What about Transit?
CAV's and Urban Mobility

Juan Carlos Muñoz
Dept. of Transport Engineering and Logistics
Pontificia Universidad Católica de Chile
¿Autonomous buses?
¿autonomous 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.

And driverless cars are already here....

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

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](http://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 driverless 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
- Low waits: Increase frequency
- Comfortable: Increase transport capacity
- Reliable: Decrease travel time variability
  
  - Increase fleet or increase speed
  - Increase fleet, vehicle size or increase speed
  - 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?

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
- Capacity of buses and stops
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?
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 grows.
- 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....

Cycle times variability grows
Operators need extra fleet and drivers due to variable cycle times
What are the **impacts**?

![Graph showing the relationship between User Satisfaction and Occupancy](image)

- **User Satisfaction** increases as **Occupancy** decreases.
Imagine a service that must be provided at a stop where passengers arrive at 10 passengers/min.

Let’s provide a 5 minute interval service. The bus arrives empty and should leave with 50 passengers each.

If bus capacity is 80 passengers then we get 63% occupancy.
What are the impacts?

User Satisfaction

80%

63%

Occupancy
What are the impacts?

Suppose the service is not regular, and operates with intervals of 2 and 8 minutes alternately (with occupancies of 25% and 100% respectively).

![Graph showing user satisfaction and occupancy relationship.](chart.png)
What are the impacts?

Average occupancy of buses will still be 63%, with an apparent satisfaction of 50%.
What are the impacts?

Average occupancy of perceived by users will be 85%, with a satisfaction level of only 26%!
What are the impacts?

This is what we planned for...

This is what we achieved with no control!
How can we achieve these attributes?

Fast  Low waits  Comfortable  Reliable

INCREASE SPEED AND REGULAR HEADWAYS!
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?
Does it have a solution?

No control

With control

Delgado et al, 2012

Color indicates bus load!
Does it have a solution?
TransitUC in Transantiago

B14 + B22 Otubound Fines at Dispatching Point - 2017

Fine Goal vs Fines
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.

In the path towards automatizing... put buses first!
What about Transit? CAV's and Urban Mobility

Juan Carlos Muñoz  @JuanCaMunozA

Dept. of Transport Engineering and Logistics
Pontificia Universidad Católica de Chile