GABRIEL SANCHEZ-MARTINEZ: Today we have two guest lecturers. The one I invited is Professor Peter Furth. He's an expert on transit signal priority. His own work on reliability before time and then how people budget for their travel times, he's a really good teacher on that.

And he's also a bike expert. He's really interested in all bicycle stuff, but let's not do this publicly. Maybe you can get him out of this class and ask him something.

Then we also have-- he dragged someone else in from the Netherlands who also knows a lot about transit signal priorities. So I don't really know what to say about him, but we'll find out. Maybe you can introduce him.

PETER FURTH: Yeah, I'll introduce him. Yeah, OK. Hi all. Thanks. It's great to be here. Before I get into transit priority, I just want to tell you a bit more about my background. So, I studied here at MIT, and my focus was on public transportation. Then, I became a professor at Northeastern.

And after several years, for one thing there weren't enough jobs in public transportation. And my students needed more training in traffic engineering because there were more jobs in that. But then the other thing is that our buses were getting stuck in traffic all the time, and I wanted to learn, well, can't we figure out a way to make the lights turn green for a bus. I mean if we can get a man on the moon surely we should be able to get the lights to turn green for a bus.

So I got the chance to go to the Netherlands for a year, a sabbatical year. And almost did a second PhD there, studying traffic signal control for transit priority. So you have to learn all the traffic signal control, and then you can learn, OK, now how do you do transit priority? Then I came back to the United States, and it took me several years to try to figure out how the Dutch traffic signal control-- they use different language but it's really about the same. There are some differences but it's mostly the same, how to say that in American traffic signal control.

And since then, I've done a lot more work now in traffic signal control and transit priority. So that's how I come here. My title is, *Is it help or is it hype?* And I really mean that because if

you go to Zurich transit signal priority is real help. I went there once on an official visit, and I told the people I was visiting, I came here because I've heard it said that the trams never have a red light.

He said, Yeah, well that's just about true. There are some exceptions he said, of course, like at the main square there are so many trams. They come from different directions so one tram has a red light for another tram. But otherwise, there are only one or two intersections in the whole city where the trams don't just get a green light.

I learned that in Portland, when they designed their light rail in the 1980s, station to station green waves are programmed into the traffic signal control. Now it doesn't mean zero delay because what that means is when a light rail train is at a station, there'll be a countdown clock for the driver. So there's no point in leaving now because you're going to have a red light. But if you wait until the appointed time to leave, then you will have a green wave to the next station.

But then we come to applications of transit signal priority in the US. And you hear these great pronouncements, oh, we're doing transit signal priority. But when you look into it, there's almost no benefit. Sometimes they're saving the bus two seconds per intersection or less. Often they're not measuring at all.

So then I have to ask, is it really a help or is it hype? And so what I'm going to tell you today is some of the standard ways of doing transit signal priority, how they work, and how they don't work very [AUDIO OUT] have to do to really be able to have our buses or trams have nearly zero delay. So before we get into detail, why are we doing transit priority? This is a class on public transportation so it probably doesn't need a lot of argument but we start with a societal objective.

Transit offers many benefits to society in terms of congestion, air quality, livable communities, and so on. And transit is mostly competing with car use. And what transit can do is break the vicious cycle. There's a vicious cycle. This is especially strong in developing countries.

Whereas people get more money, one of the first things they want to buy when they have more money is a car. And then with the car the car roads become congested and then that slows down transit. So then people don't want to use transit so then they get more cars and it just keeps going. If you can do priority for a bus, then that breaks that cycle and now people will say, I'm going to use the bus or the train to have priority.

And then having priority for transit makes a lot of sense because the tradition in Boston has been a very extreme all or nothing priority. We know one way to give transit priority. Total grade separation. We build a subway, and they're protected from congestion.

So we know how to do the $2 billion priority and we also know the other extreme, which is nothing. Buses you're welcome to use our roads. I mean when the light turns green everybody else can go, I guess you can too. It doesn't make sense to only have those two extremes. And that's what the city of Zurich did.

The main planners for Zurich wanted to build a subway. This was in the 1970s. Big cities that didn't have subway systems then were building them. But the citizens said, no, spend a tenth of the money-- because subways are incredibly expensive, spend about a tenth of that money to give our trams priority, and then we don't have to walk down in the basement. And instead we like how the trams are right.

It's almost like an extension of the sidewalk. You just step on, ride, step off. So it makes sense to have some means of priority that's in between all or nothing. And we have two ways of doing priority.

It's priority in space. That means you give the buses or the trams their own lane, their own space. And then there's priority at time, which comes at traffic signals. Priority, it's easy to see what it means to a transit user.

It means you get a faster ride and a more reliable ride. So it saves you time. The reliability means it also saves you in buffer time.

But it's important to know what transit priority means to a transit operator. The savings in time means they might be able to run their route with fewer vehicles and less labor. And the improved reliability means they don't have to have as much recovery time. So in Portland they had a case at Tri-Mat Line 12. The transit priority they put in didn't reduce the running time that much.

But it reduced the variability of running time so much that they were able to reduce the cycle time by 11 minutes. And if you reduce the cycle time by 11 minutes on a route that runs every 11 minutes or every-- then you save one bus and one operator. And that lowers your cost tremendously. So priority is important for passengers, it's important for the operator.

And I told you I studied traffic signals in the Netherlands and it was in the context of transit priority-- how can we make transit service better? So here you have two graphs, each line represents the trajectory of a vehicle. On the bottom is space. We're going from station CL across to station S. And on the vertical axis is how far off schedule are we?

So if you're at the 0 line, that means you're perfectly on schedule. And as you go above the line, you're earlier and earlier. And as you go below the line your later and later. So this is what the operation was, kind of if you just let it be. The buses will start pretty close to on time but they got later and later and later, and the spread just gets worse and worse and worse.

This is nothing new. If you know about transit service you know how there's these random shocks could make a bus late. And once you're late you become later and later and later. And once you're early you become earlier and earlier and earlier.

But here they put in a system with priority at the traffic lights. And it's conditional priority. If the bus is early, no priority for you but if the bus is late, we're going to give very aggressive priority so that bus can cruise right through the intersection. So if the average time to get through an intersection is let's say half a minute, but with priority that's going to be 10 seconds and without priority that's going to be 50 seconds.

That's a 40 second difference that I can make my bus 20 seconds later by not giving it priority. I can make my bus 50 seconds earlier by giving it priority. So with that you see how much tighter the lines are, how much better the reliability is because the priority system is able to keep those buses right on schedule. Yeah.

AUDIENCE: [INAUDIBLE] people driving on the road would have to use that traffic light and they know it normally takes them 30 seconds and all of a sudden it's 50 seconds or is this a separate thing?

PETER FURTH: No, this is not let's hold the light red extra long. This is just we won't give priority, that's all. So, yeah when I say we won't give priority, I'm not talking about holding. So we're not deliberately holding the light red.

It's just, if the bus arrives in the light is green, OK bus you get to go through. But if you arrive when it's red, I'm not going to hurry up and turn the light green for you if you're early. I'm only going to do that if you're late.

And priority makes transit more competitive because after all if transit has to stop to pick people up, that slows it down, you have to walk to get to the station that adds more travel time. How can we compete with car? Well one way we can compete is we can give transit priority and it makes it more acceptable. And because I got late, I get don't get to tell you the story about my great aunt.

So there are different levels of priority. One of the things you'll often hear if you ever hear a presentation about priority, they'll say, it's not preemption. Preemption is a technical term in traffic signal control, and preemption is what we'll do for a fire truck. And that just means oh, preempt the signal, just stop. Every conflicting movement goes to yellow, goes to red, and we just stop everything so the fire truck can go through.

And by the way the street that the fire truck is on we don't turn that one red, we would make that one green. It's not like we ask everybody to pull over out of the way of the fire truck. We ask everybody just keep driving, go, go, go, go, go, go, go. Give them green wave, go, go, go, and then the fire engine comes along. So that's preemption.

We do that for fire engines. And we do that for trains because trains can't brake. You get a train coming along at 40, 50 miles an hour, trains-- that steel wheel on steel rail, they can't brake very quickly. So we will preempt a light for a train.

So priority is something short of preemption. For instance, with transit priority we will not cut off a pedestrian phase. There's a certain clearance for pedestrians to be able to cross the street. You've seen the countdown signals. So for a fire engine they'll just-- it could be 15, 14, 0. But we won't do that for transit.

And preemption it doesn't think a moment about the impact on the other traffic. We got to save a life. Somebody's life is at stake, somebody's house is burning down, and there's a train coming that would kill everybody in its way. So when it comes to saving a life you don't worry about, is it costing people a few extra seconds, minutes of time?

But transit priority we're going to give priority to transit vehicle every five minutes every, three minutes. You can't be completely disrupting and screwing up traffic every three minutes. You have to think about how it affects others.

So there are some standard tactics. The main ones I'll talk about are listed here. Green extension and early green, but I'll also talked about some more intelligent tactics and some

ways of changing the background. So let's look at the most popular tactic, which is green extension.

Green extension means the street that the bus is on, the light is green. It's about to turn yellow, but we detect, oh, there's a bus coming and it's only 12 seconds away. All right, then we'll just delay turning yellow. We'll just extend the green, and then the bus will come right through. And then the light can turn yellow and turn red.

So that offers, as I have there on the slide, a very large benefit to the buses who take advantage of this. I mean, because the bus who gets the green extension, that's the bus that if they didn't get that extension they would arrive right near the beginning of red. And they'd have the longest wait of anybody in the cycle. They'd have to wait whole red period until they can finally go on. So if the red period is 70 seconds long, you just save that bus about 70 seconds.

So it's a very large benefit, but it's a benefit only to a few buses. Because which buses get to enjoy that benefit? Only the ones arriving during the first few seconds of red. Let's say you're willing to give a 15 second green extension, then any bus arriving in the first 15 seconds of red that gets a benefit. But if the cycle is 100 seconds long and buses arrive at random, well that's only 15% of the arrivals that are in that window.

So green extension is a large benefit but to a small number of buses. And we can model that benefit this way. On the horizontal axis is time in the cycle. And on the vertical axis, I have arrivals and so you have cumulative vehicles arriving. And then the red lines going across, that's-- you're raising your hand?

AUDIENCE: I have a question.

PETER FURTH: Yeah.

AUDIENCE: So but now that you said, it's a large benefit to a small number of buses--

PETER FURTH: Yeah.

AUDIENCE: --per intersection because if the whole bus run is 10-20 signal intersection, then over time the probability of every single bus enjoying that and every bus that runs [INAUDIBLE]

PETER FURTH: Sure.

AUDIENCE: Yeah. You say it's only 15% of buses, it's actually a lot more and it's--

PETER FURTH: So let's say 15% of bus arrivals at a signal.

AUDIENCE: At a signal but--

PETER FURTH: Yeah.

AUDIENCE: --over a lot of signals?

PETER FURTH: Yeah. Yeah. If I'm running a route in which I'm going through 20 signals and I'm going to get the benefit of 15% of them on average, I'll get that benefit, well, that would be three times 15% of 20. Yeah. So the red lines here represent the time that a person is in the queue. So like the car arrival-- here's arrival number one and then this line is the departure curve. Cars arrive at a relatively slow rate, let's say one car every five seconds. And they pull out at a much faster rate, say one car every two seconds.

So each horizontal line represents a certain vehicle. So let's say the vehicle number two arrives here. And vehicle number two doesn't depart until here. So that horizontal line is the waiting time of vehicle number two. So in this representation, horizontal distance is waiting time.

So for the bus with a green extension, instead of red starting at times throw, the red actually doesn't start until here. So a bus that would have arrived and had been delayed, now those buses aren't-- buses that arrive after the extension time still are delayed. So the possibility for delay, which is represented by the red area, there is less of it. And you find the average horizontal length between these lines. And then you do a little bit of geometry.

And we find that the expected delay in the first case, this is the standard delay for cars, has to do with the length of the [AUDIO OUT] car, the cycle length, C, and the ratio of the arrival rate to the discharge rate, that's v over s. And when we put in a green extension, we have that same term minus this term here. And I give that the name the priority push. So that's the reduction in delay thanks to green extension.

And that reduction in delay has to do with how long an extension are you willing to give. In some places though they say, well, I'm willing to extend for 10 seconds. In Toronto, they often say, I'm willing to extend for 30 seconds. So it depends on how long is your extension. But it also depends a lot on how long is your red and how long is your cycle. So just so you can have

some numbers of-- Yeah.

AUDIENCE: Sorry. [INAUDIBLE] why is the order [INAUDIBLE] assigned to that?

PETER FURTH: So this line here?

AUDIENCE: Mhm.

PETER FURTH: OK. So that represents the cumulative departing cars, OK? So at a certain point in time, the light turns green and then the first car departs. The second car doesn't depart until about two seconds later. The cars follow one another. So this line has a slope of about one car every two seconds as they depart.

This is as they arrive. It's maybe one car every five, six, seven, eight seconds, OK? And where the two lines meet, that means the last car in the queue is now gone. And after that, as cars arrive and depart without any joining acuity, just go through.

So to put some numbers on that priority push, let's consider a sort of typical intersection with a cycle length of 100 seconds, 50 seconds of red time, and the v over s. That v over s term is such that the degree of saturation is 85% which that's pretty typical. So this shows how the priority push varies with the green extension. The longer an extension you're willing to give the more of a priority push. But notice they're not equal to each other.

For instance, when the green extension is 15 seconds that gives me a priority push of about eight seconds. So often if anybody does try to describe the priority tactics they're using, they'll say something like, oh, when we give 15 second green extension. Well that doesn't mean it's going to speed the buses up by 15 seconds. In this case, how it affects each individual bus varies but on average that will reduce the delay of buses-- this is averaged over all buses, reduce the delay by eight seconds.

And then it has a lot to do also with the cycling. So let's again consider 100 second cycle, degree saturation 85. This time hold the green extension period fixed to 15 seconds. And look at different amounts of red time. So if you're red time is low, that's like the buses on the through road that gets green most of the time.

We're green most of the time and only a small part of the cycle is for the cross street. Well then the priority push is pretty small, only about five seconds. But if the red time is long, if it's 100 second cycle and the light is red for you 90 out of those 100 seconds, well then getting

pushed ahead 15 seconds will save you a lot. Now when is the light red for 90 out of 100 seconds? Under what kind of traffic movement would it be that is red almost all the time with a very short green?

AUDIENCE: Maybe like a city center pedestrian plaza?

PETER FURTH: No, probably not. Because if you only give the cars 10 seconds you just can't get much traffic through. Yeah?

AUDIENCE: D street in South Boston.

PETER FURTH: Ho, ho, ho, ho, ho you got it. You got it. But that's not a typical case.

AUDIENCE: The cross streets of a major thoroughfare?

PETER FURTH: So the cross streets, even they get more like 25-30 seconds.

AUDIENCE: Like a protected class.

PETER FURTH: A left turn, that's it. This is the one that really, really could benefit from a green extension. So right next to Northeastern is Ruggles Station, and you got all these buses making left turns. And if they don't make it, uh sorry, 120 second cycle, 100 seconds of red. So that's a situation where a green extension would be-- it's valuable in all these cases but it's especially valuable when there's a really long red time.

So I'm glad you mentioned D Street. I'll be talking about D Street. All right. OK, how do we do detection? Technically to detect the bus, it's almost trivial. There's so many different ways to do it.

I'll say something about technologies, but where we want to detect the bus. So we want to have a check-in detector so the bus reports in. Hello, I'm a bus. Can you give me priority? And there is a trade-off.

The sooner we know, the better because then we can prepare for it and get that light to be red. But if you tell me two minutes in advance there's a bus coming, bus travel time is not deterministic. All right? So there might be stops in between and random dwell time. There might be other traffic signals in between. So usually we want our check-in to be as far away as can be but no farther than the next stop or the next intersection so there's a pretty deterministic travel time.

We also want there to be a check-out detector. Some systems omit the check-out detector. So if you omit the check-out detector, here's how inefficient you are. You say, oh, there's a bus coming. I'll give it a 15 second extension. The bus goes through after three seconds, and you still hold the light green for the full 15.

That doesn't make any sense. So have a check-out detector. As soon as the bus hits that, you cancel the extension request, let the light turn yellow. The traditional technology for extension is we bury in the ground a loop-- not just a dumb loop of cable but a loop that acts like an antenna.

So the bus is coming along, giving along a very low energy signal. I'm a bus. I'm bus number 2356 so you can check my ID to make sure that this is not a stolen unit. And it could give off some information like, I'm turning left so I need the left arrow. There's another bus route coming along that's going straight.

So that's one way of doing it. Nowadays, we'll be doing it with GPS and basically cell phone technology, texting. The bus sets up text messages with the controller and says, here are my coordinates, here are my coordinates, and just keep sending essentially the packets of cell data like text messages. And then we know where the bus is, and we can take action.

So I can skip that. So one difficulty of giving priority is, well, what if there's a near side stop? If you looked at locating stops for buses, you know there's a basic choice between the near side, the upstream side intersection or the far side. Well, if you're on the near side, remember stop dwell time is random. So I don't even want to check the bus in until it's left the stop.

Well, that means my check-in point is going to be awfully close. So what? I'm going to find out two seconds before the bus comes that a bus is coming? If you only have two seconds advance notice, how long a green extension can you give?

AUDIENCE: Two seconds.

PETER FURTH: Two seconds. Think about it. You can't give a 15 second extension if you're only detecting the bus two seconds early, right? If I was going to end the green at time-- let's just pick a number at time 50 and I said, oh, I'm willing to wait till time 65. But I don't know when the bus is there until time 63, how would I know to extend the green? Yeah. You cannot give a green extension longer than the advance notice that you have.

So this is a killer. Yeah.

AUDIENCE: I'm just curious about the actual mechanics of the signal extension.

PETER FURTH: Yeah.

AUDIENCE: Is this a signal you're sending to just that one traffic intersection or are you sending a signal to some central control that's controlling the whole city's traffic lights?

PETER FURTH: A single place. Now, it can work through the central place, but I'm talking about, yeah, a bus is detected for a particular light, hold that particular light green for me. It doesn't do anything to any other intersection.

AUDIENCE: But I meant does it send a signal to some central control which then tells that light to change?

PETER FURTH: That's an option. So in Zurich, yes, they do that but man you need all kinds of cabling for that. In Zurich the controllers on the street are 100% slaves. All they do is, when the central computer tells them to change from green to yellow they just say, yes. And the only other software they have running in them is some kind of checking to make sure that they're not violating something. But that's a very unusual setup that was done ages ago.

Nowadays we have very reliable microcomputers in the controllers. So the central computer will make sure every intersection is on the clock, every intersection is supposed to have its certain offset-- you turn green at a certain time in the cycle. And it will give them the basic parameters-- 30 seconds for this street, 20 seconds for this phase, 20 seconds for this phase, and so on. And it will say, and you're allowed to give a 15 second green extension. And then it's the local controller that will actually do it. Yeah.

AUDIENCE: [INAUDIBLE] means that the detector is right there at the intersection?

PETER FURTH: Well it means that the stop is just before the intersection.

AUDIENCE: OK.

PETER FURTH: So if I put my detector-- normally, let's say I want to give a 15 second extension, I locate my detector 15 seconds upstream of the traffic light. Well, what's 15 seconds ahead when there is a dwell time in there? So you know how random dwell times are, right?

Are there going to be one, two, five people getting off? How many people are getting on?

Maybe somebody who needs assistance or having trouble with their fares. So because of that we won't usually call for an extension if there is a stop in between because we don't know how long it's going to be.

So near side stops, not entirely but they get some benefit. If the bus is pulling out two seconds of extension, that's nice but it's only two seconds. So it nearly kills the effectiveness of green extension. So that's a reason if you want to do transit priority, you review your route and you say, can I move the stops to the far side.

There are a lot of other reasons to move stops to the far side. Transit agencies around the country where they can are moving stops to the far side. So in the NBTA recently they did a review of all their key routes. And one thing they looked at is, can we relocate stops?

But they have criteria-- where there's a stop there has to be a level landing place. There can't be fire hydrants and telephone poles in the way. There can't be driveways. So some of the streets that I've looked at for, could we do transit priority, and first thing I would say, oh no, it's a near side stop. We've got to move it to the other side of the street.

But on the other side of the street there's a driveway every 30 feet, you can't put a bus stop there. Or there's a firehouse, you can't put a bus stop there. So sometimes we're stuck with near side stops. And then green extension just ain't going to help us very much.

OK. Before I go into more tactics, let me go through this list of common weaknesses in trying to do it. So one weakness that I've seen a lot here in the US is what I call cautious priority. So all this equipment they put in this transit priority system. But the traffic engineers are so afraid it's going to screw up traffic that they'll say, once we give priority to a bus we inhibit the whole system for five minutes to give the signal a chance to recover or we inhibit at least for another cycle. Or if the traffic level on the cross street is too much, just turn off the signal priorities.

OK. So the Silver Line running on Washington Street has a priority system. Some of the cross streets have so much traffic that they have this rule-- if the cross street volume is too much, turn it off. Well it's turned off, OK. So the bus never gets priority at Melnea Cass, it never gets priority at Mass Ave.

Many of the cross streets bus has the green light for like 70 out of 90 seconds in the cycle. So it's almost always green so the bus almost never needs priority. So there is priority, but the benefit is very time. So in the end, what do you get? You get almost nothing.

And then a second weakness is not thinking about the impact of priority on traffic and then unnecessarily hurting traffic, like not having a check-out detector that I mentioned. But the second bullet there, that's an important one I want you to think about, is compensation. Compensation is a key to making priority not hurt traffic so bad. And by compensation what do I mean?

What I mean is if I'm going to give the bus street 15 seconds, I'm taking those 15 seconds away from somebody. Are you going to give it back? The language that traffic engineers use is they use the word borrow. They say, oh, we'll just borrow 15 seconds from phase two.

And then I ask are you going to give it back? And they say, well, no. I say, well, then it's not borrowing, that's stealing. So if you take away 15 seconds from phase two, and phase two now they can't clear its queue. So now it's going to have a long queue.

And then the traffic engineers will say, oh no, now if we let them have priority in the next cycle as well, oh no, what a disaster. So that's why you get these rules, like if we do priority, no priority for the next cycle or the next five minutes. But if I hold the light green for let's say East Street for the bus, so I hold the light green 15 seconds for East Street, who's going to get through in addition to the bus? A bunch of cars, right?

A bunch of cars who otherwise would have been in the queue for the next cycle. So that means when we come around to the next cycle, East Street is not going to need as much green because some of their cars already got through. Meanwhile, other streets whose green we took they need more green. So hey, why not just be reasonable and fair about it. Since we gave East Street some extra green, in the next cycle we'll give the other streets extra green and we'll take some away from East Street.

That's compensation. That's a sensible way of doing things. And what you'll see is we don't do that. We can't do that with much of the standard way of controlling lights that we follow here in the US. And that's the inflexibility that I'll be explaining later on.

Then another weakness is we'll do the easy things. Green extension is easy. So we just do green extension. And then, like I said, if you have near side stops, well you don't get any benefit. And there are other tactics that are harder to do, but we only do the easy ones.

And then the last weakness is failing to collect data. In something like this, it's hard to get it right the first time. You need to do it, collect data. See, are my buses getting the priority they're

supposed to? If they're not, make some fixes.

Is car traffic doing all right? Are there places where huge queues are building up? And try to fix it. So take the objective seriously.

So now I need to move away from transit priority and just tell you something about traffic signal control in general because it's something that isn't covered in a lot of the standard transportation planning curriculum. So there are two basic paradigms for signal control. One is fully actuated and the other is coordinated.

So fully actuated that's uncoordinated. With fully actuated that means every approach I've got detectors. And the standard detector it's a loop of copper in the street, a couple rounds that goes to a box. And through the miracles of electromagnetism if a vehicle drives over it, it induces a voltage. And you can pick up that voltage, and so you know there's a car there. Yeah.

AUDIENCE: [INAUDIBLE]

PETER FURTH: So there is a setting of how much of a voltage change is enough because it has to become digital. It's either 0 or 1. So if we increase the sensitivity, then it'll detect a bike. But then the danger is it will also detect a car in the next lane over. So there is a trade off there.

So then if we want to detect bikes, we use a figure 8 configuration. And then we try to educate the bicyclists, drive right down the middle of that figure 8. And that's where you'll get picked up the most. Hardly anybody knows that though.

There's another solution to bike detection, which is if you're a bicyclist like me, I like green. I like red. I like yellow. I like all colors. I just go.

All right. So with fully actuated control I've got detectors. And based on those detectors, I will know how many seconds has it been since a car passed through and [AUDIO OUT] gap. And once the gap reaches a certain threshold, 2 and 1/2 seconds, 3 seconds, then you have gapped out. Boom, your turn is over. And it's the next one's turn.

So there's no fixed cycle length. Who knows? If traffic volume is light, we serve you, we serve the next, we serve the next, and now we're back. Traffic is heavy. It might take 90 seconds to cycle around. But it's completely flexible like that.

And if I interrupt something like that for transit priority and now there's a longer queue-- OK, everybody's been waiting an extra 15 seconds because of this transit priority. Well, when their turn comes up if they've got more cars, well the detector will say, hey, they still have cars, still have cars, yeah. So keep them going, keep them going. OK. Now we finally have a gap you're over, onto the next one.

And if East Street like I was saying has less traffic, the street that the bus was on because it got that green extension, when its turn comes up instead of holding the light for 35 seconds like it usually does it'll hold the light for 25 seconds and then say, I'm all done. No more traffic. So fully actuated control is a great background for priority because it's inherently flexible, it's cycle free, it has that built in compensation.

But then there's another way of doing control, another basic paradigm for control, which is coordinated control. In the US, I'm showing the most kind of the basic paradigm, which is the dual ring with eight phases. I'm not including right turns because right turns usually don't have their own lights. The right turns just go with the through movements.

And with coordinated control like this we have EBL, that means eastbound left, westbound through, WBT, westbound through. So the east-west street has its time. There's an upper ring and a lower ring. And the rings that are in parallel they can move together. So when the light starts green, eastbound left and westbound left, one and five, they're green together.

What comes next, two or six? That depends. Whichever one has more traffic, one or five, that will stay green because it has detectors while the other one gaps out. So maybe five gaps out first because it had less traffic. Then six becomes green along with one. Eventually one gaps out, and now six is green along with two.

But then six and two have to end together. And then we have the same thing for the north-south street. So this could be fully actuated, but when I say it's coordinated what I mean is phases two and six those are the coordinated phases. And the cycle goes from the end of two and six until the next end of two and six.

And that is a fixed amount of time. So if it's 110 second cycle, it's always 110 seconds from this point until when it comes around again. These phases can have some actuation. They can have some detectors. And so they might run shorter than scheduled.

And if they gap out quicker, run short, and this one gaps out, it runs short, this one gaps out, it

runs short that means two and six are going to start early. But if they start early, they never end early. They run their full length because that's how we have the full cycle. And the advantage to do that is when you have many signals in a line on an arterial and you want a green wave, you have them all on the same cycle. And then you have their different offsets.

So let's say signal 1 it's green starts at time 0. The next one that's maybe 20 seconds away, well it's green starts at time 20. And that way the cars can get a green wave. That's the idea. Yeah.

AUDIENCE: Are these doing that while left turns [INAUDIBLE]?

PETER FURTH: Yeah. As I drew it here, it's protected left turns. You can have protected plus permitted. I mean there are variations. If there might be no left turns, then you can just take them out but that's the basic scheme.

Now, what I want you to think about is suppose the bus is on phase two which is a common case. That's your Main Street the street that's coordinated. And the bus says, I need an extension. Extend the green. All right. We're going to borrow some time from the later phases.

So we're going to hold the light green an extra 15 seconds. But remember we are guaranteeing that at the end we've got to be on time again. So now we've only got 85 seconds left to complete the cycle. And phase two and six, they are not only guaranteed their ending time, they're also guaranteed they're starting time. So that means we have to take those 15 seconds out of 3, 7, 4, 8, and 1, 5.

So to make things simple let's only look at the bottom ring. So I have to take 15 seconds. The first generation, they would take the whole 15 seconds out of phase seven and then phase seven would get canceled. Well that caused big problems. So now what they'll do is they'll proportionally take it out.

So let's say phase seven is normally scheduled to have 20 seconds, and this one is normally scheduled at 30 seconds, and this one is normally scheduled to have 20 seconds. So 20, 30, 20, that's sums up to 70. So I'm taking 15 seconds out.

So a portion of that I'd take from you, I'd take from you, I'd take from you. You get the idea. Is there any compensation going on here? None at all.

Phase six, the coordinated phase, got an extra 15 seconds. But the competing phases, they all

got cut short. And now phase six comes up for a full phase. That's the way our coordinated systems are programmed to work.

They don't have to be programmed that way, but that's the way they are. If you buy them from any American supplier, that's how they're programmed to work. So when you say let's add transit priority on top of that, now you can understand why the traffic engineers say, I don't know about a 30 second extension. Or oh, after giving priority in one cycle we better not give priority in the next. Because it can really screw up traffic.

It lacks this mechanism for compensation. And compensating would be easy. It would be say, let seven run for its full scheduled time unless it gaps out. I mean if it gaps out if there's no traffic, don't. And allow six to start late because six got some extra time.

It probably doesn't need its full amount. But we don't do that. And then if we do a longer extension, we get out of coordination, we have to return back, and I won't go into that.

I'll talk about a second tactic, and then I'm going to take a break so you can hear about how they've done priority in the Netherlands. A second tactic is Early Green, OK? So in this diagram, the phase that's green, that's the phase in which the bus is coming, OK? And the phases that precede it, those are competing phases, the cross street or left turns that are waiting, OK? And the red dash line, that's when in the cycle the bus is going to arrive.

So I've got a situation where the bus is expected to arrive near the beginning of the left turn phase. And then it would have to wait through the end of the left turn phase. And finally its phase would be green. So with early green, I could shorten the left turn phase. I could even shorten the north-south phase before it.

So that now it's a shorter wait until the bus's green comes up. Maybe I even skip the left turn. I shorten the through, phase skip the left turn and really make things better for the bus that way. So an interesting way to look at early green compared to green extension.

It's a small benefit because if I make the green start 10 seconds early, that will reduce the delay for the bus by 10 seconds. Remember with green extension, 10 second extension could save a bus 90 seconds. But this-- it's a small benefit, but who benefits? Any bus arriving on red. And red is usually a long time, and a large percentage of buses arrive on red.

Actually, the early part of green, buses can also benefit. So it's a small benefit to a large number of buses. Yeah.

AUDIENCE: For skip you have the question marks. Why wouldn't you just flip the two cycles, flip the left--

PETER FURTH: Well that's a great idea. Flipping them, but now then you'd have to give that tactic a different name. And that name is called phase rotation. So yeah. And some people think phase rotation is an invitation to traffic Armageddon. It's going to be disaster.

Cars are going to be smashing into each other because people expect their phase to come up at a certain time. And if it doesn't, they're going to think the light is broken and go through. This is something that can be tested.

AUDIENCE: Yeah. I was just going to ask whether or not-- I think I've been at a light before where I had a skipped left turn and I was pretty pissed off. I was just curious how that goes down.

How many people does it--

PETER FURTH: So in Zurich when the traffic signal programmers said, we can give better priority if we can do this. The higher ups were worried about so they said, what we're going to do is we're going to have a campaign in which we're going to let the people in the city know that for the next six months the sequence of traffic signals is going to be completely random. Just wait until your green comes up. And they did that. And then they went to having a phase rotation.

AUDIENCE: Isn't it the law that you're supposed to wait until the green light? And they're assuming people--

PETER FURTH: Yeah. So in my life-- and my life is a little longer than yours, so in my lifetime of being out on the streets and I do drive a car sometimes, once I went through a red light because I waited like two whole cycles and my phase never came up. So I figured the detector was broken and there's no traffic around here anyway, so I'm going. So people will do that now and then. It doesn't happen often though.

But what you say about won't people wait, there is one class of people who won't wait. And that's called bicyclists. So you got to watch out for them. Think about their safety. Now, in practice, often you can't get much benefit from early green because who's green are you trying to cut short?

If what you're trying to cut short is the cross streets green, the cross streets green is often determined by pedestrians. And we don't cut pedestrian phases. Pedestrians and transit you

know we're on the same team. We don't want to hurt one to help the other because all of our transit passengers become pedestrians as soon as they get off the bus.

So a lot of times you just can't do early green because you've got a wide street, the cars need about 15 seconds of green to get through, but the pedestrians need 24 seconds. So the green light's 24 seconds, it's entirely because it's what the pedestrians need. You can't cut that short. So that's a practical issue that early green there are limitations unless you can detect the bus really far in advance and cut something else short.

So let me take a break now and introduce Jan Nederveen. Jan is a senior transportation planner with the city of Delft. And I get the privilege every summer for the last 10 years, I've been taking 20 or 25 Northeastern students to Delft for five weeks for a course in sustainable transportation.

And there they get to enjoy incredible bike paths, incredible roundabouts, streets rebuilt to be safe for public transportation systems, new train station, fantastic stuff. And it turns out the guy who plans a lot of this stuff is sitting right here. And he often speaks to our students and explains it and the philosophy behind it. So Jan, would you come and say something about how do you do transit priority in Delft.

JAN NEDERVEEN: OK. Welcome. Thank you for having me here. I'm going to tell you something that works that I don't do but my colleagues do. I've got three people in my department doing traffic engineering, traffic lights. They design it, they build it, and they maintain it. So what I'll show you here is part of the thoughts they have done and I only focus on public transport.

Peter offers many times a lot about cycling but this time it will be public transport. First I'll give you some views about the network. And then I'll show you the two current types of priority we give. We do physical priority, and we do time priority. I'll show you some slides for some examples of Delft.

First our city Delft, 100,000 residents close to of The Hague with 600,000 residents. That's how we oriented in the busiest part, dense part of the Netherlands. First we had one system to try to serve everybody. And we didn't succeed in it because our public transport system was too slow.

And then we figured out, oh, that's good. We have two kinds of groups we like to facilitate. One group are the commuters going to their work. And what they love is speed as soon as possible

going to destination.

In their view they only need one stop between their front door and at their destination. And everything between is not needed for them. Well, I need to collect so much more passengers that we say, we make straight lines, few stops, serving high dense volume housing with high dense jobs together. And then you can go for the high speed, the high quality, and we see that we attract more passengers.

The second group is everybody else-- usually elderly people, people without a job. And we focus on them, as you say, they need coverage. They have to go to many local locations. So we make a citywide network covering every area.

And that is located on a lower speed because I have to cover everything low frequency. That's the way we handle public transport. The first group is growing, the second group is stable If you look at the data.

This is how our network works. I've got a purple line. That's the Delft railway system connecting all major cities of the Netherlands. If you get in Delft central station, within an hour you're standing on the central market in Amsterdam, within 10 minutes to 50 minutes you're in Rotterdam or The Hague. Nationwide system very good quality, 11 trains each hour each direction. So it's perfect.

If you live in Delft, you can reach 1 million jobs within 45 minutes. So if you need a place, live in Delft. That's our first system. The second one, if I asked the people what do they like, most people like light rail like tram. There's a large group of car drivers who love light rail and don't like buses.

So I tried to convert my complete network to light rail. That is the dotted lines over here. The red ones are already built. And we're still talking with the regional government to get funding for the black one. And if that's done, you see a spider kind of network covering most of the city.

And I add some regional bus lines through its radial lines. That's the next coverage of our system. And that's the commuter network. And that's the last network covering everything. Step on a bus, pay $2, you've got the whole city to view if you've got the time. That's how we cover the complete area.

And the last group is transport on demand. If you're unable to use a public bus, we use

smaller buses. You have to phone every one hour, search a bus driving through, and you were picked up and delivered door to door transport.

It's a fantastic system but it's awful expensive. So what we're trying to do is get people out of this system, this market is growing, and getting them back in a normal bus. So we modify the bus so they are more attractive for people with light handicaps.

And the other thing we are thinking about, maybe we can offer a discount to the buses as a sort of timetable. We have a line structure for driving that kind of business. So it looks like more public transport which makes it more cheaper to run.

Physical priority. That's the first thing we do. If a bus is in the same lane as a car or if there's many bicycles usually there's the same speed, and I cannot give them any priority, let's give them bus lines. Where the center of city, center is city Delft, that is the downtown area, the central market square, this is where all the shops are and all the restaurants. That's the most historical center. It's a lovely place to be.

You see the square over there, that is the central railroad station. If you'd like to leave the city, go there. And we designed all the bus lines going to the central railroad station. We can give them good priority on that location.

When do we need a bus lane? We need it if there is a delay of driving with the cars. So on busy streets I like to have a bus lane. And that's difficult because if it's a busy street, you need probably four lanes or two lanes of car traffic. And I'm asking one lane for six or eight buses per hour in each direction.

So then we have to compete, as I said, in the busiest areas. We start searching for a bus lane or a light rail lane so we can give them priority. And elsewhere-- this is a residential area, it's nice to have but you don't need to have it. This was thought in the 80s, OK, let's make a bus lane everywhere so we get the bus lane in a residential area. And the only place we need it that it's crossing the highway in that location is because that's our big intersections.

Another part of priority is at the central station of Delft. This area, if you look at Delft and you take in Delft area, urban development, railroad you see a huge development in the downtown area. Over here is the old station. Over there is a new one. We have spent 500 million Euros to get the railroad tracks under the ground for 1 and 1/2 miles.

And we built a complete railroad station, a new bus platform, and we did a complete separation of all the transfer flows. On the surface level we offered public transport. So in the open air, that's public transport. On minus one, in the basement, we have the huge parking facility with parking lanes underground to bus platform. So we have a physical separation of the bike transport going to the railroad station and the bus transport.

Now on level minus two, we have the railroad tracks. That's one way of separation. You can see it here in the picture. This is the town hall, the glass building. And the first floor, the ground floor, that's the railroad station.

We have the name Delft on it. And underneath in it right, you can see people standing at the entrance of the parking garage. We've got 100,000 people living in Delft. This parking garage for bicycles is today 8,000 places, and it's not enough. So a few years later there will be 10,000 places for 100,000 residents. So bike parking is very important.

AUDIENCE: There's also the university there, so they're not all residents. Yeah. Not all the students are residents [INAUDIBLE].

JAN NEDERVEEN: Yeah. It's students. It's also residents now. Yes. OK. But when the students are at the university and you look at the parking facility, it's also full. And other people leaving Delft. Some of them are also students going into a university in Leiden or in Rotterdam but also normal people like myself are parking there.

It's not a student parking garage. Yeah. It's true that a large group of them are students. Well minus one is for the bikes and the bus platform is operational on this level. So buses don't have to deal with cars or with pedestrians or with bikes. Yes.

AUDIENCE: So if minus one is parking for bikes, do they also travel on that level or do they [INAUDIBLE]?

JAN NEDERVEEN: The bikes also travel on minus one. The bike lane goes here under this bridge and then entering the park. You can see there's a rim over it. So he has a complete separation to minus one in the most busiest area. And that saves me a lot of time because the first traffic light, very close to the railroad station, should otherwise have to deal with 10,000 bicycles a day.

But I've offered them a tunnel so I've got a normal intersection with a normal traffic light. All the rest I cannot handle that amount of cyclists, and this Peter here among this group, he will not stop. Here's an aerial view of the system. The town hall is in the front. And we have also an east-west separation.

On the down inner city side that's over here, we put the bus lane, the light rail lane. And on the other side, we've got the lane with the car traffic. And that's very important because at the top of the picture on the left side, I have an intersection where all public transport has to make all the left or right turns. And that's the only one that make that turn because the car route is blocked and the bike lane is underground in a tunnel. So I have an intersection where only public transport makes left and right turns.

And on the other intersection that's almost falling off the picture on the right side, that is my car intersection where all the light rail traffic only has to cross, they go straight through. So it was much easier to handle if a separate public transport and car transport on different intersections. And my transport engineers were interested in traffic lights. I took them, let me have a look if this is the same. Can you build a traffic light for this location? Because the alternative was one big crossing with everything, and that didn't work.

I do also have some discussions with my urban planners. And they love the light rail and the green grass in the middle. And my public transport here, lots of asphalt. What do you like? I pick you out. Which one would you like and why?

AUDIENCE: I'd prefer the light lines because I feel like you're more in tune with-- you experience the road better that way. You can serve the demand like that. You should go green.

JAN NEDERVEEN: So which one do you like, the light rail in the green or the light rail in the asphalt?

AUDIENCE: In the green.

JAN NEDERVEEN: In the green. It's lovely, nicer.

AUDIENCE: [INAUDIBLE]

JAN NEDERVEEN: Yeah. Well we had that discussion also. I also think the top picture is the most beautiful. But this has one big disadvantage. If I have a bus link or a public transport link but I like to operate buses as well as light rail, in this situation they can both use the same line. And I've got one platform, and you can decide if you take a bus or light rail.

And the one on top, if I would like to add the bus lane, well that would be a bus stop without priority on the normal street. I [INAUDIBLE] that one because it doesn't have a bus lane anymore because I replaced it by a light rail. Yes.

AUDIENCE: What is the typical frequency of light rail lines?

JAN NEDERVEEN: The minimum is four light rail vehicles an hour each direction. That's the minimum. Otherwise--

AUDIENCE: Rush hour?

JAN NEDERVEEN: It goes up to 6 or 8 in Delft. And in other cities it can be more. But eight is all pretty much for city with 100,000 people. And it has to compete with cycling. So many people who cycle you take them out from the public transport system. These guys, cab drivers always ask me, may I use your bus lanes? Because they are so fast and they have beautiful traffic lights. I couldn't find a letter size bigger than this one. I said no! Absolutely not! I've got maybe 2018 cabs in Delft, but it's no, no.

AUDIENCE: It's not more efficient than driving.

JAN NEDERVEEN: Oh, they love to drive my bus lanes like the fire department, who is pretty fast, but no way I want it. Because if they enter a huge intersection and there is a bus going at that intersection, I know that bus will make a left turn. Because every bus on that intersection will make a left turn. And that means all other directions can get green. I don't know where that cab is going. So you have to completely block the intersection for one cab. Yes?

AUDIENCE: Why is that London lets taxis use the bus lanes? Are you familiar with that?

JAN NEDERVEEN: In London?

AUDIENCE: Yeah.

JAN NEDERVEEN: Yeah, maybe they block out all the other directions to give them the priority. And that will seriously harm all other modes of transport. It would harm car traffic and bike traffic. And we like to give priority to the buses with many people, but this is one taxi who have maybe one or two people inside it. That's not worth the effort. And it's a big risk to give him green and see what is happening.

Time priority. Peter already taught some things but that is what we do. You have special traffic lights, the [INAUDIBLE] traffic lights that's in the picture on the black/white border column. That's showing if you get green to left or to right or straight through for our bus.

And we have two kinds of detection. The first one is the intelligent one. So every vehicle says, I'm bus 24 vehicle number, so I should be here 20 minutes past five. So it's also telling it's time per table. And then we know, OK, you're one minute early, we will not give you priority That's the expensive one.

And the other one, that's a simple detection. Some vehicle is crossing a detector and notice, oh, this is a vehicle. I even don't know which bus it is. Even if you are a car you are detected and then you get some priority. That's the way of detection.

The top one is the best. So if we are in charge and it's our traffic light, we put in the intelligent one. If somebody is else doing the design, a regional government, sometimes you get the cheap one. Especially in the Delft University, top technology campus, the cheap one is installed.

Traffic light priority. Peter showed you a bus stop close to an intersection. Well, here's an example of a traffic light priority at a huge intersection. The term has to make a turn to the left. And what we do, we put in to two lines.

The first one is the location where the light rail, the [AUDIO OUT] for handling the passengers. I don't know how long that will take. And I don't want to stop all the other traffic because he is still handling passengers. If I do so, I get many letters from people waiting for nothing. So there's a second stop line, go straightforward on the intersection.

And then the light rail will [INAUDIBLE], hey, hello I'm here. Please can you give me what priority. And what this system does, he will not break off all the other signals. He says, oh, I've finished my phase, I then add in the phase with public transport, and then I continue with all the rest. I don't take out any time from the others, just merge in a priority for the traffic lights.

So this intersection is four phases so there are four chances to give him priority. So the waiting time is not a full cycle but only a quarter of it. That's how it works. This is that same intersection from the air. So it's a huge one, the biggest intersection we have in the built up area.

We have total detection all directions. Also the bicycles are detected. We have a detector. We don't use an eight. We've got a good detector. So we detect bikes. There also is a button if you like, but most of the time you're already detected.

We have a fixed sequence which groups go together. And what the sequence is? We have

defined a maximum green time that might be possible for each direction. And we stop giving green if we achieve a free flow situation. So I don't give green to free flow traffic.

And if the traffic's still congested after a certain amount of time we say, OK, now it's enough, now the others have to go. You have bus priority and light rail priority and fire truck priority. And we don't build intersections in Delft. We have a traffic light sequence of 120 seconds. That's the max.

So if the area is congested, the maximum cycle time is 1 minute and 20 seconds. And my [INAUDIBLE] if you look at our intersections, I'm trying to bring back the cycle time for as many intersections back to 90 seconds. And they did and for most intersections it worked. And it was a huge benefit for everybody. The maximum waiting time is reduced 30 seconds.

So if you missed going first 30 seconds, you're simply reducing the cycle time. You can also do it physically, make your intersections smaller. That's a huge benefit for the cycling time. And we noticed some intersections were pretty sharp, 90 seconds.

People get used to it so they didn't miss the first second of green. They were green, [INAUDIBLE], driving. So we could handle the same number of cars in a shorter green time.

A special one was the fire truck priority. The fire department has a depot exactly at that intersection. And they've got a beautiful red button. So if I press that red button, the intersection will stand in a way that the order directions are blocked that the fire department has to cross. So if you're not in the direction of a fire that the fire department has to go, you still get green because it is an intelligence red button.

So I press this button showing I have a fire in Delft North, and they will follow this route. Then that route will get green for the fire truck on the time we think he will be there. So while driving North, he continues detected, and the traffic lights are switched that way that we will get green. We do not block completely all these intersections for the fire trucks since he knows if we do so, we might cause a traffic jam because all the directions are blocked.

And that's the way how we get there. And we also detect if you pressed the right button and if we make a system that is going perfectly to the north. Maybe he didn't use that route but in certain times the system arguments, OK, I did the measuring so somebody has disappeared or gone somewhere else. Well let's switch back to normal. That's the fire priority we've got in Delft.

And it was very important when we built the railroad tunnel because the whole area was under construction with all the traffic lights kept to that priority. And that's the example from Delft. Thank you.

PETER FURTH: My new graphic. Yeah. So I told you that [AUDIO OUT] are green extension, which is great if you've got a far side stop and you can predict events. Early green, which is a little more limited but we need more flexibility. So like what Jan was describing there, they have these four phases in the cycle. To make it simple, let's just say we have east and west left and then east and west through and then north and south left and north and south through, phase one, two, three, four, and the tram, in this case, because it actually conflicts with all of them.

So the normal thinking of a traffic engineer would be, OK, and then we'll have a tram phase here. And now that's the cycle. But the Delft thinking is, we'll put a tram phase here, we'll put a tram phase here, we'll put a tram phase here, and a tram phase here. And if there's no tram, well we skip it. And if there is a tram, then the tram gets to go. So the tram never has to wait long.

So that's part of the, if we can get a man on the moon, we can turn the light green. So let me say something. I'll leave the rest of these plans. They have some details there. But let me tell you something about D Street and the Silver Line, OK? So the Waterfront Silver Line--

AUDIENCE: [INAUDIBLE]

PETER FURTH: Huh?

AUDIENCE: Do you have a video?

PETER FURTH: No, no. I'm not going to do the video. This is something new. How many of you are familiar with the Silver Line that goes to and from the airport? Yeah. D street is where, if you're going toward the airport, it comes out of the tunnel and then it stops at a red light.

And while you're waiting at the red light you can watch, and there's no cars going by. And you think, why is the light red? So on a map here's Congress Street. This is D Street. And then this is Silver Line Way.

So the traffic engineers are concerned that that's a short distance. And if they turn the light red for Congress Street, two bad things can happen. One is spill back. Traffic comes to here, oh,

the light is red, and now queue spills back, and it hurts the capacity.

And the second one is starvation. The light turns green here for northbound traffic, but the light is still red here. So cars start to go, but nobody can go because they're stuck. It's starved. So they don't want to close D Street while either of those things can happen.

So there is a cycle; it's a 120 second cycle. This time I'll draw the cycle in a circle. And they've decided here is the time in the cycle the bus can go. So that's why you just wait, you just wait. You arrive and you just wait until your time in the cycle.

So I just recently had some students study it in my advanced traffic control class. We actually took the whole class there for a field trip during morning peak hour because I had to see it myself. Is it really the disaster people talk about? It is not a traffic disaster. It is a transit disaster because the frequency the Silver Line, it's about one bus every two minutes, and they go in both directions.

So that means in a 120 second cycle, if they're perfectly on schedule, you'd have one bus at most one per direction. Of course they're not. So often you've got two buses, sometimes three buses waiting to go. And they wait, and they wait, and they wait, and they wait, and most of the time there is no conflicting traffic.

So my students learn how to do traffic simulations. There's some standard packages for that. They learn how to program their own traffic control. And they said, let's try just all out aggressive priority.

When we detect the bus, we just stop the street, let the bus go through. The bus only needs like 14 seconds, and then it goes back. And I can hear people saying, oh, but sometimes you've got to serve two or three buses. Yeah, when buses have to wait two minutes till their turn comes. But when they don't have to wait, you're never going to be serving more than one at a time.

And it only takes 15 seconds. We put that into the simulation to see, OK, how's it going to affect cars? How is it going to affect buses? Average delay for bus goes from 50 seconds down to four seconds.

Why four? That's only because if we do turn the light green for a bus, for the cars a minimum 20 second before the next bus. So there's a bus in one direction, the bus coming in the other direction 15 seconds later might have to wait a few seconds. So delay for bus goes down

almost zero. Delay for cars also goes down because the system they have now will stop the cars even when there's no bus. I don't know why.

And there's another thing about the system they have now that is not so intelligent. So the main message I want to get across is the old way I said is if we can put a man on the moon, we can get the light to turn green for the bus. That is if you use intelligent tactics, we can almost always reduce the delay for a bus down to near zero without really increasing the delay for cars. Bus only needs a few seconds to get through. They just need a few seconds at the right time.

Just rearrange the time a little bit. Give the bus the green when it needs. And what's in the way is this inflexible paradigm of fixed time control with a fixed cycle, long fixed cycles. Like Jan was saying, the long cycles are killer. If you have short cycles, the delay won't be too much.

So what Europe has done with transit priority is just amazing. Some of the things that I saw there, it just blew my mind how they're just giving priority to transit. They just do it. They just do it. They just do it.

There was an intersection in The Hague, right near Delft, where a tram line was intersecting the main ring road. Lots of traffic and big traffic jams. And my friends are telling me, oh yeah, big traffic jams here. How come? Well because we have to give the tram priority.

It's like you just have to. You drink coffee in the morning, and you give the tram priority. Who would ever think of making the tram wait at a red light? No! You have to give the tram priority. And there are lots of trams. And it's causing a big traffic jam.

So what's the solution? Spend a lot of money, grade separation, and now the tram has absolutely zero delay. And the cars go underneath, and they have no delay either, and everybody's happy. But it started because of this attitude that we just give priority to our important transit lines. So if we have that attitude, we can do it a lot better than what we're doing.