



PONTIFICIA
UNIVERSIDAD
CATÓLICA
DE CHILE



Connected and automated vehicles? Let's start with buses, the low hanging fruit

Juan Carlos Muñoz  @JuanCaMunozA

Dept. of Transport Engineering and Logistics

Pontificia Universidad Católica de Chile

What do we understand by automated vehicles?



What do we understand by connected vehicles?



What can we achieve with automated and controlled vehicles....

Safety

Capacity flow

Useful travel time

The problems are very important

Empty miles

Increased traveled miles

Auto-dependency

Impact in neighborhoods

Shouldn't we start with the transport mode we need to encourage?

Autonomous bikes



Autonomous bikes

Autonomous public transport

Autonomous buses? Connected buses?



Autonomous buses? Connected buses?

Does it make sense?

Where are the benefits?

Is it really possible?



Autonomous public transport has been around for decades



Modern Metro systems are **driverless** or have drivers that do not drive

So we are going straight from driverless Metro to driverless cars.

This innovation seems to be ignoring buses.

If we consider automation in buses....

which should be the first step for buses towards automation?

Driverless Metro seem feasible because of rails and a fully segregated way. Buses lack rails

But...



The conflicts with other vehicles and pedestrians for a bus in a **corridor** are much easier to predict than for a car moving in regular traffic

Thus, automatizing buses should start with buses operating in corridors.

According to www.brtdata.org there are 452 BRT corridors in 205 cities worldwide, serving more than 34 million passengers per day.

The benefits from automatizing for these passengers would be huge.

A centralized coordinating control can become the rails for these buses and much more

Some potential **benefits** of automated and controlled operation

Smoother bus docking at stations

Safety

Traffic signal priority

Eco-driving

Schedules (waiting times and transfers)

Headway regularity

What do people **seek** when travelling
in public transport?



Fast



Low waits



Comfortable



Reliable

How can we **achieve** these attributes?



Fast

**DECREASE
TRAVEL TIME**

INCREASE SPEED



Low waits

**INCREASE
FREQUENCY**

**INCREASE FLEET
OR
INCREASE SPEED**



Comfortable

**INCREASE
TRANSPORT CAPACITY**

**INCREASE FLEET, VEHICLE SIZE
OR
INCREASE SPEED**



Reliable

**DECREASE
TRAVEL TIME VARIABILITY**

REGULAR HEADWAYS

How can we **achieve** these attributes?



Fast



Low waits



Comfortable



Reliable

INCREASE SPEED!

AND THEN MAYBE IF WE
HAVE SPARE TIME FOCUS
ON REGULAR HEADWAYS....

How can we **achieve** these attributes?



Fast



Low waits



Comfortable



Reliable

**INCREASE SPEED
AND
REGULAR HEADWAYS!**

Vehicles in public transport systems
behave like magnets....

Regular intervals is an **unstable** equilibrium



Any perturbation and the **equilibrium is lost**... all around the world.

Bus bunching... found in London



Bus bunching... found in **Beijing**



Bus bunching... found in **Santiago**



Today we will address **three questions**

- 1 Why does bus bunching happen?
- 2 What are the impacts?
- 3 Does it have a solution?

Why does **bus bunching** happen?

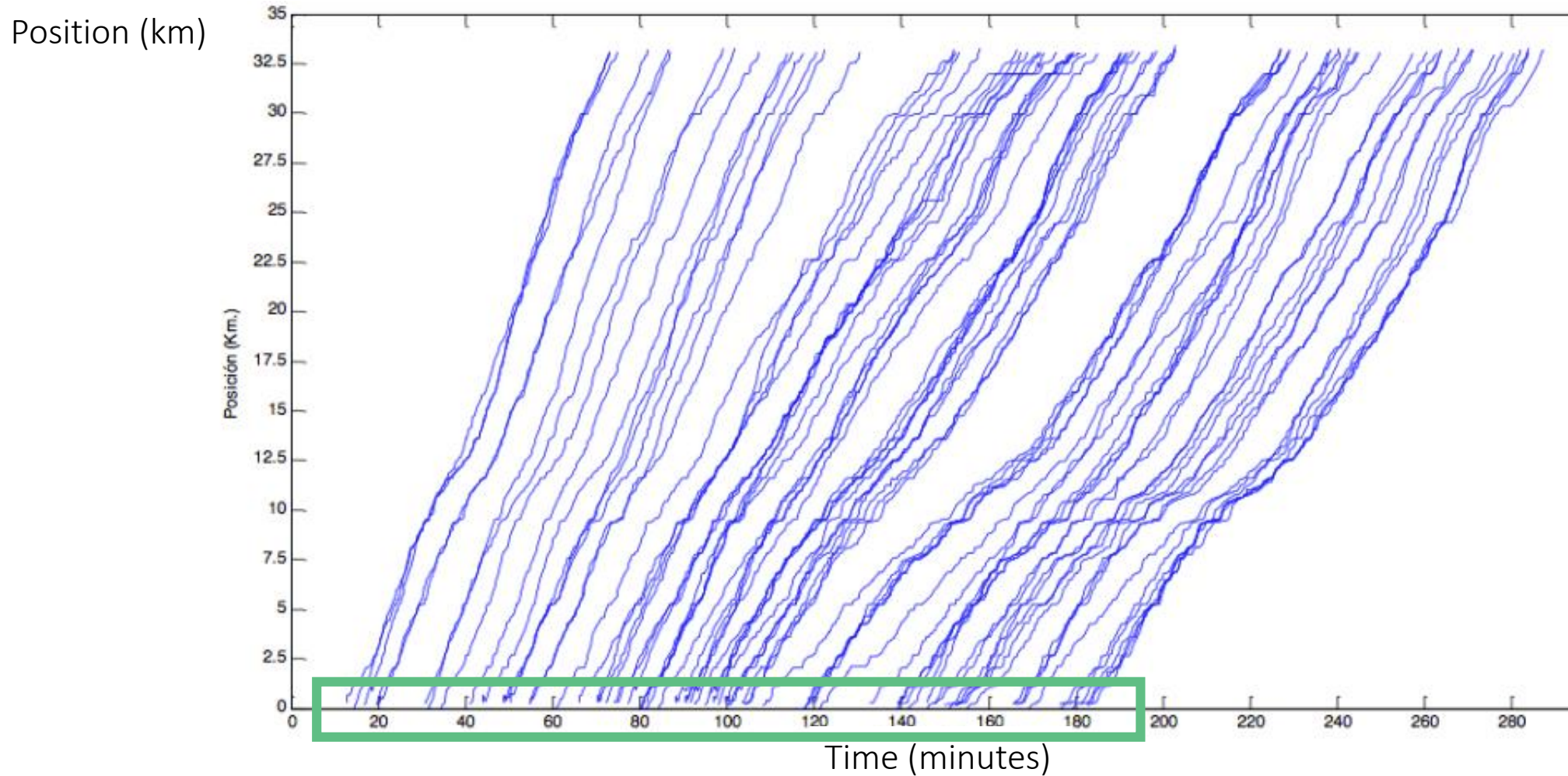
Lack of dispatch **strategy**

Speed variability

Travel time variability

Dwell time variability

Why does **bus bunching** happen?



Why does **bus bunching** happen?

Dispatch strategy

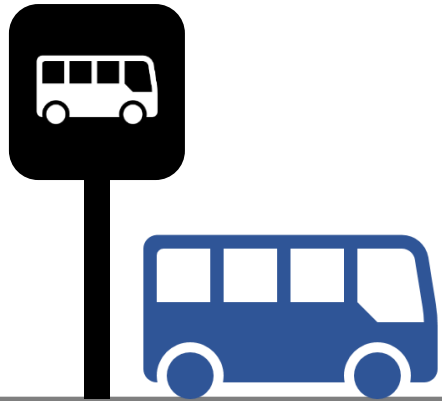
Speed variability

Travel time variability

Dwell time variability

Why does **bus bunching** happen?

Travel time variability



Congestion

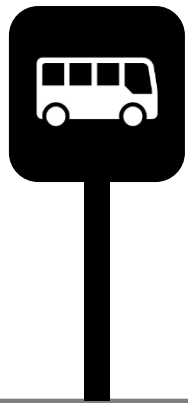


Traffic lights

Driver heterogeneity

Why does **bus bunching** happen?

Dwell time variability



Stochastic passenger arrivals
at each stop

Today we will address **three questions**

- 1 Why does bus bunching happen?
- 2 What are the impacts?
- 3 Does it have a solution?

What are the **impacts**?

Impacts are various, affecting:



Users



Operators

What are the **impacts**?

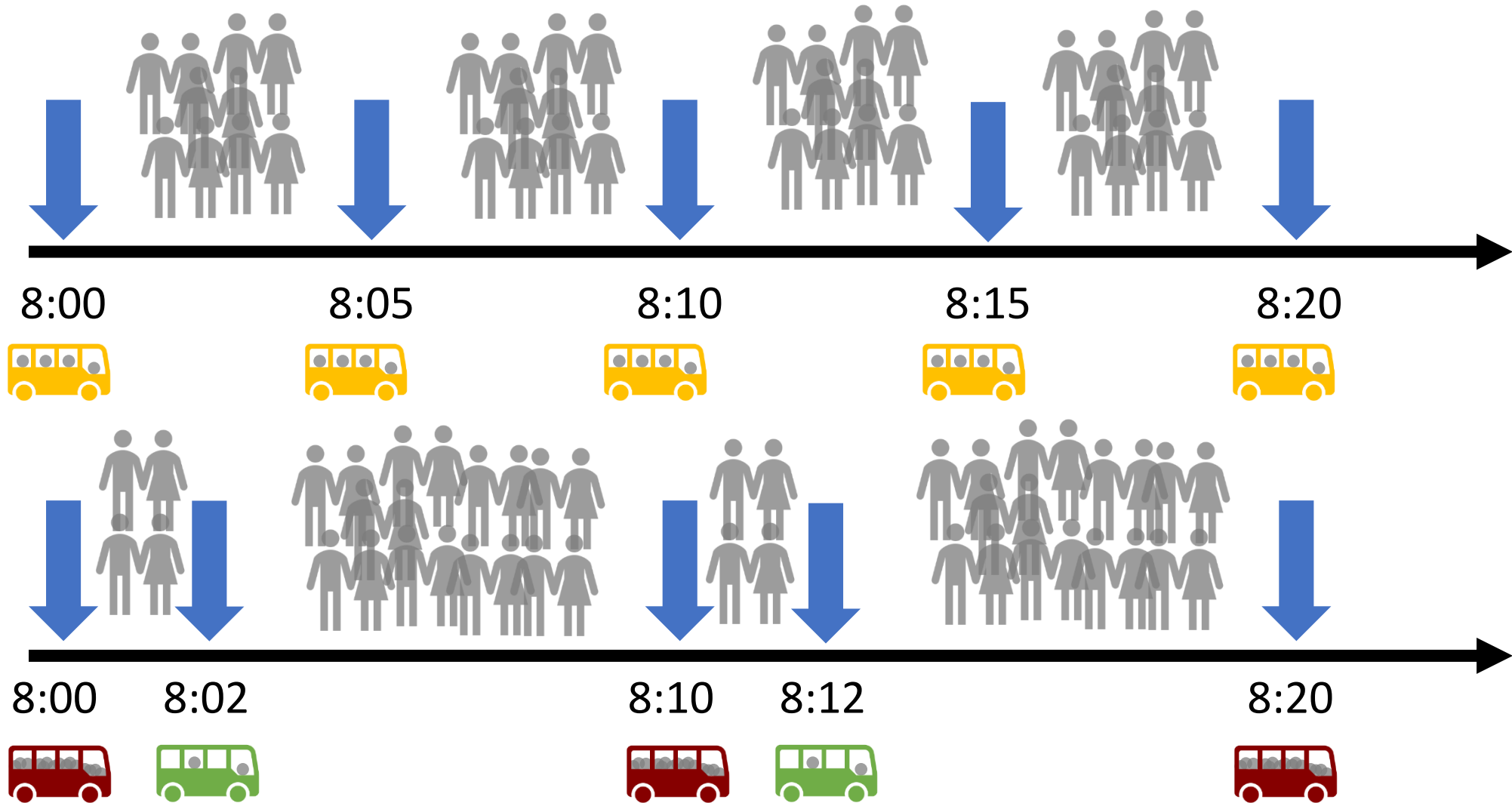
Consider the following bus service

5 min average headway

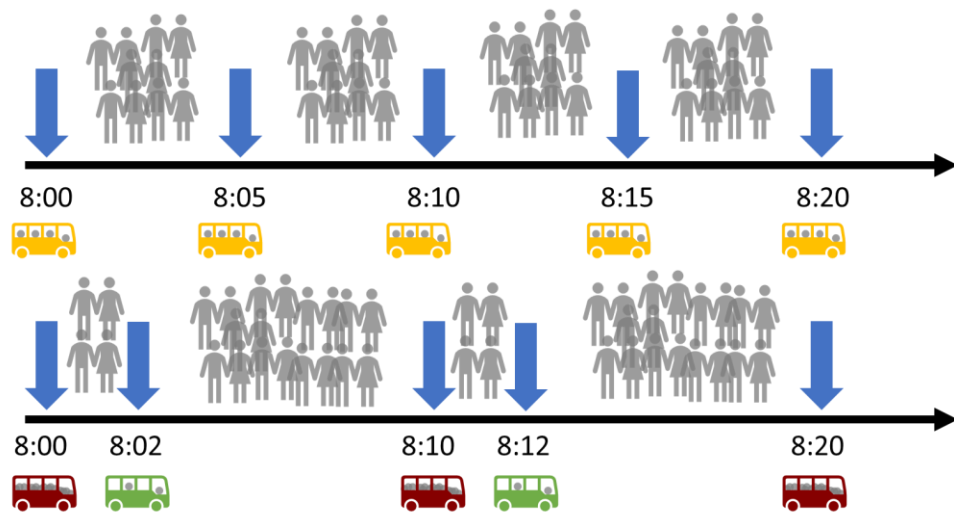
80-pax capacity buses

An average demand of **50 pax/bus**

What are the **impacts**?



What are the **impacts**?



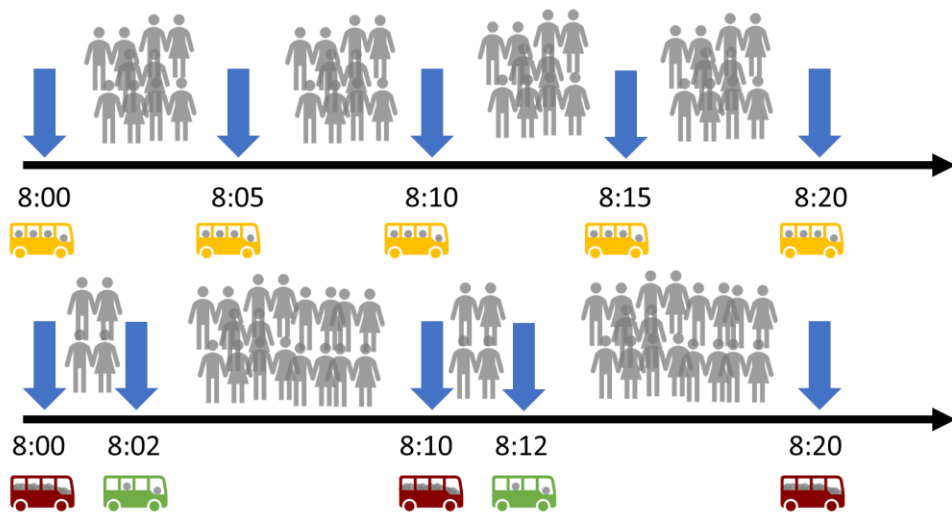
Waiting times grow

One minute of waiting is perceived as two or three minutes of in-vehicle time

Waiting times variability grow

Leads to earlier departures for users

What are the **impacts**?



Average crowdedness grow

Longer waiting times correlate with high occupancy

More users suffer high occupancy

Users tend to remember the worst experiences

What are the **impacts**?



Dwell times grow

Boarding and alighting is slow creating friction that damages the experience

Speed drops.... And capacity drops

Cycle times variability grows

Operators need extra fleet and drivers due to variable cycle times

Cities **need** its citizens to use public transport

This is easier if citizens like their public transport,
if they are **satisfied** with its use

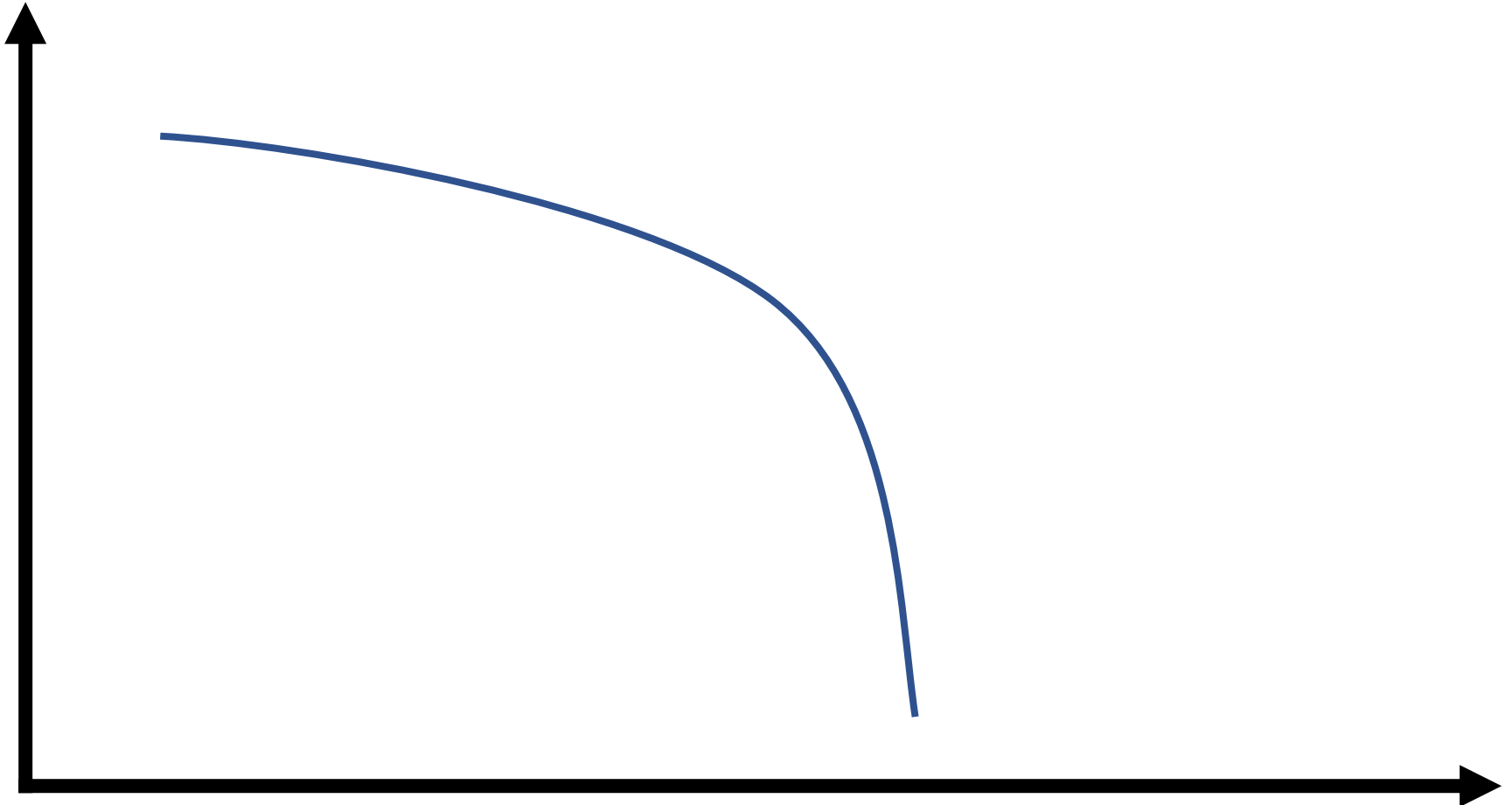
Cities need its citizens to use public transport

This is easier if citizens like their public transport,
if they are satisfied with its use

How does reliability affect user satisfaction?

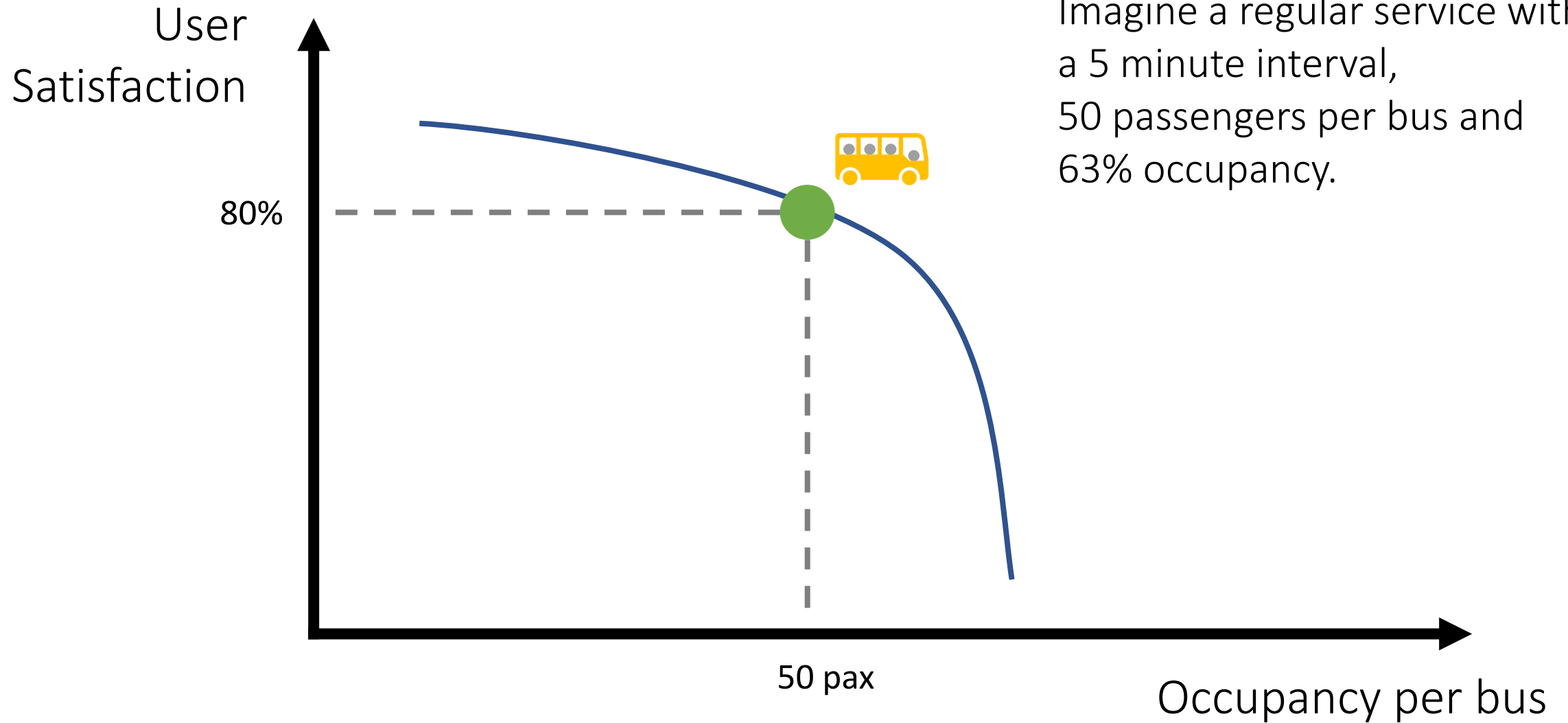
What are the **impacts**?

User
Satisfaction

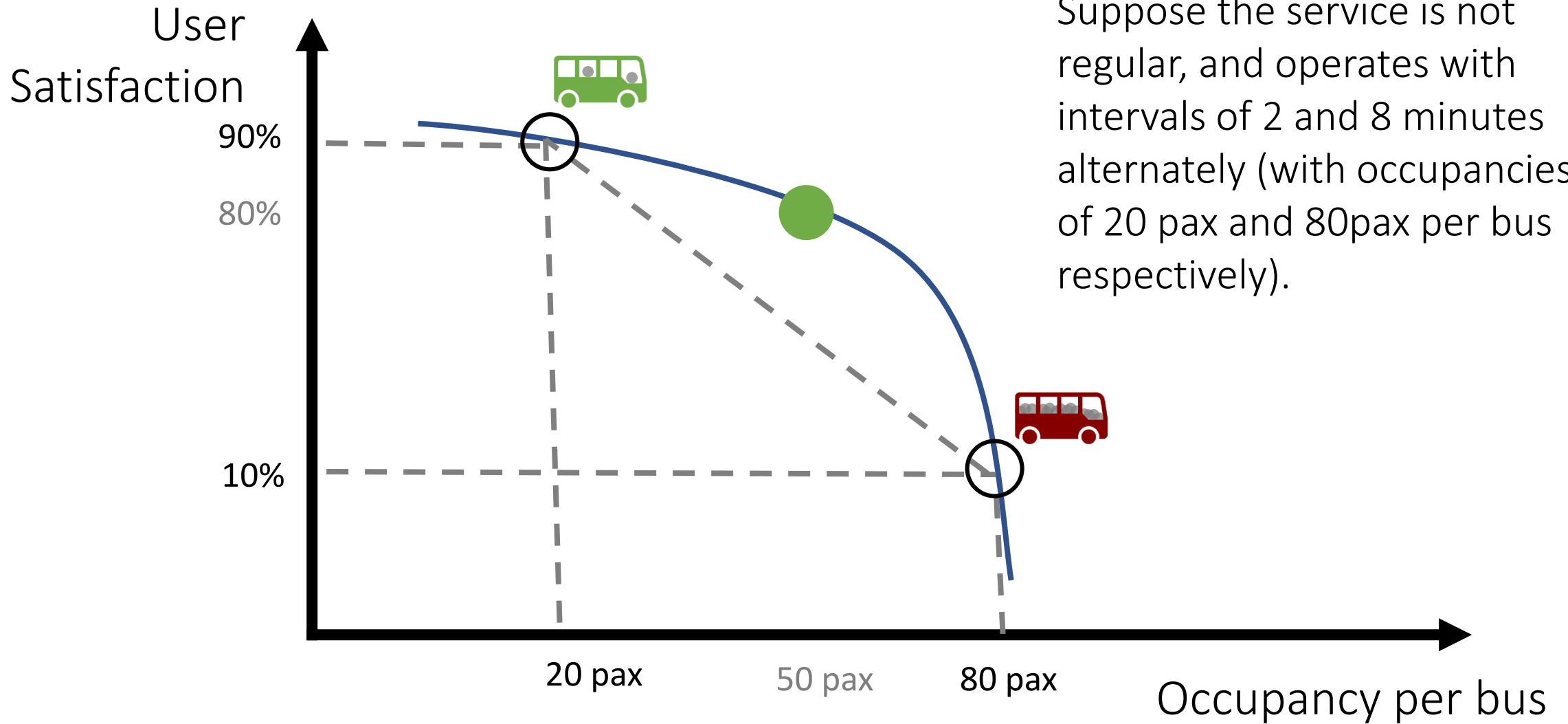


Occupancy per bus

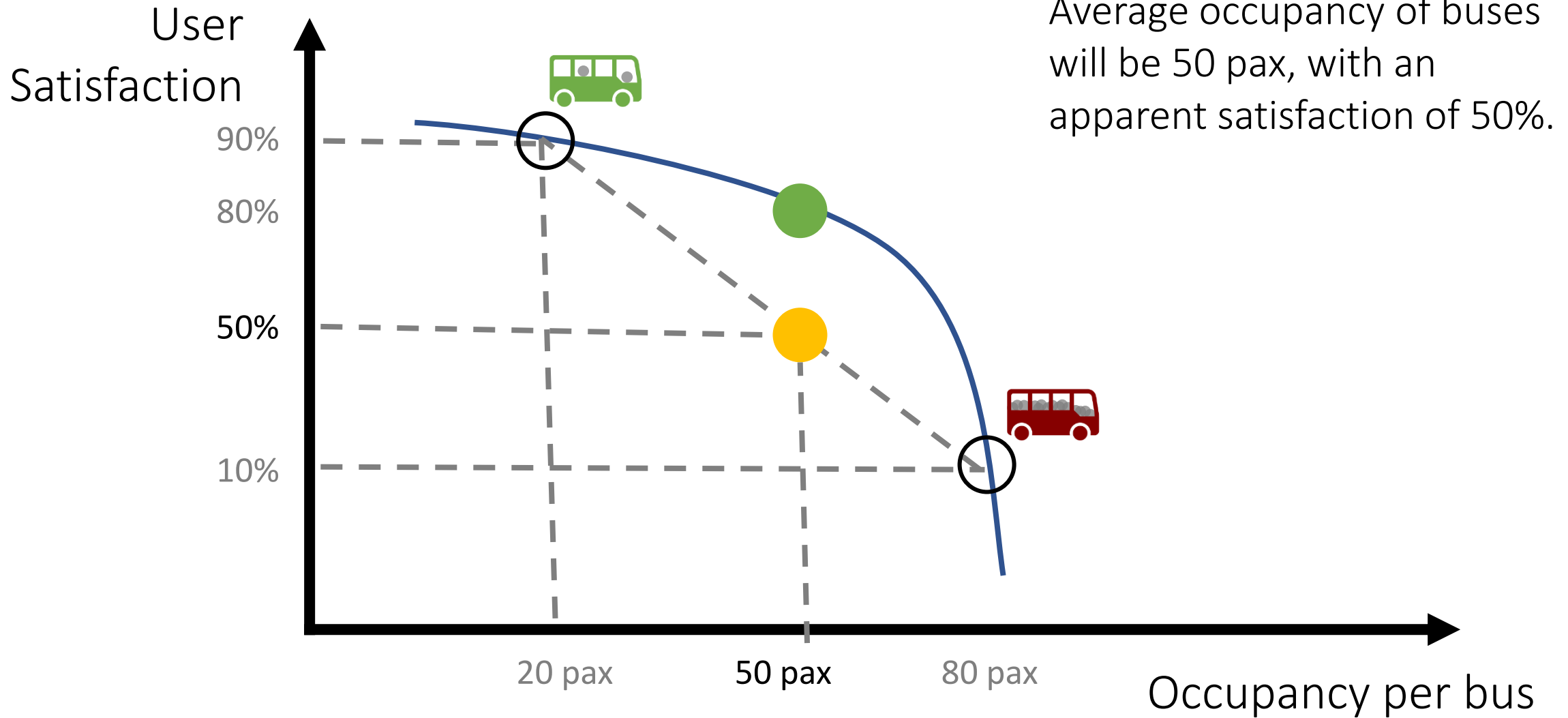
What are the **impacts**?



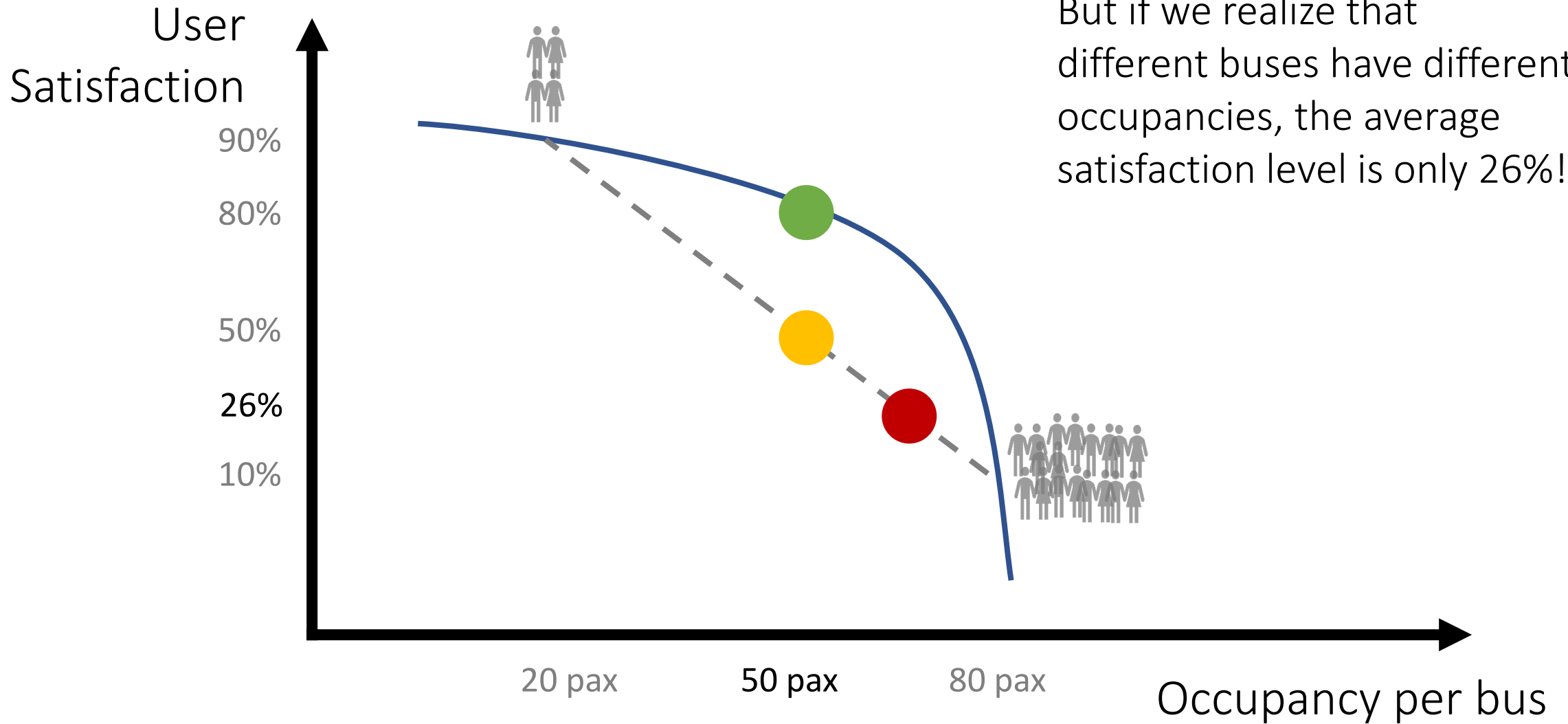
What are the **impacts**?



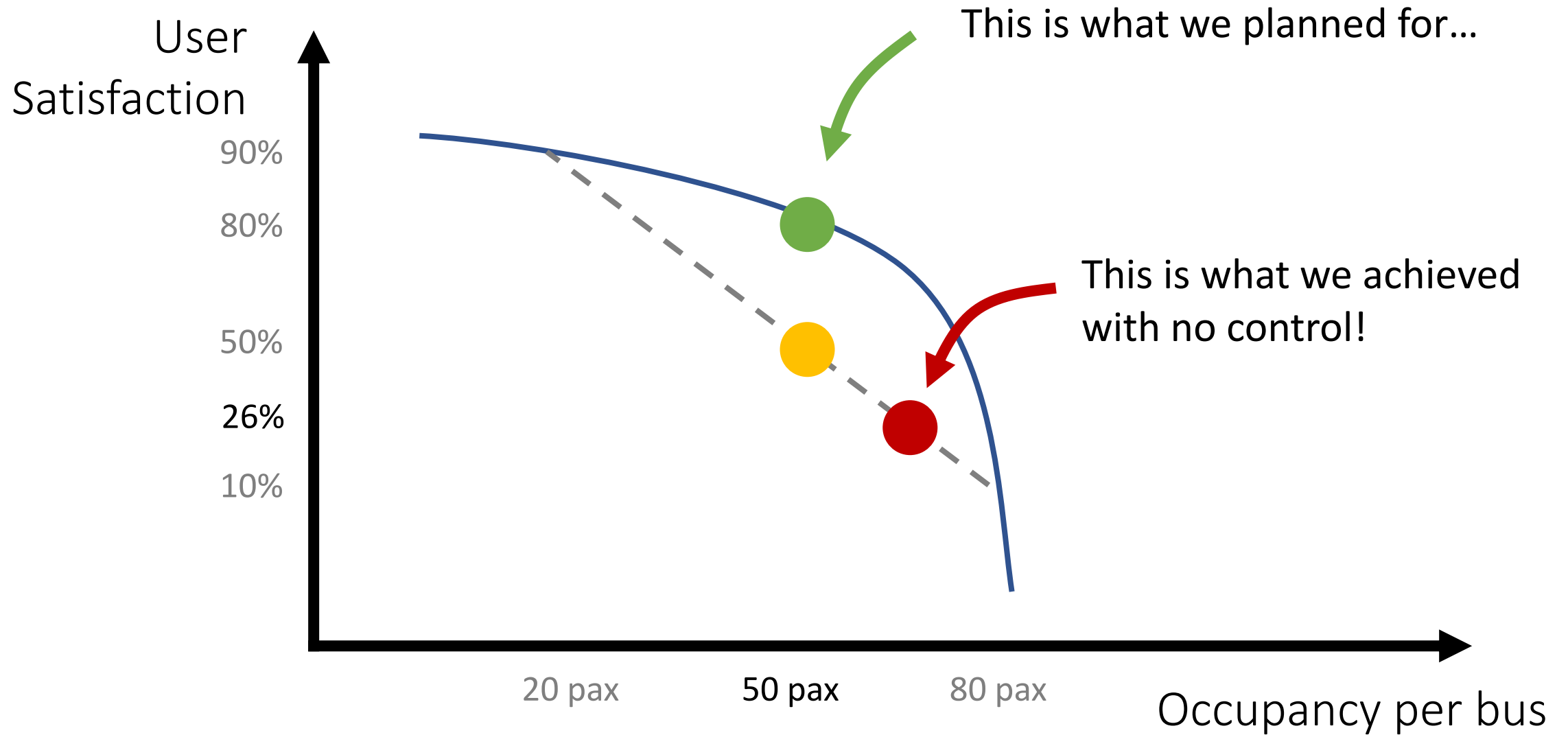
What are the **impacts**?



What are the **impacts**?



What are the **impacts**?



How can we **achieve** these attributes?



Fast



Low waits



Comfortable



Reliable

I N C R E A S E S P E E D

A N D

R E G U L A R H E A D W A Y S !

Today we will address **three questions**

- 1 Why does bus bunching happen?
- 2 What are the impacts?
- 3 Does it have a solution?

Does it have a **solution**?

Yes!

Dedicated infrastructure

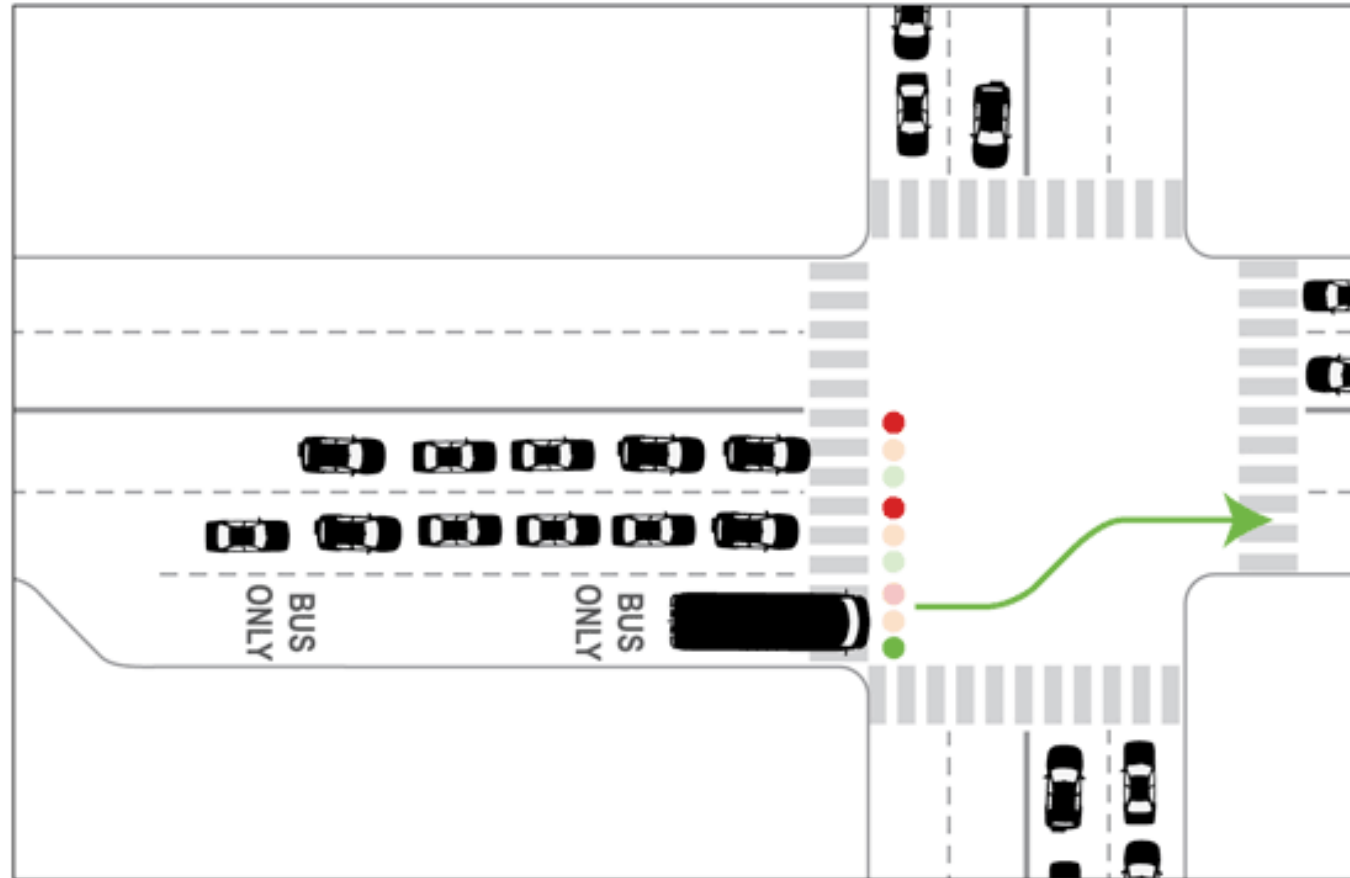
Transit signal priority

Real-time control at dispatching
and along the route

Does it have a **solution**?



Does it have a **solution**?



Source: mto.gov.on.ca

Does it have a **solution**?

TransitUC



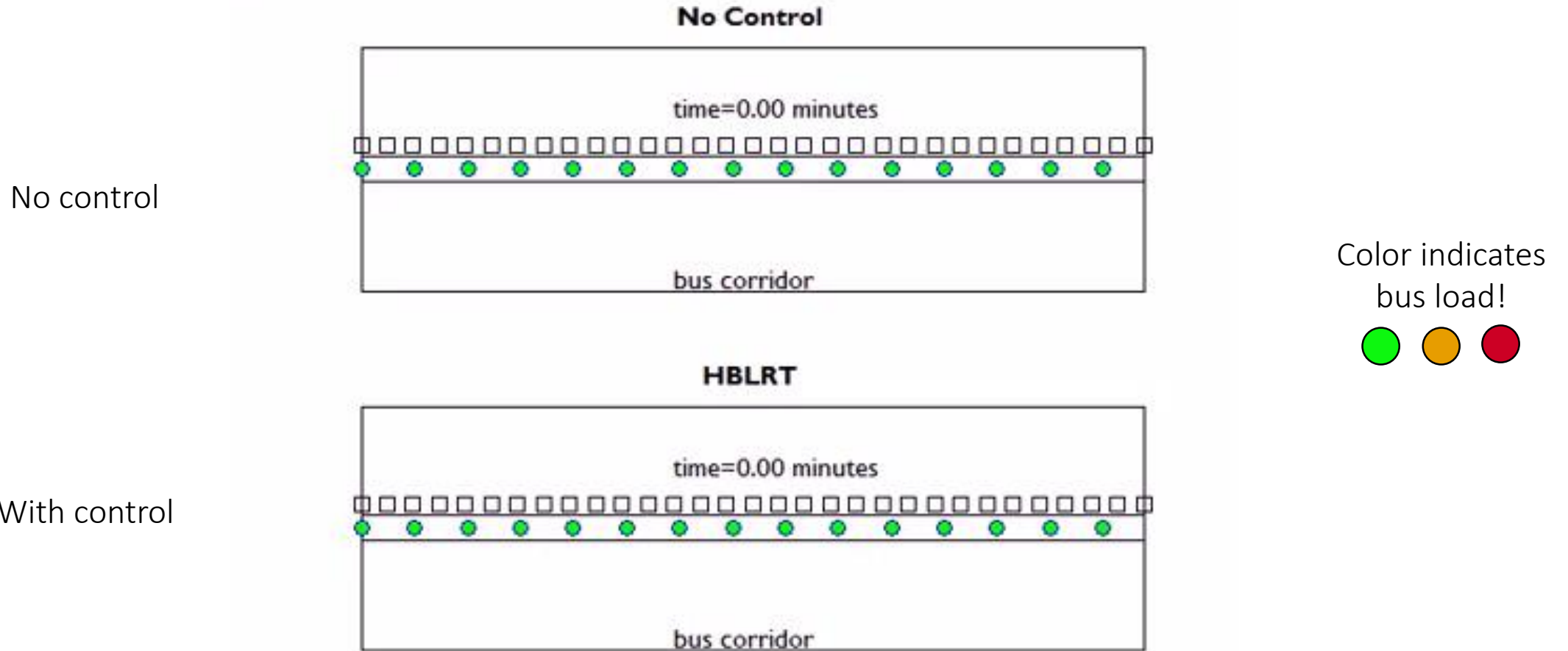
Ok!

Hold

Go faster
(if possible)

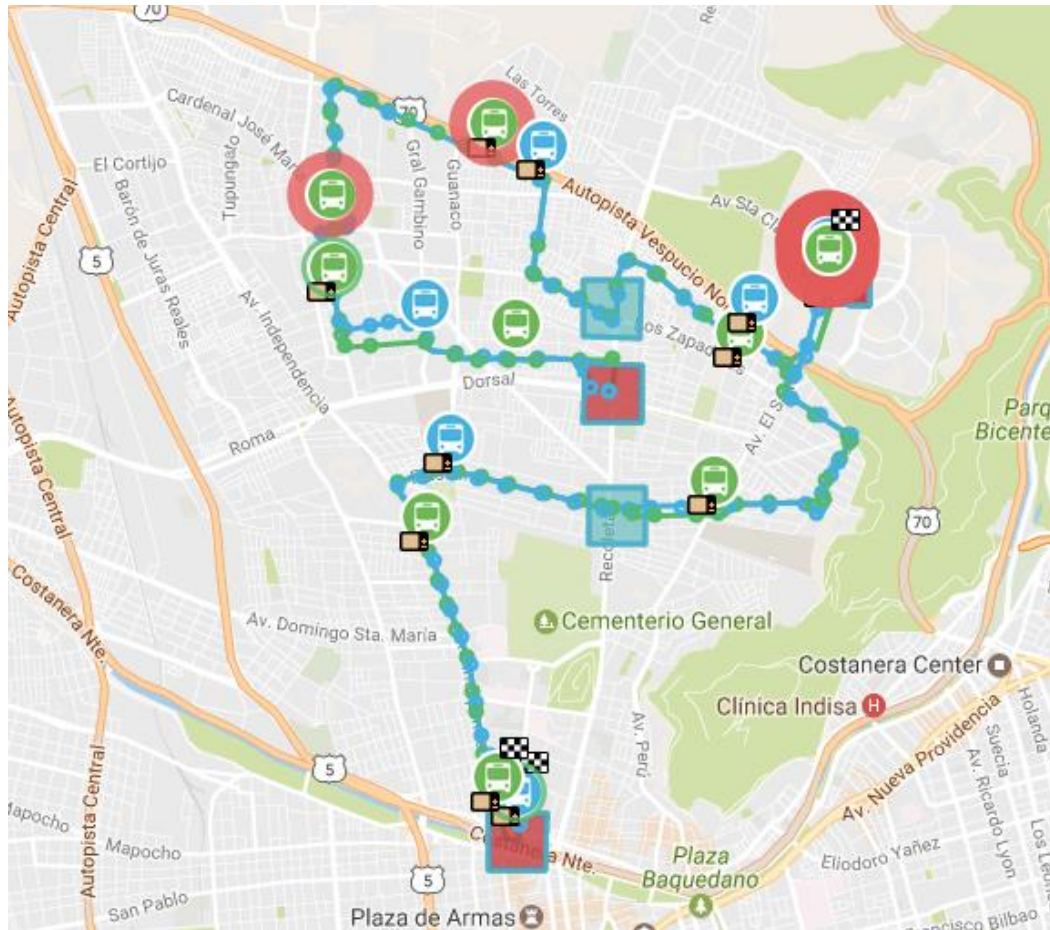
Slow down

Does it have a solution?



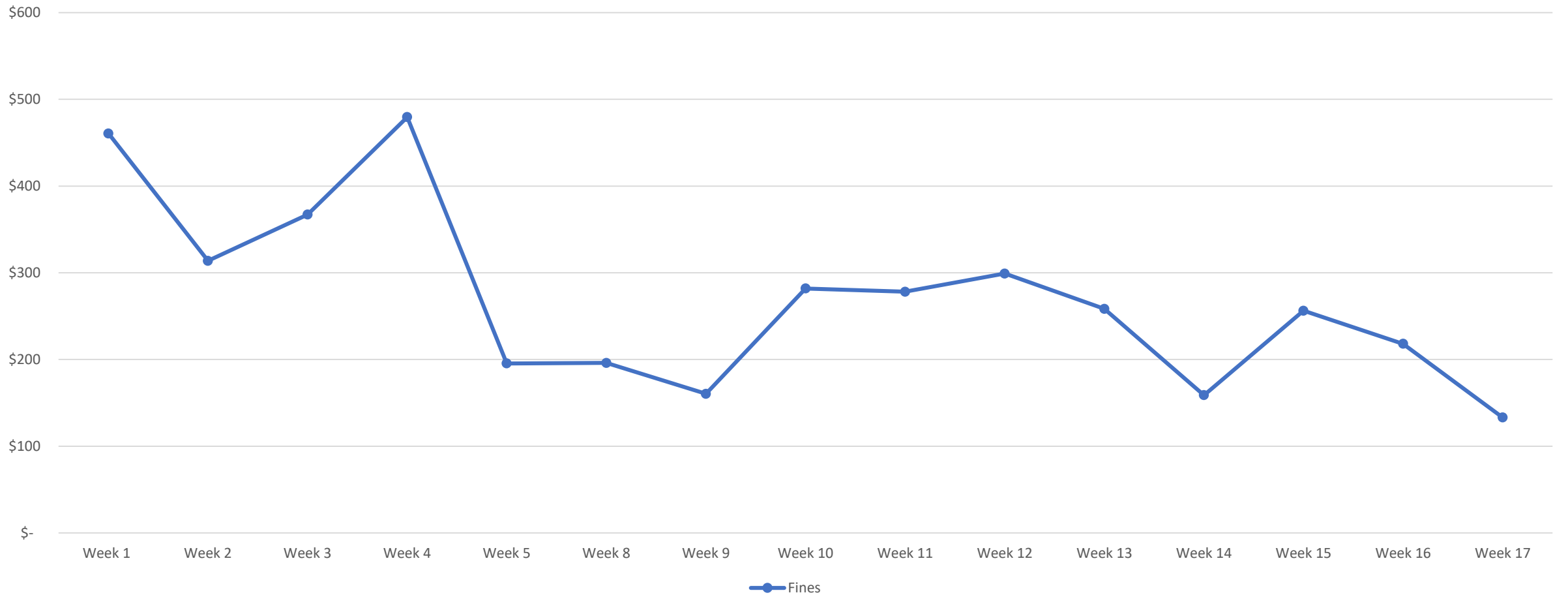
Does it have a solution?

TransitUC

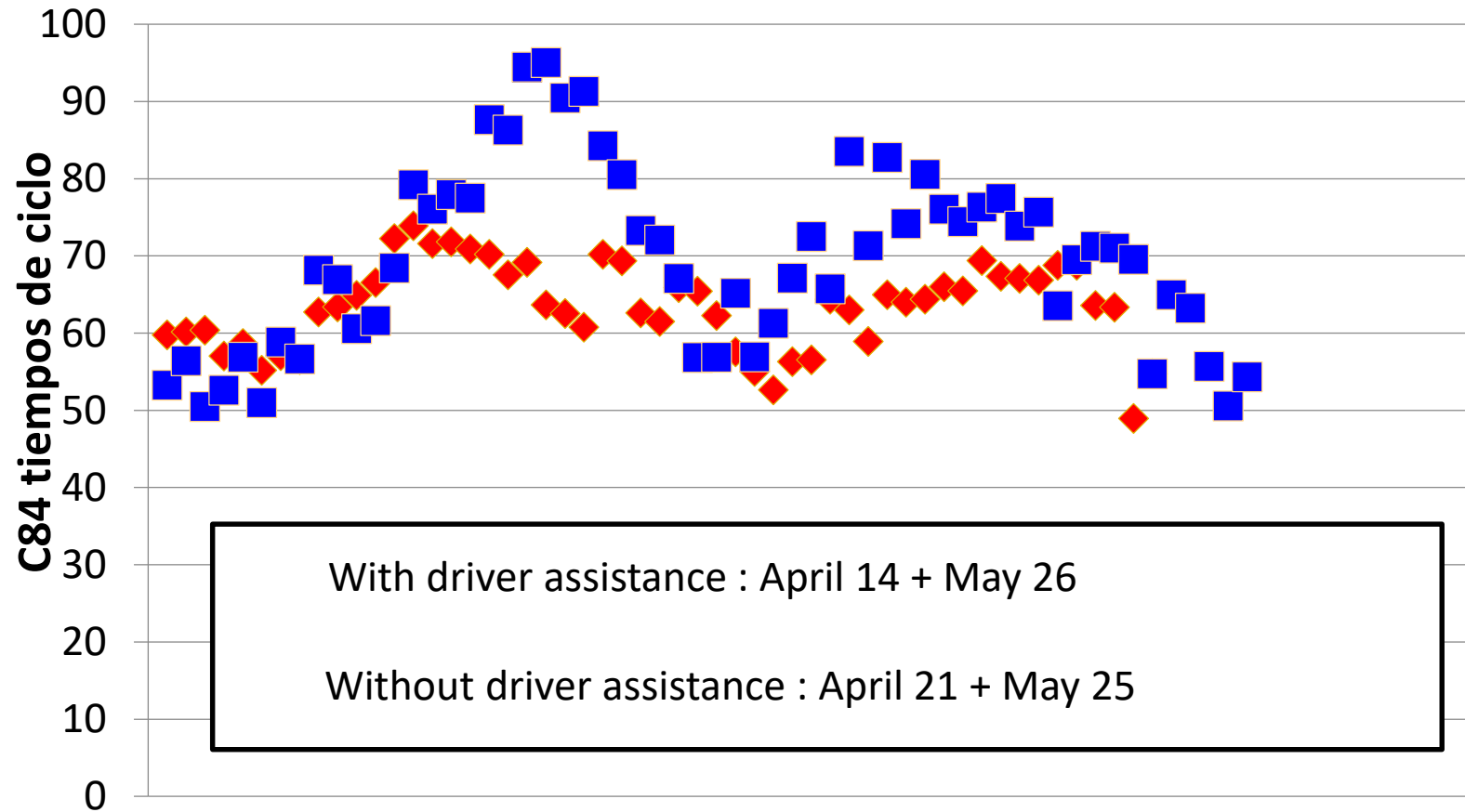


TransitUC in Transantiago

B14 + B22 Otubound Fines at Dispatching Point - 2017



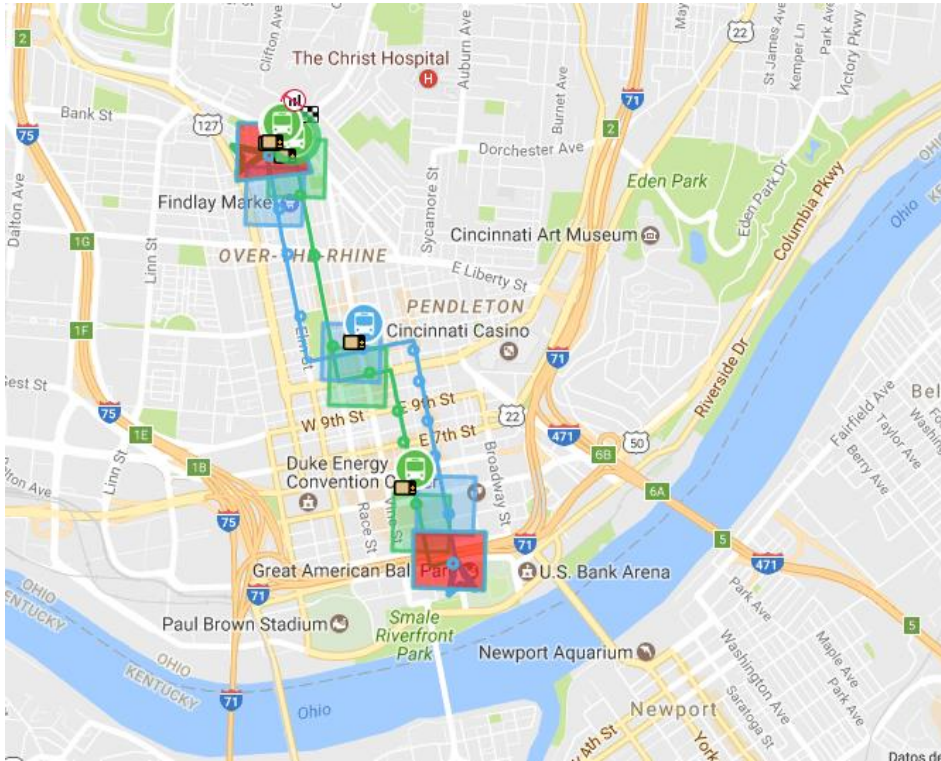
Transmilenio in Bogota



With driver assistance: cycle time = 63,4 min & Std Dev = 5,6 min

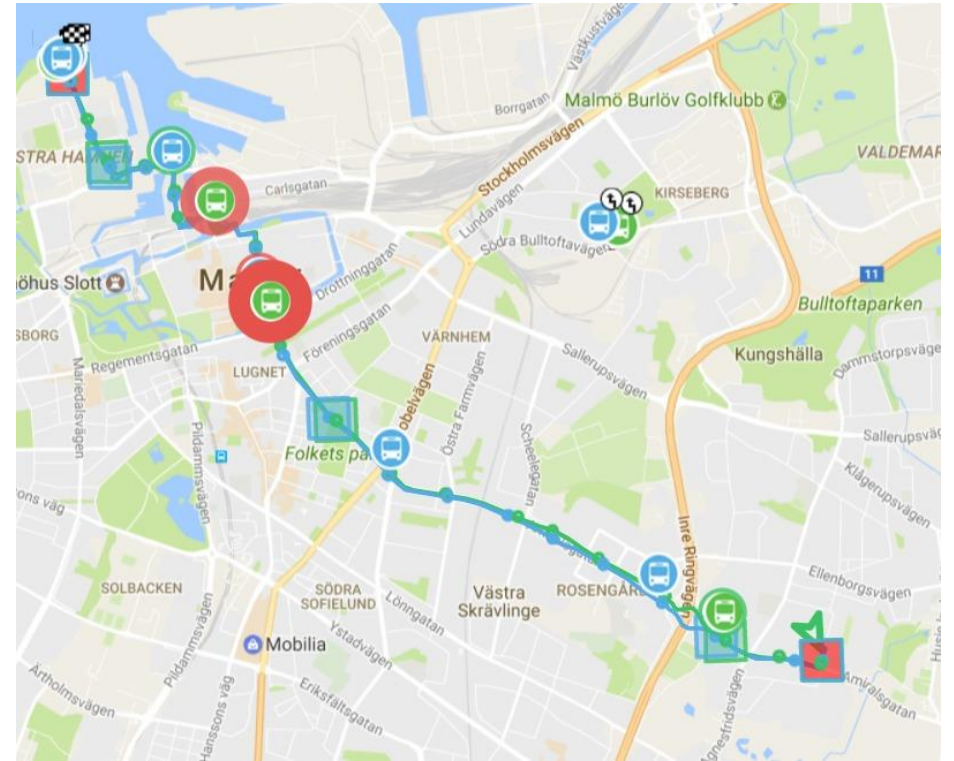
Without driver assistance: cycle time = 69,5 min & Std Dev = 11,8 min

Cincinnati Streetcar



5 streetcars
12 minute headway

Route 5 - Malmö BRT



16 BRT buses
5 minute headway

Open versus closed BRT

Some cities are operating **open BRT corridors** in which buses join and leave the corridor providing a direct trip for some journeys.

In such cases the driver should only drive while the bus is not in the corridor.

Notice that drivers are the critical link....

We have shown that (Phillips et al, 2014) it takes few drivers not obeying instructions systematically to severely damage the benefits of automated and coordinated control.

Martinez et al (2019) quantifies the impact of having drivers driving at heterogeneous speeds in headway variability.

In the path towards automatizing...put **buses operating in corridors** first!



PONTIFICIA
UNIVERSIDAD
CATÓLICA
DE CHILE



Connected and automated vehicles? Let's start with buses, the low hanging fruit

Juan Carlos Muñoz  @JuanCaMunozA

Dept. of Transport Engineering and Logistics

Pontificia Universidad Católica de Chile