.80. For light rail \$3. For commuter rail \$10. And for paratransit \$26. So this is how much it costs to run that service when you divide it by the number of people taking it. Questions?

AUDIENCE:

So like in London, the bus is like half the price of the Tube? For example, at least, most of the time so would that imply that either the buses in London are probably a lot cheaper than these or that they're subsidizing the bus trips because the less affluent people tend to take the bus versus the Tube?

GABRIEL

More the latter.

SANCHEZ-

MARTINEZ:

AUDIENCE: That take the bus?

GABRIEL Yeah. So, yeah.

SANCHEZ-

MARTINEZ:

AUDIENCE: So buses tend to be more.

GABRIEL I mean, it's cheaper to run one bus. But if you look at how many people can ride a bus and
SANCHEZ- how many people can ride a train, yeah. The Tube unit cost basis is-- yeah, it's more efficient.

MARTINEZ: The other thing is that you put Metro service in places where there is high demand. So it's somewhat cyclical, right? Bus service, you might have a mandate to cover a big area.

So some of the bus corridors might be operating on profit. And some of them might be, you're doing it because you have a mandate to provide service. And it's running-- it's underutilized and the price that your cost per rider might be much higher.

AUDIENCE: These are all operating costs to just to keep it running--

GABRIEL Yes, yes.

SANCHEZ-

MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL No capital costs. And we're not talking about fares here. So this is how much it costs to pay the
SANCHEZ- driver, the fuel, the maintenance. Yeah. OK. Let's look at mean passenger load. I think this is
MARTINEZ: interesting. So 10.7 for bus. So if you look at if you take a bus in the US at random, the average number of people in it will be 11 people. Does that make sense? Is that your experience? Seems a little low.

So one way of thinking about it-- maybe I can clear the board a little bit here. I'm sorry it's very-- yeah. they're all used up. One way of thinking about it is let's think of the AM peak. So, and let's just keep it very simple. So you have service going this way from one terminal to the other. Let's say A and B and service going back, right?

And because this is the AM peak and this is the central business district, let's say that everybody's going in. Nobody's coming out. So you have a lot of people boarding the bus

closer to the city. Well, yeah, let's do it the other way more realistically. People are boarding the bus. And as they get to the CBD, they alight. They get off at the city center, right?

So let's say that a bus-- this bus fits 45 people. So that's the people right there. So what's the average in that direction? It's half of 45, right? And then if you divide 45 by half and then by half, because there's only one direction providing service, you have 45 by four. Right, 45 by four is 11. So there you go. Just making sense of it, right, a quick check.

AUDIENCE: There is another piece that a lot of us have taken buses in Boston, others in San Francisco where there are a lot of people who take the bus [INAUDIBLE]

GABRIEL Yeah. Yeah.

**SANCHEZ-
MARTINEZ:**

AUDIENCE: [INAUDIBLE]

GABRIEL Yeah. And there is some of that in some of these other modes. So heavy rail. For [INAUDIBLE]
SANCHEZ- reasons, 25. This is per car not per train so--

MARTINEZ:

AUDIENCE: Oh, [INAUDIBLE].

GABRIEL OK. Light rail also by car, although many light rail systems or single car or two car, so-- I think
SANCHEZ- commuter rail is higher, 35.3 [INAUDIBLE] two things. One is that you're mostly operating on the
MARTINEZ: peak power. So you're not providing much service off peak. Therefore, there's this higher demand there. The other thing is that it [INAUDIBLE] right? So these cars are bigger. They have two decks sometimes, and they fit more people. So that's why you have higher mean passenger load.

OK. So just looking at some sort of averages nationwide and make some sense of them. Ridership by mode and [INAUDIBLE] start with heavy [INAUDIBLE] systems from two classes ago we saw that the oldest systems are the first ones to be built. And they're in cities that depends a lot on transit and use a lot of transit.

So these five older systems, this was the ridership in 2009. If you look at seven newer systems built after that, that's the combined rider, much lower, right? So you see the older systems are carrying a lot more people. And if you look at the change from '74 to 2009, [INAUDIBLE] the

old [INAUDIBLE] grew 63% and [INAUDIBLE]

With light rail, you have-- you start with seven old systems, 188 million. It grew by 26%. A lot of newer systems, do you see that, there are much more newer light rail systems so there are newer heavy rail systems. Commuter rail, four old, 12 new, same idea. The older systems grew by 36%, 12 new systems carried much less than the four old systems though.

And here's four bus. We had 5-- 5.4 billion. It grew 10%. So that's just giving you an idea of how heavily the [INAUDIBLE] systems are being used. If you look at what has happened from 1999 to 2009, so one decade, the number of active vehicles 10%. So the investments, the supply in heavy rail grew by 10%, though the demand [INAUDIBLE] case supply measured in another way, revenue vehicle miles operated, 20%, or 19%.

For light rail, we see that many more vehicles are being [INAUDIBLE] and much more revenue models are being operated. So again, more investments in light rail than in heavy rail. And, yeah, commuter rail is somewhere in between. For bus it's much less. It looks like there is a higher level of [INAUDIBLE] in light rail systems than in other modes.

OK, and service trends by mode. So we have here boardings per revenue vehicle mile. So this is a way of measuring how much supply. In 2009 this how much 5.2 for heavy rail and light rail. Heavy rail grew by 16%. Light rail decreased by 15%. Again, more investment in light rail but more of the growth happening in heavy rail.

Commuter rail same thing. Some of this could be people, more people moving towards cities and not requiring commuter rail or suburbanization, people living in the suburbs and working in the suburbs for not having to take commuter rail. For loads, we see, again, loads increasing in heavy rail, decreasing somewhat or staying flat in other [INAUDIBLE]. So these are general trends. OK. [INAUDIBLE] do you have any questions on these modes and their characteristics and the role they play in-- yes?

AUDIENCE:

Two questions. First of all, what exactly [INAUDIBLE] and second of all can you talk about why light rail is [INAUDIBLE] being so much more operated on than [INAUDIBLE] why those changed.

GABRIEL

OK. So revenue vehicle miles. Let's start with the first one. What is revenue vehicle mile? It's a measure of the distance, total distance covered by a vehicle that is serving trips. So it excludes that heads from garages to the beginning of our route or any other vehicle movement where

SANCHEZ-

MARTINEZ:

the vehicle is not serving people. It's not-- this doesn't have its head sign on and-- if it's a bust, right?

So that answered the first question. And the second one was, why is there-- why does there seem to be investment in light rail when it seems like the ridership is decreasing and the amount of revenue vehicle miles are going down as well? So, this is more of a planning and politics question, I think, cities and urban planners.

Because light-- because rail has more power to change the urban landscape. Because in people's minds, it is more-- it's more physically present and permanent. There is a preference towards rail systems over bus systems. Metro is appropriate for very large cities that a lot of them-- a lot of those cities that require Metro already have Metro.

So what we're seeing is that there is a lot of cities that are maybe not as big to require Metro. But they could use a light rail system. They could also use BRT. But they have a bias towards light rail in planning and for political reasons. A politician might prefer to claim, I built this train system, not I put some buses on the road, right? So these are real factors that influence the mode choice.

The other thing is that a lot of these newer systems, because they are in smaller cities, they bring the average down. So--

AUDIENCE:

Yeah, [INAUDIBLE] even if I could add on that [INAUDIBLE] the US you had new light rail systems in Cincinnati, in Tucson, and Kansas City. But even if-- but their increase in ridership, so there, their contribution to the increase in ridership of light rail might not even compensate for loss of ridership in other cities that have old systems like Philadelphia or Boston.

GABRIEL

Right.

SANCHEZ-

MARTINEZ:

AUDIENCE:

And so if Philadelphia has a decrease, I'm not saying it did, but if it did, then it could wipe out the increase that Cincinnati contributed.

GABRIEL

Yep. It goes both ways. These are averages. So-- any other questions? Yes?

SANCHEZ-

MARTINEZ:

AUDIENCE: [INAUDIBLE] by local agency or like [INAUDIBLE]

GABRIEL It could be. So the question is [INAUDIBLE] commuter rail referred to in terms of the operator?

SANCHEZ- Who operates commuter rail and is that one of the characteristics that-- but yeah. I didn't

MARTINEZ: include that here. Because there are many different arrangements for what commuter rail is and if it's publicly operated or privately operated through a contract through the public sector. Yeah, there's all sorts of arrangements.

Sometimes there's a separate agency that operates commuter rail. And it's not the same agency that operates the inner city bus and Metro. So--

AUDIENCE: You used the word [INAUDIBLE]

GABRIEL So commuter rail is usually characterized by more service. The purpose of commuter rail is to

SANCHEZ- bring workers into the city. Right? So you have a service that is radial going into the city. The

MARTINEZ: frequency of service is higher in the AM peak and the PM peak, lower off peak. Whereas intercity is more of a scheduled-- intercity rail is more like airplanes and the airline industry where you have a schedule and trains leave every hour or every two hours. And you book in advance. And right? So slightly different characteristics. [INAUDIBLE]?

AUDIENCE: I had a couple of questions. Well, I guess the first one is if you go to pretty much any airport and they have an airport transit system, they have automated-- it's automated as platform screen doors and all the like, and we've been building those in the US since the '70s, why are there-- why is that never put forth except for a couple of occasions in, I guess, Vancouver and a couple of very small systems? That's the second part of it. So is there any good reason for that?

GABRIEL My guess is that you have more space in airports. And it's less political. You have the

SANCHEZ- stakeholders of the airport, the airport has funding streams to-- for capital projects. You have

MARTINEZ: the space. The airline has to use eminent domain to build any system, if that's what you're talking about. If you're talking about building a new system.

In terms of retrofitting an old system, well, that's harder than building a new one from the beginning, right? So the investment required to-- the station shutdowns and all the headaches that you have to deal with if you're retrofitting a system, putting in a new signal linked system, all these things, you might require a new fleet that is capable of operating this way. So it's a heavy lift--

AUDIENCE: Yeah.

GABRIEL --to do the retrofitting. But it's being done. If you look at London, London's been doing it.
SANCHEZ- They're-- yeah, the Jubilee Line, which is the color silver in the map of London, is operating
MARTINEZ: with--

AUDIENCE: [INAUDIBLE]

GABRIEL --with-- but from screen doors in the center at least. And--
SANCHEZ-
MARTINEZ:

AUDIENCE: Also the full DLR system in London.

GABRIEL Yeah.
SANCHEZ-
MARTINEZ:

AUDIENCE: Yeah.

GABRIEL Yeah, yeah. And that's-- it's funny, because that's Docklands Light Railway, right? L is for light.
SANCHEZ- But it's Metro according to what we covered today. It's heavy rail.
MARTINEZ:

AUDIENCE: And then the second question was, if you look at something like cross-linked or RER or something that's [INAUDIBLE] which is your sort of hybrid commuter rail but then operate on transit very high frequency--

GABRIEL Yeah.
SANCHEZ-
MARTINEZ:

AUDIENCE: Perfect questions.

GABRIEL Yeah. So again, we talked about stereotypes and the lines are blurry. And I think it's useful to--
SANCHEZ- the point of this is not to really categorize everything and be able to claim this is a heavy rail.
MARTINEZ: This is a light rail. It's more as just a framework to think about if you're a planner, or a consultant, and you're in charge of deciding or helping your city decide what mode to use for some project, here are the things you should think about.

Here are the key decisions that you have to make, station spacing, capacity, what are you dealing with? So in that sense, this context is-- this framework is useful. But I wouldn't go-- I wouldn't use it to necessarily classify everything into one with one label. Yeah?

AUDIENCE: So these trends that you've shown are pretty much all [INAUDIBLE] the US systems?

GABRIEL Well, we have many pictures from internationally, yeah.

SANCHEZ-
MARTINEZ:

AUDIENCE: You touched on [INAUDIBLE]

GABRIEL There's Canada, Mumbai. Right, so--

SANCHEZ-
MARTINEZ:

AUDIENCE: [INAUDIBLE]

GABRIEL OK. Yeah.

SANCHEZ-
MARTINEZ:

AUDIENCE: Yes, but the trends, though [INAUDIBLE]

GABRIEL Oh, yes, yes.

SANCHEZ-
MARTINEZ:

AUDIENCE: Ridership.

GABRIEL That's right, yes.

SANCHEZ-
MARTINEZ:

AUDIENCE: That sort of stuff--

GABRIEL Yeah.

SANCHEZ-

MARTINEZ:

AUDIENCE: --is not quite the same outside of the US?

**GABRIEL
SANCHEZ-
MARTINEZ:** Yeah, I'm not as knowledgeable on the trends in Europe and Africa and Asia, South America, though I'm sure that other countries and the European Union have something similar in terms of reporting. So, yeah, I happen to know the Fact Book and the NTD statistics. I'm familiar with them. So I can go and refresh them and look at the unit costs. ; I'm sure you could do the same thing. I just haven't done it.

It would be interesting to see how those trends have compared [INAUDIBLE]. All right, if there are no more questions, class is dismissed. Please, meet with your teams and pick a day for data collection.