# Bus control strategy application: case study of Santiago transit system

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Motivation

Proposed Headway Control Strategy

Simulation Results

Case Study Results

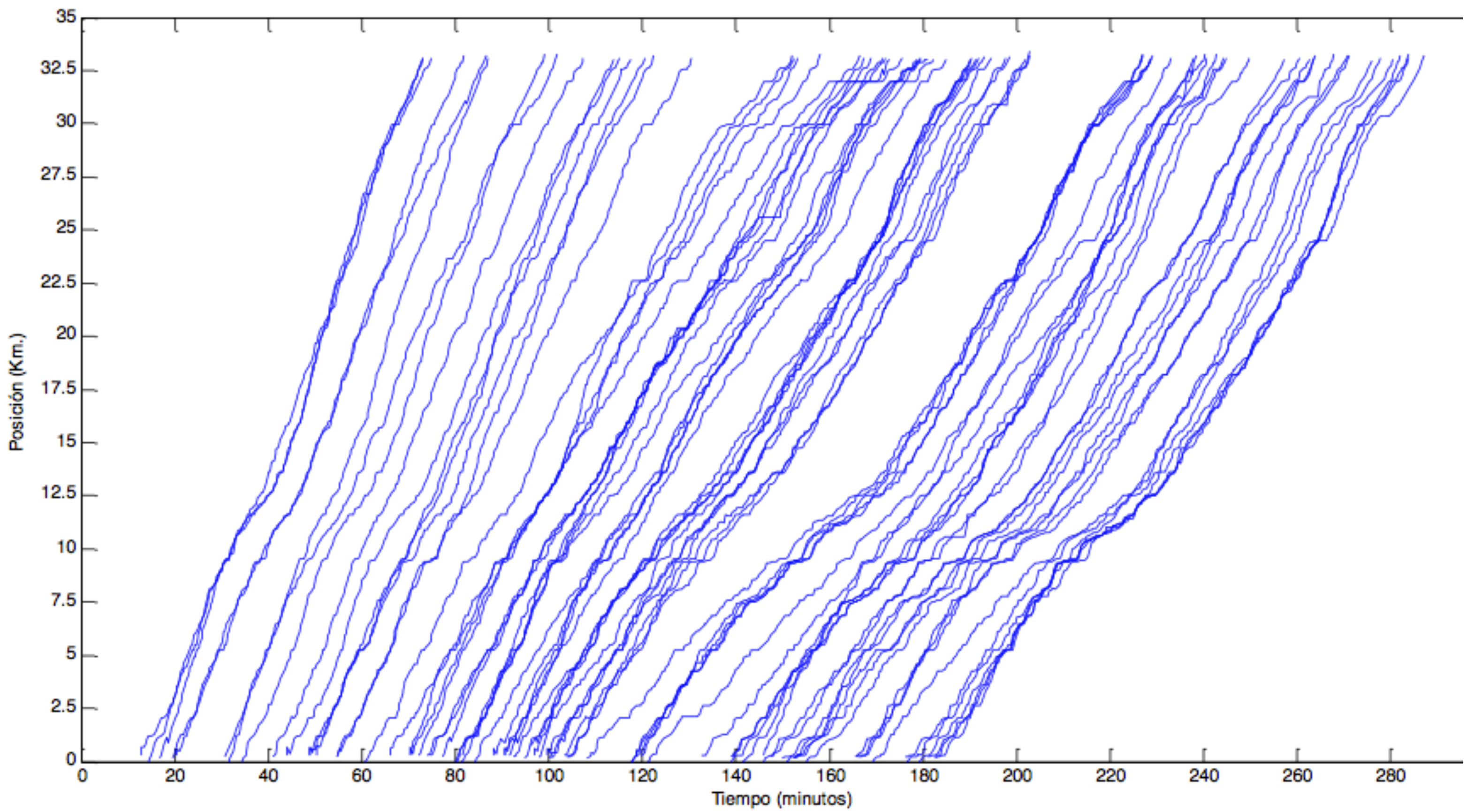
Conclusions

# Bus bunching

- **Santiago, Chile**

# Bus bunching

- **Trajectories: Time vs. Distance**



# Bus bunching is a challenging problem

- Increases average waiting times
- Reduces transit comfort and reliability
- Pushes transit agencies to increase the number of buses

**Solution: Control headways**

# Santiago Transit System (Transantiago)

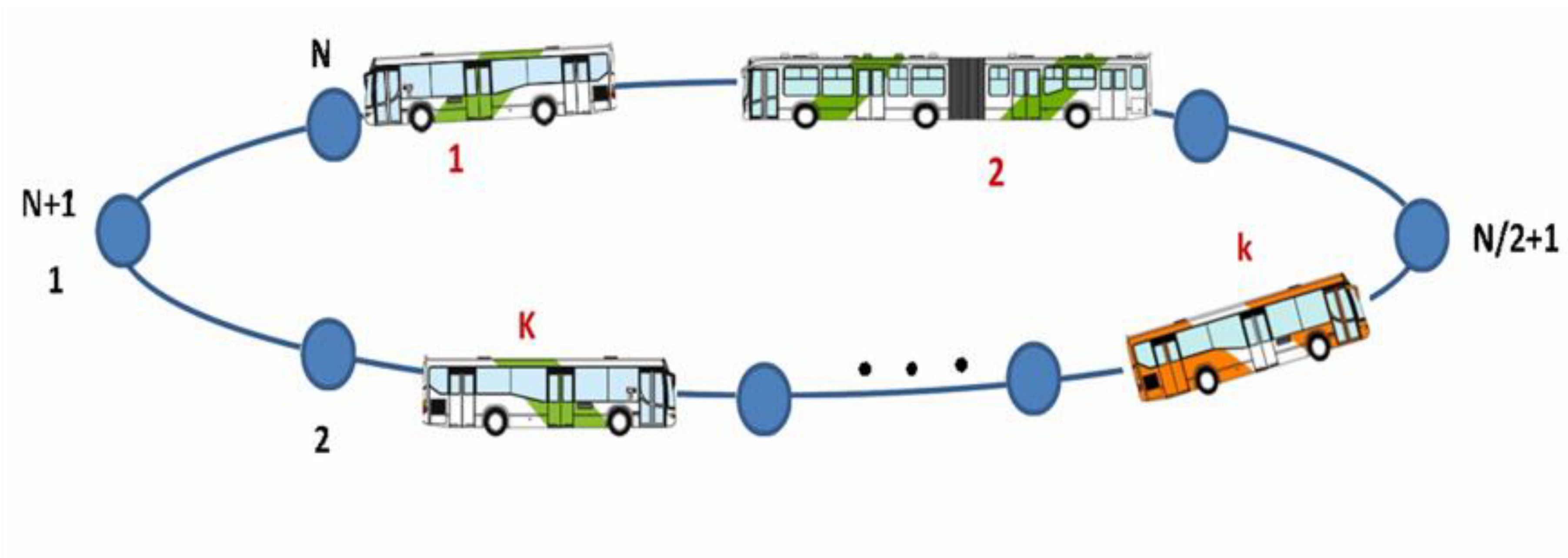
- ✓ Operators pay fines based on 2 KPI:
  - ICF : Index of Frequency Compliance
    - Fines if vehicles per hour are less than those on the contracts
  - ICR : Index of Regularity Compliance
    - Fines if observed headways exceed a threshold

These have put into evidence the lack of cost-effective solutions available in the market

# Proposed headway control model

- Rolling horizon mathematical programming optimization model that explicitly **considers capacity constraints** (i.e. boarding denial)(Delgado *et al*., 2012)
- Minimize user waiting times subject to system constraints
- Seeks to regularize operation and address bus bunching with real-time information
- Decision variable: holding times at bus stops, increase or decrease bus speed
- Buses do not follow a schedule: supply is adjusted to demand depending on real-time system conditions (traffic and bus headways and capacities)

# Proposed headway control model



# Proposed headway control model

$$\underset{h_{kn}, w_{kn}}{Min} \frac{\theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE}{PAX}$$

# Proposed headway control model

Waiting time for first bus
to arrive at a bus stop

$$\underset{h_{kn},w_{kn}}{Min}\ \frac{\theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE}{PAX}$$

$$W_{first} = \sum_{k=1}^{K} \sum_{n=e_k+1}^{e_{(k-1)}} \left\{ \frac{\lambda_n}{2} \cdot (td_{kn} - t_0)^2 + c_n \cdot (td_{kn} - t_0) \right\} + \sum_{k=2}^{K} \sum_{n=e_{(k-1)}+1}^{e_k} \left\{ \frac{\lambda_n}{2} \cdot (td_{kn} - td_{k-1n})^2 \right\} + \sum_{n=e_K+1}^{e_1} \left\{ \frac{\lambda_n}{2} \cdot (td_{1n} - td_{Kn})^2 \right\}$$

# Proposed headway control model

In vehicle waiting time due to bus holding

$$\min_{h_{kn}, w_{kn}} \frac{\theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE}{PAX}$$

$$W_{in\text{-}veh} = \sum_{k=1}^{K} \sum_{n=2}^{N} mt_{kn} \cdot h_{kn-1} + \sum_{k=1}^{K} mt_{k1} \cdot h_{kN}$$

# Proposed headway control model

Extra waiting time for second bus when first bus it at capacity

$$\min_{h_{kn}, w_{kn}} \frac{\theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE}{PAX}$$

$$W_{extra} = \sum_{k=1}^{K-1} \sum_{n=e_{(k-1)}+1}^{e_k} w_{k-1n} \cdot (td_{kn} - td_{k-1n}) + \sum_{n=e_K+1}^{e_1} w_{Kn} \cdot (td_{1n} - td_{Kn})$$

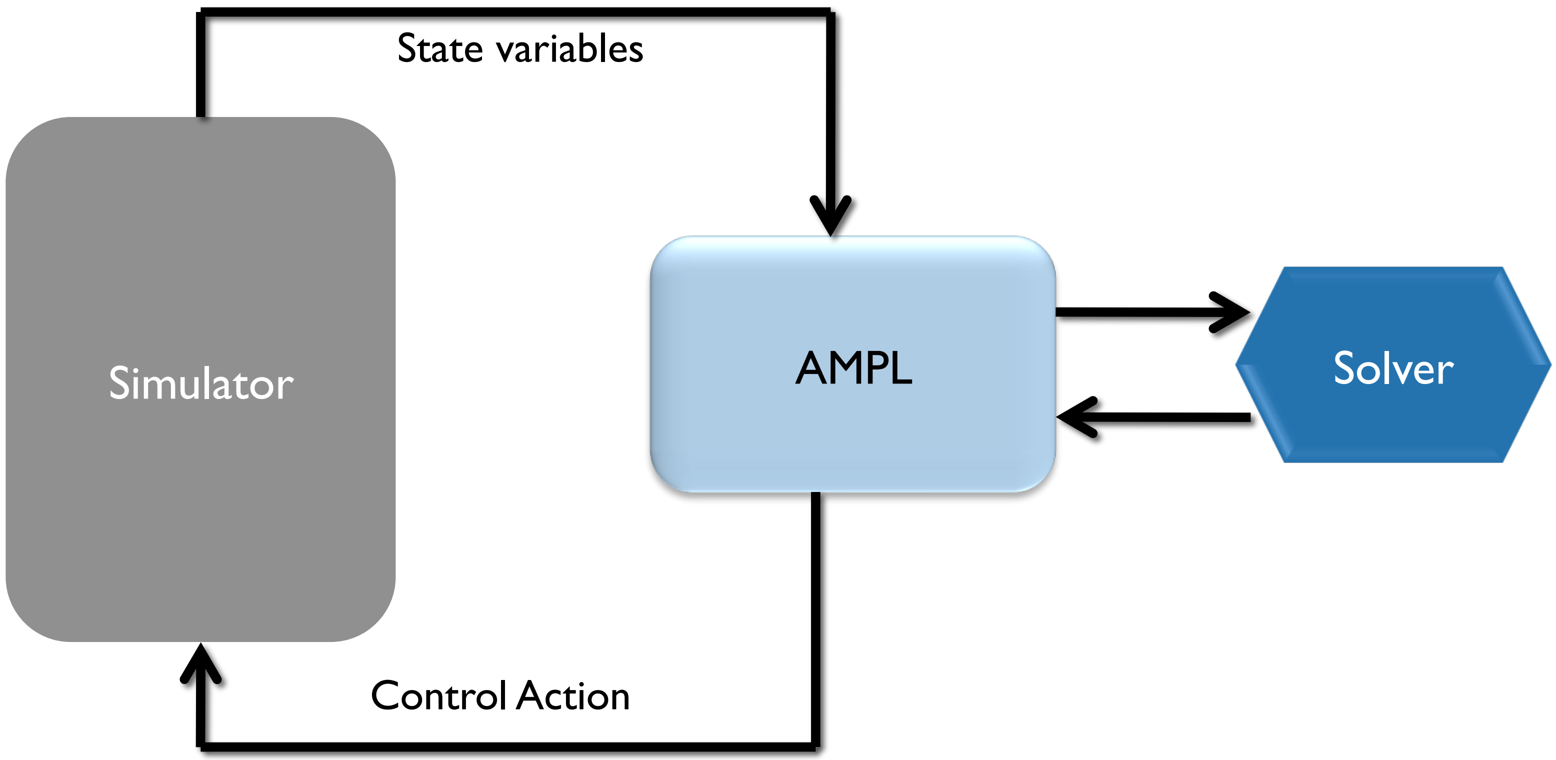
# Proposed headway control model

Penalty for passengeres left behind if there is available capacity

$$\underset{h_{kn},w_{kn}}{Min} \frac{\theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE}{PAX}$$

$$PE = \sum_{k=1}^{K} \sum_{n=2}^{N} w_{kn-1} \cdot s_{kn} + \sum_{k=1}^{K} w_{kN} \cdot s_{k1}$$

# Simulation Framework

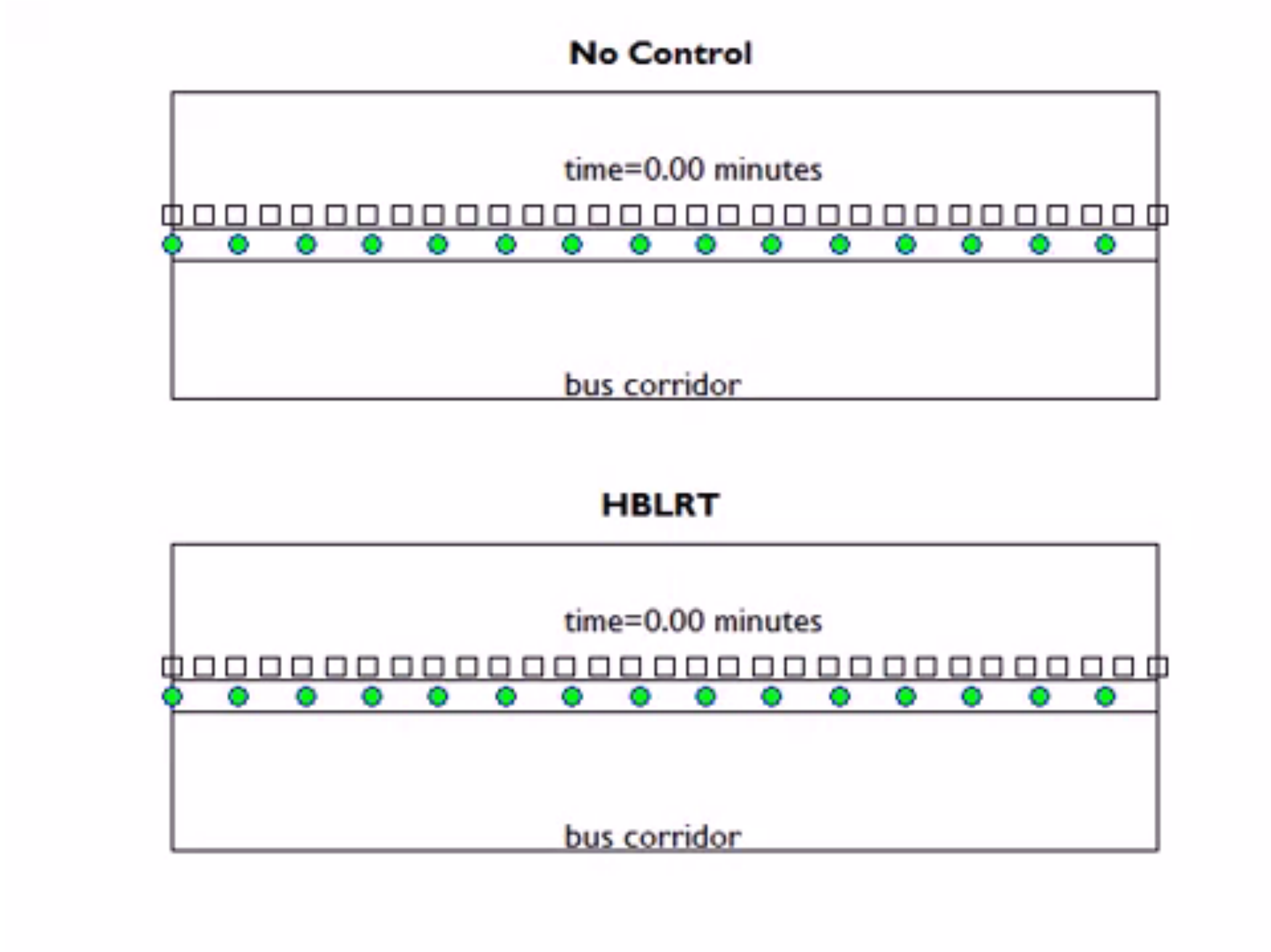


# Simulation results

- Both in BRT corridors and mixed-traffic services the following benefits have been observed:

  - ✓ Reduced waiting times and their variability
  - ✓ More regular headways: decreased regularity fines
  - ✓ More even bus loads: improved bus confort
  - ✓ Improved cycle time regularity making terminal operations smoother

# Simulation results: video




No control

Circle: buses

Color: bus loads
(green: empty….red: at capacity)

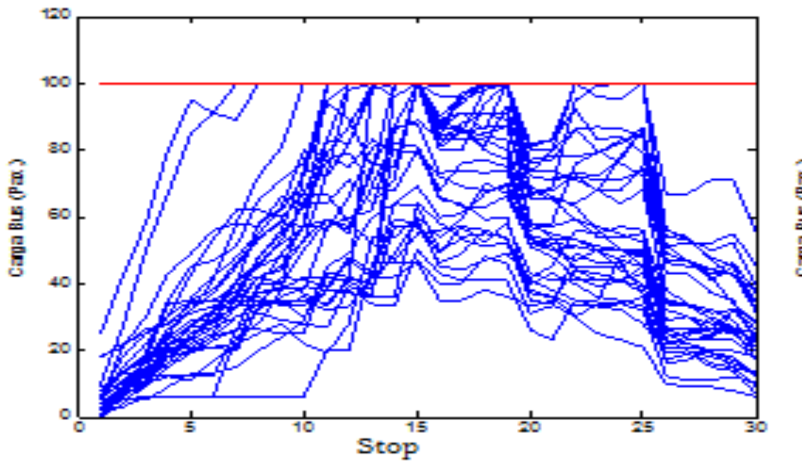
With control

# Results: Vehicle cap. constraints & medium frequency

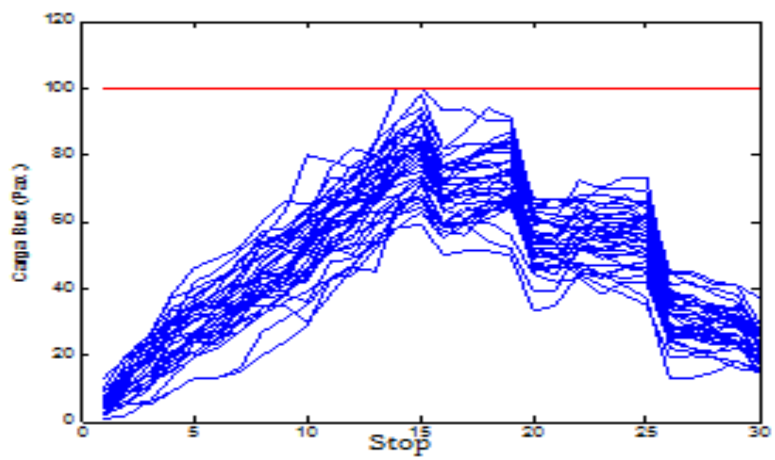
| | % of passengers that have to wait between: | | |
|---|---|---|---|
| | **0-5 min.** | **5-10 min.** | **more than 10 min.** |
| **No control** | 78.90 | 17.52 | 3.58 |
| **Treshold control** | 89.26 | 9.80 | 0.95 |
| **HRT** | 92.46 | 7.50 | 0.04 |
| **HBLRT** | 93.74 | 6.19 | 0.07 |

# Simulation Results: Bus Loads

(Capacity reached & high frequency)



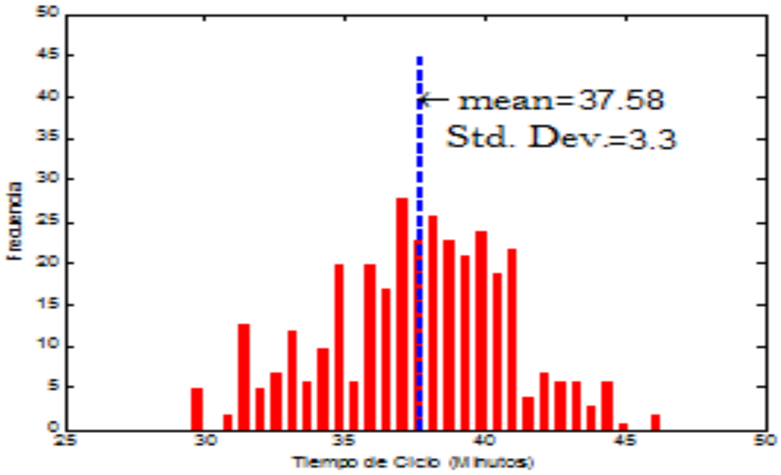

a) No control



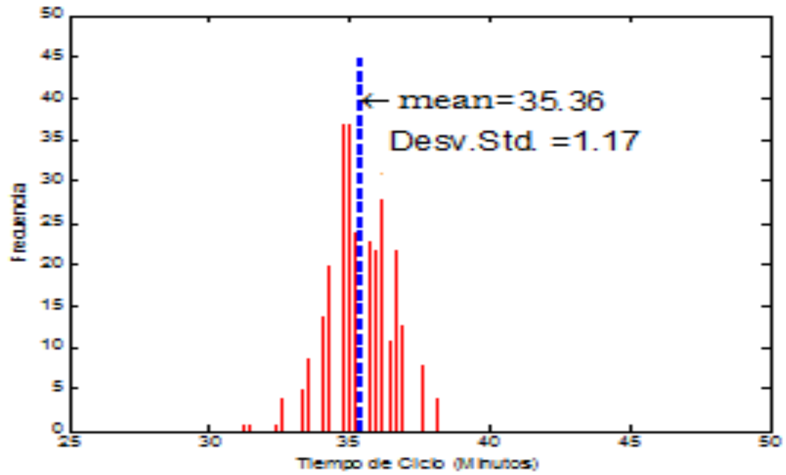

c) Proposed

# Simulation Results: Cycle Time

## (Capacity reached & high frequency)



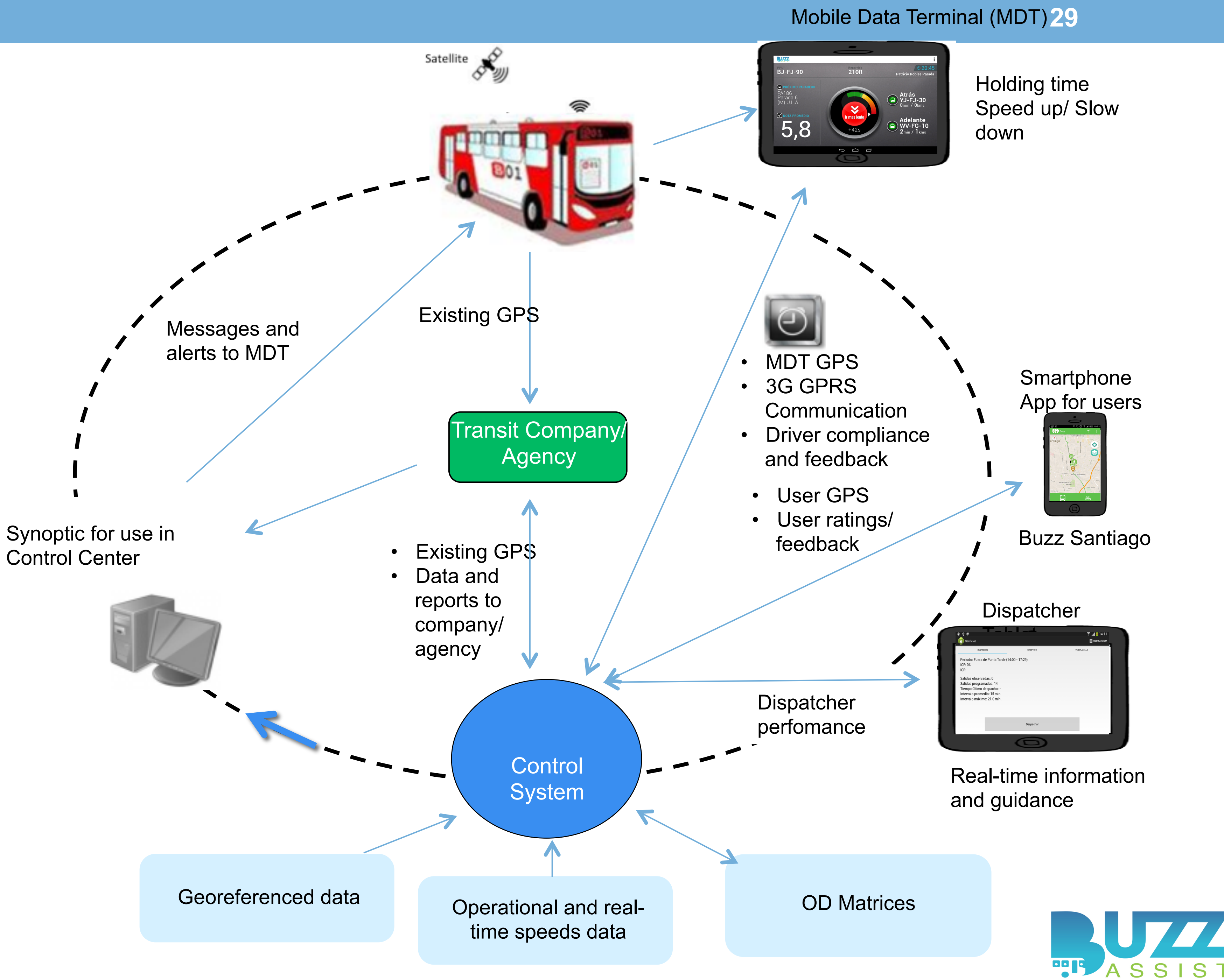

a) No control




c) Proposed

# Headway control software: Buzz Assist

- Develop software and implement solution in real bus services
- Retrieve real-time bus location and run the proposed optimization model on a rolling horizon framework every one minute
- Control instructions are then sent to any Android commercial or industrial tablet (with GPS and data plan) installed in the bus
- Software is flexible enough to adapt to existing transit system technology (GPS devices and consoles)
- Operates in headway and schedule based control systems

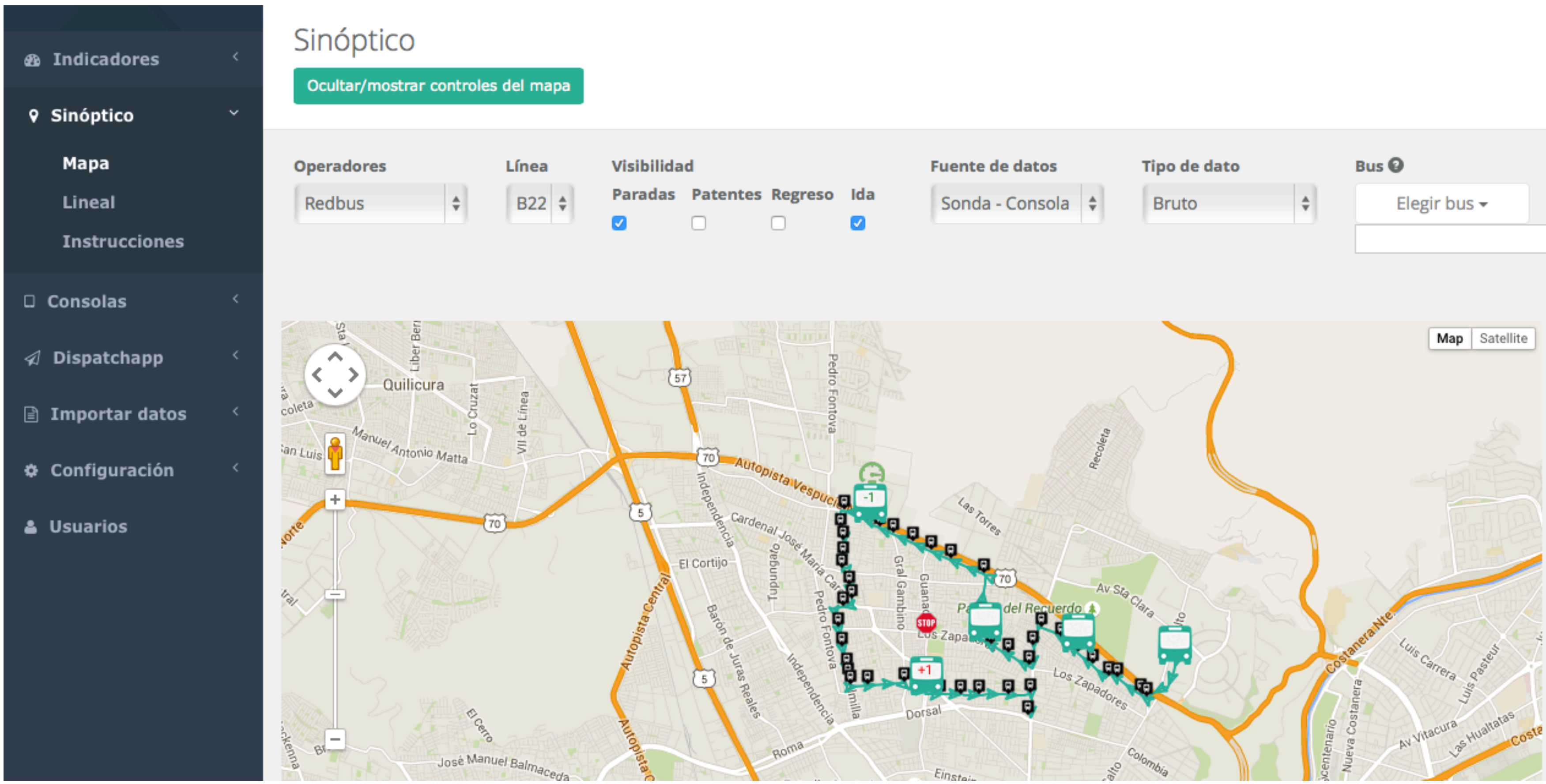

Mobile Data Terminal (MDT)
Satellite
Holding time
Speed up/ Slow down
5,8
Messages and alerts to MDT
Existing GPS
Transit Company/ Agency
• MDT GPS
• 3G GPRS Communication
• Driver compliance and feedback
• User GPS
• User ratings/ feedback
Smartphone App for users
Buzz Santiago
Synoptic for use in Control Center
• Existing GPS
• Data and reports to company/ agency
Dispatcher
Dispatcher perfomance
Real-time information and guidance
Control System
Georeferenced data
Operational and real-time speeds data
OD Matrices

# Software input information

- Static transit system data:
  - Bus services, operating programs, bus stop locations, etc: data in General Transit Feed Specification (GTFS) format (used by Google Transit)
- Real-time bus positions:
  - GPS devices already installed in buses
  - Industrial Tablet GPS
- Demand data:
  - Passive smart card information: OD matrices and historical bus stop arrival rates
- Segment speeds:
  - Combination of real-time speeds with historical speeds

# Synoptic & dashboard web tool

- Visualize buses and control instructions, modify system parameters and download daily operating reports



# Pilot tests in services B22 and B14

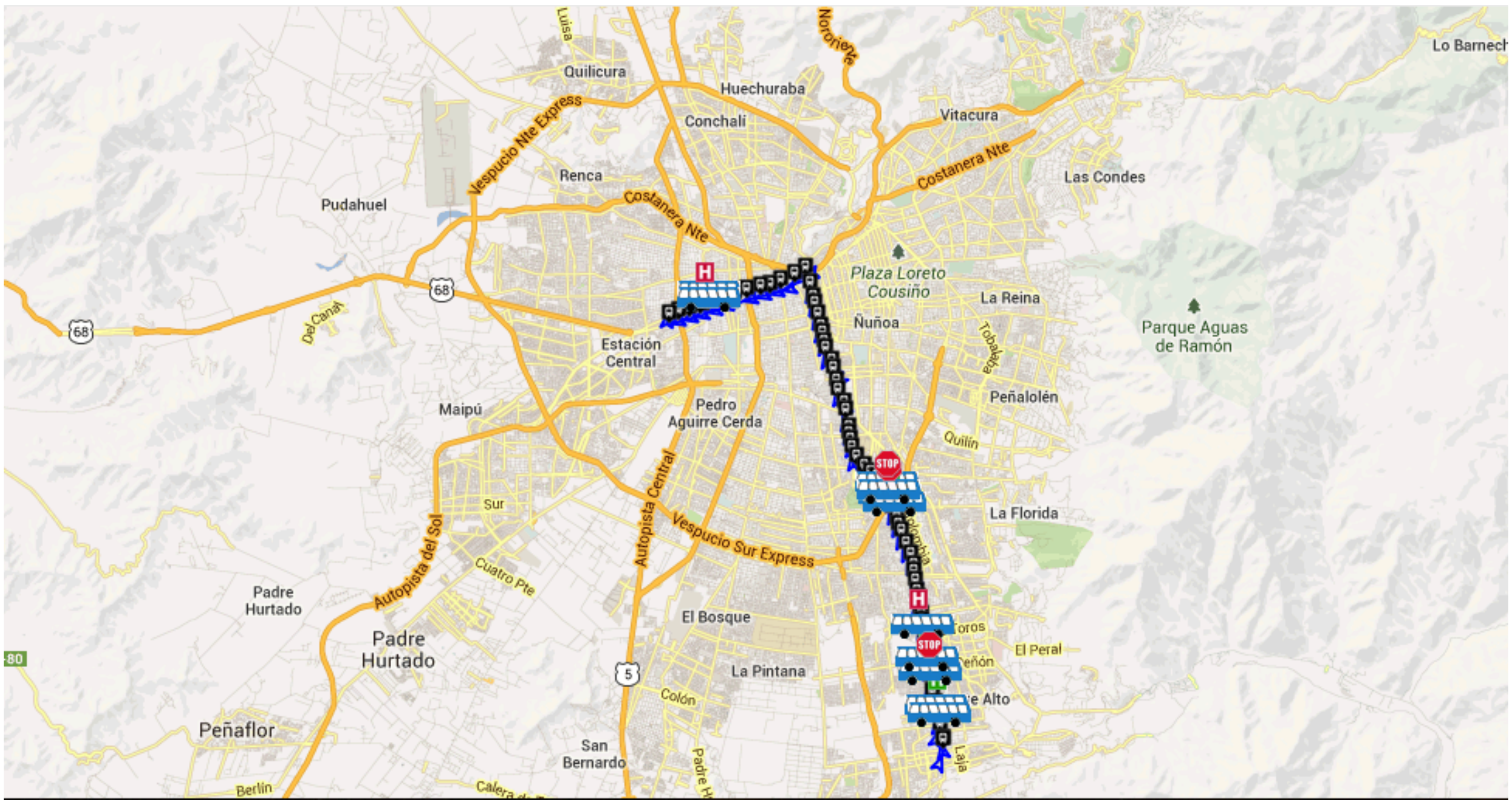
- 25 buses with Android industrial MDT and anti-theft and ruggedized support structures
- Started **last week** … we are waiting for the first results
- Lessons: Not possible to use commercial tablets and need to control headways at the dispatching point

# Pilot tests in B22 and B14 services

# Pilot tests in B22 and B14 services

# 210 Pilot Plan

- Example of bus bunching in 210 service:



# Integration to existing technological system

- Successfully integrated our technology to an existing fleet management system

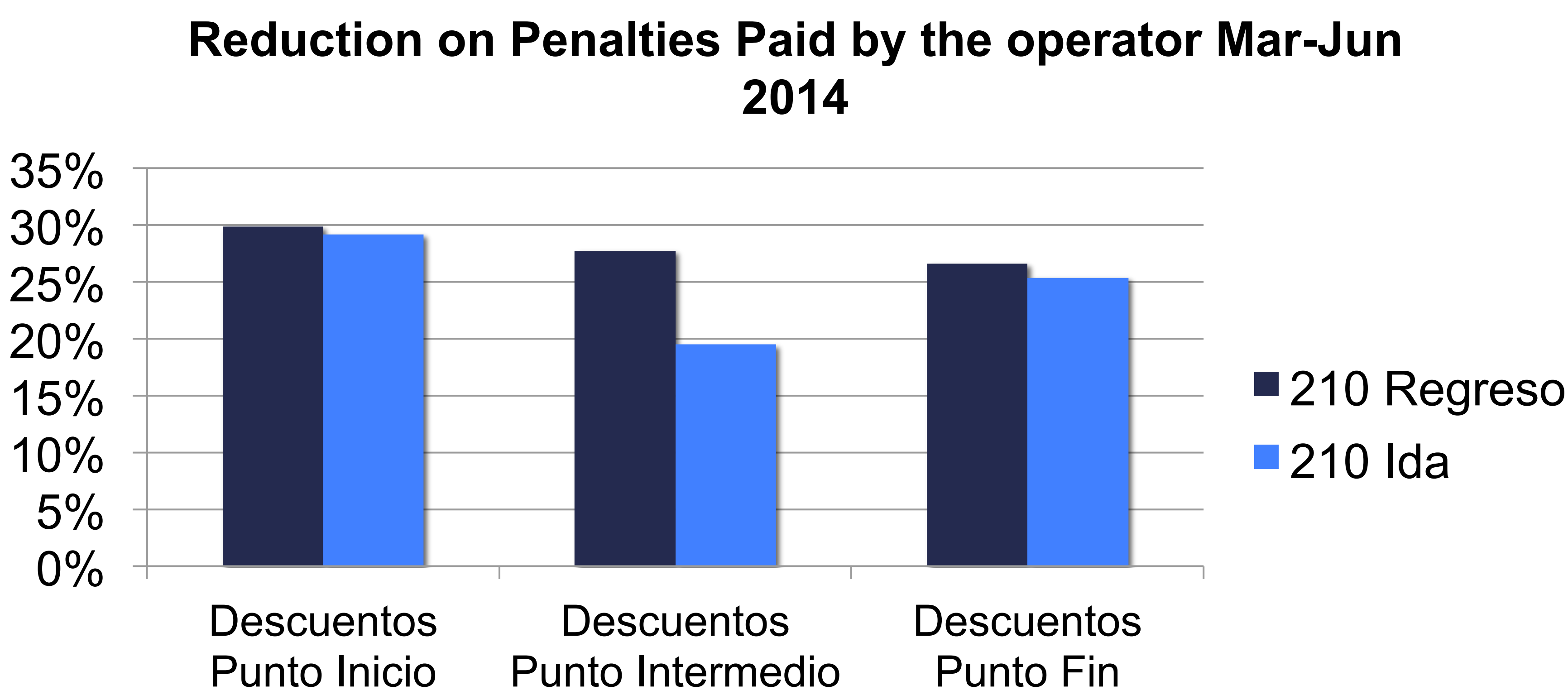
Time with forward and backward buses


Holding Instruction

# 210 Pilot Plan – Bus console

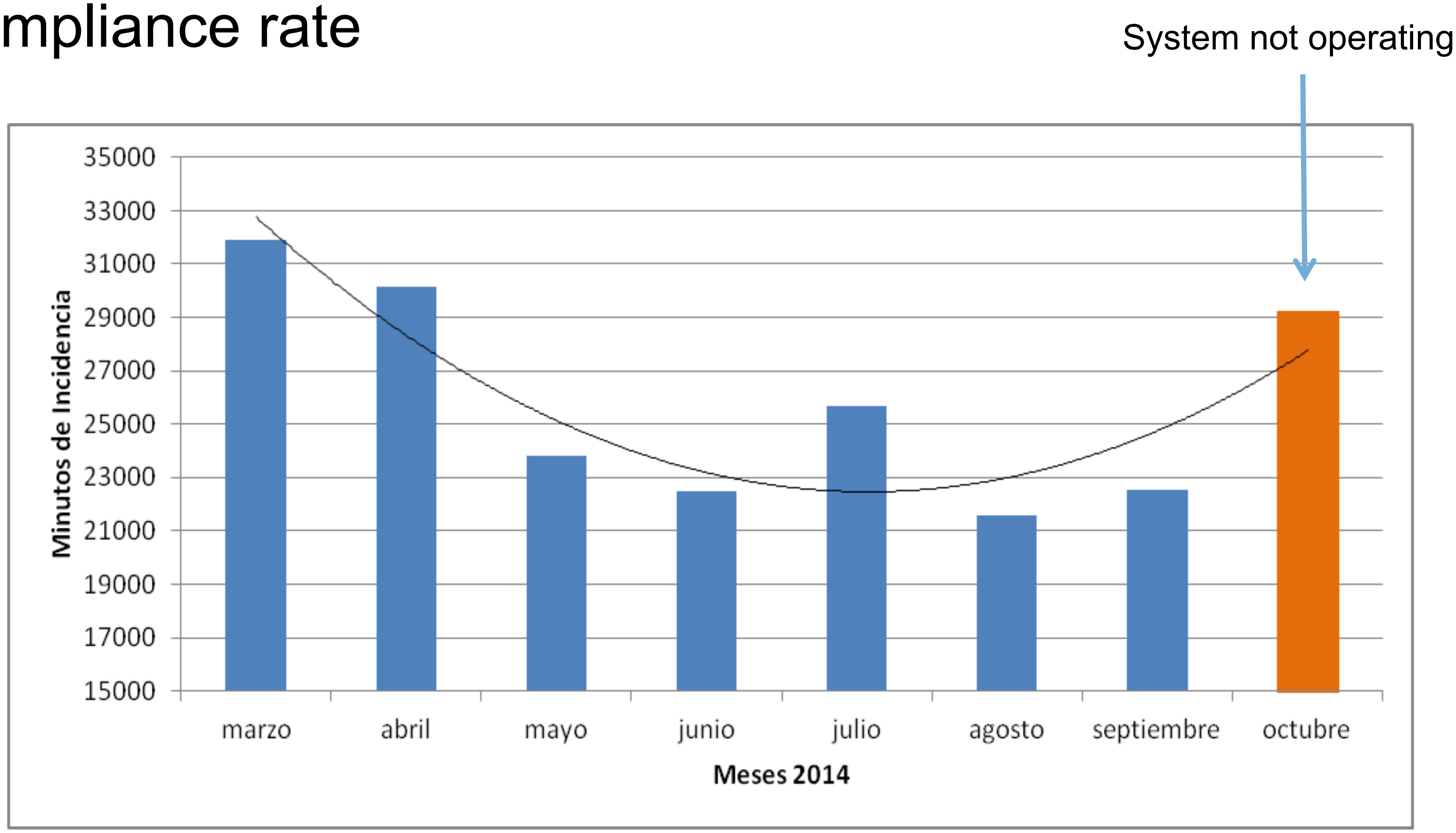
# Pilot test on Line 210

- With less than 20% of fulfillment on holding instructions



# Integration to existing technological system

- Pilot test in service 210 since March 2014
- Results: 40-50% decrease in fines despite a 25% compliance rate



# Transmilenio Pilot Tests

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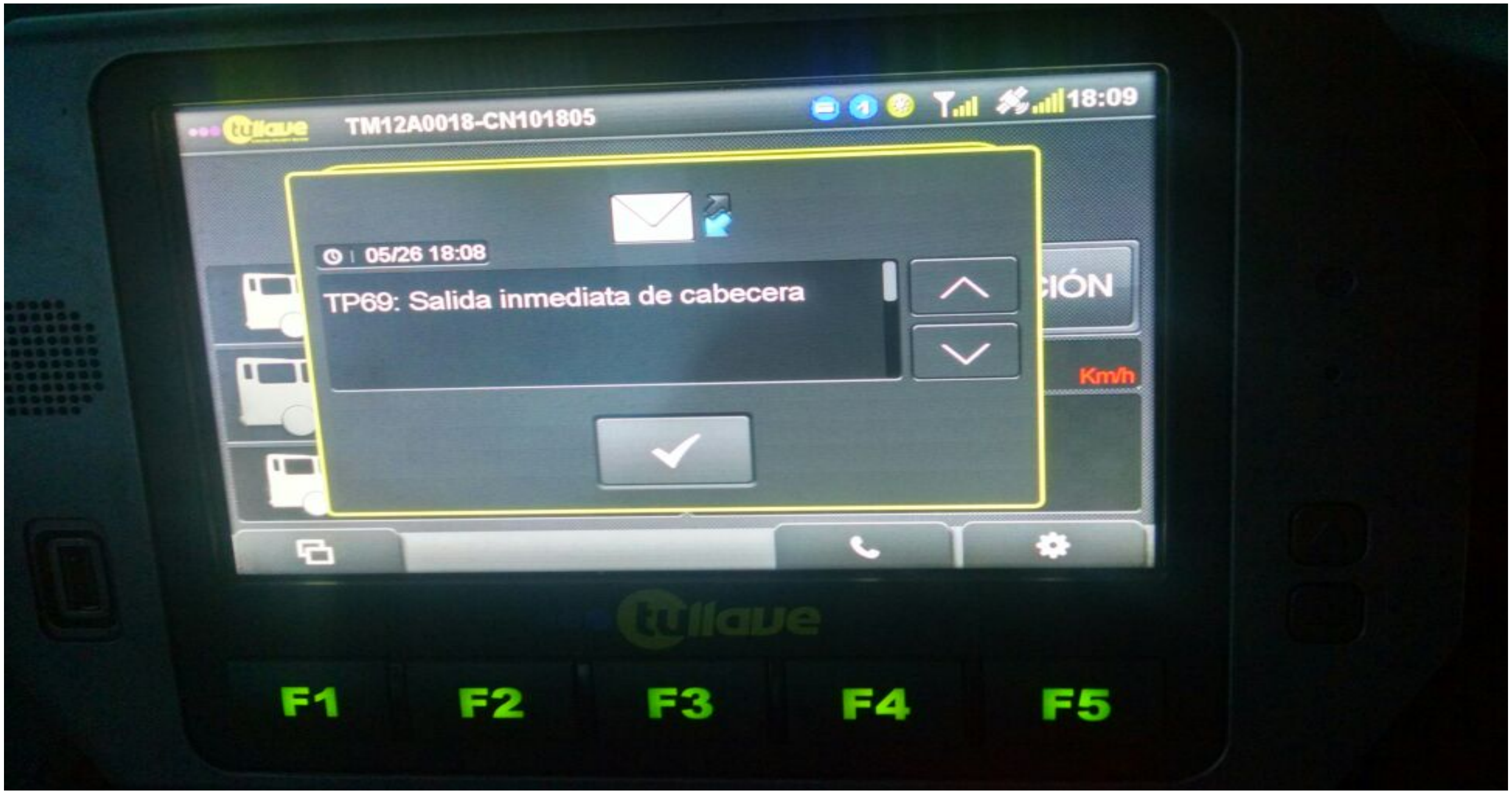
- 84 dual service
- Text instructions sent manually to already installed MDTs



# Transmilenio Pilot Tests

How to measure regularity when there are no fines?

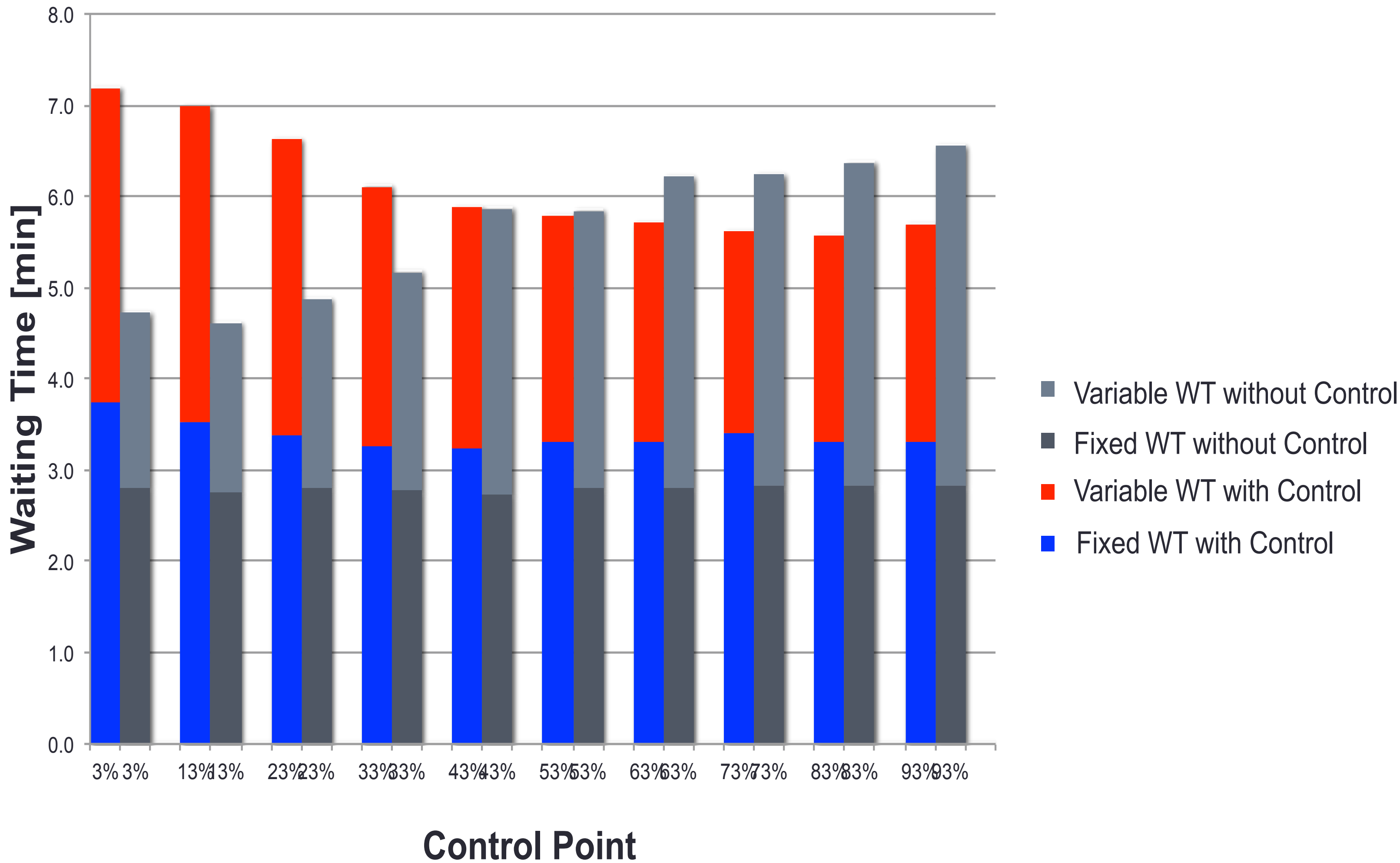
$$E(W) = \frac{E(H^2)}{2E(H)} = \frac{E(H)}{2} + \frac{Var(H)}{2E(H)}$$

$E(H)/2$ is a funtion of frequency ($1/H$), which depends on the number of buses (n) and the cycle time ($T_c$). ( $H = T_c / n$ )

Second term depends on the variability of headways. We aim to reduce this term

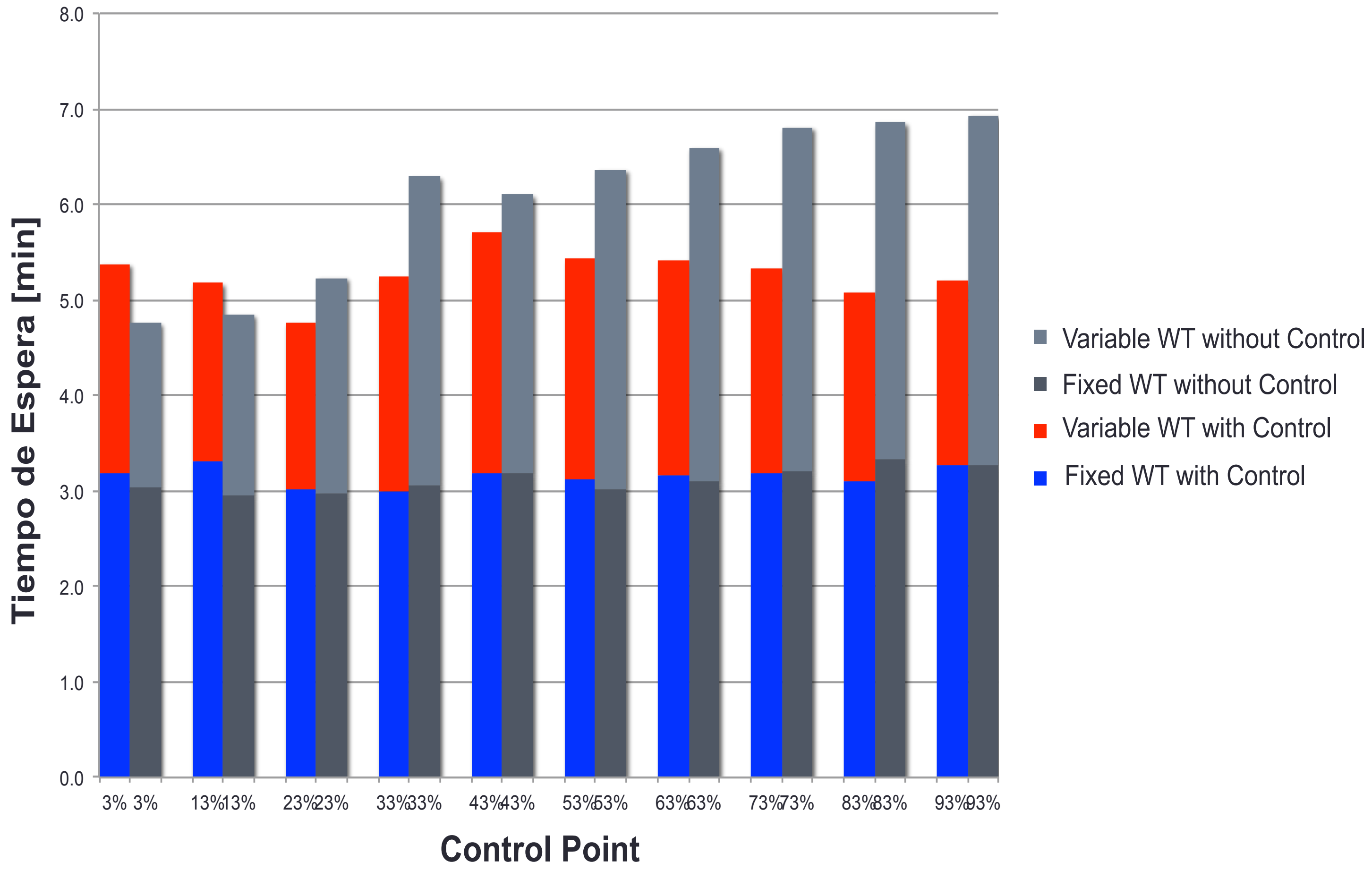
# Results: Transmilenio Pilot tests

- March 16th with Control vs. March 17th without Control



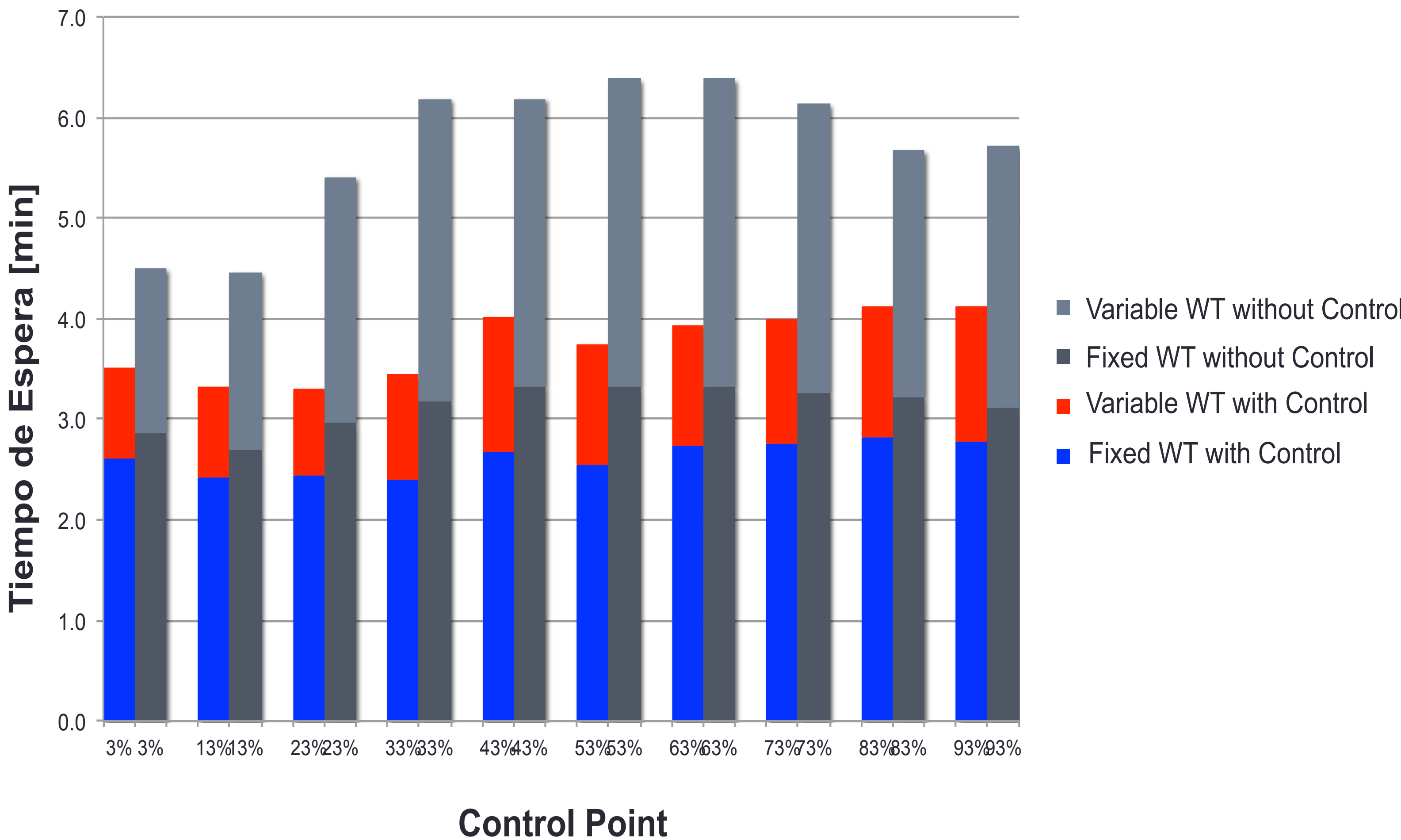
# Results: Transmilenio Pilot tests

- April 14th with Control vs. April 21st without Control

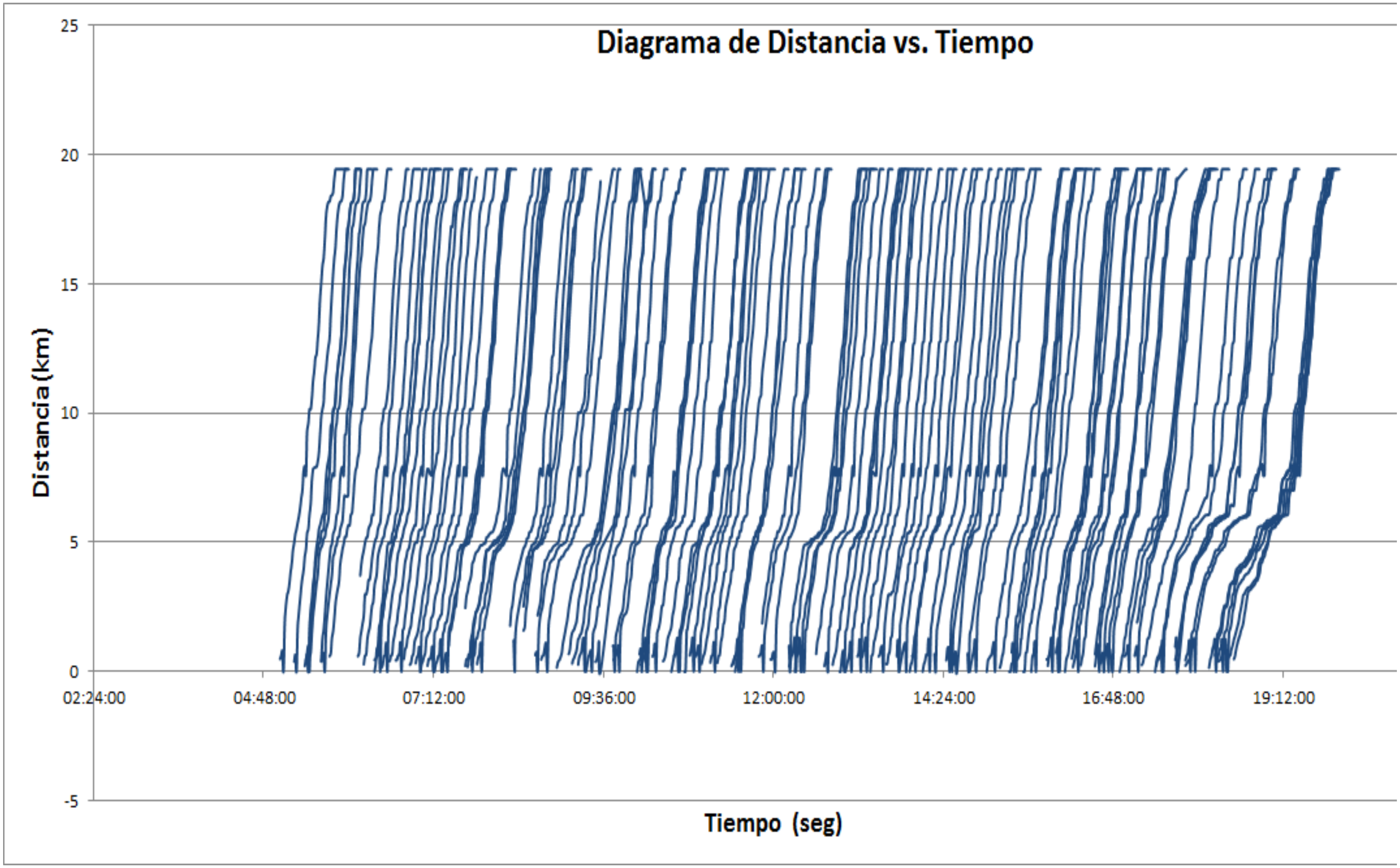


# Results: Transmilenio Pilot tests

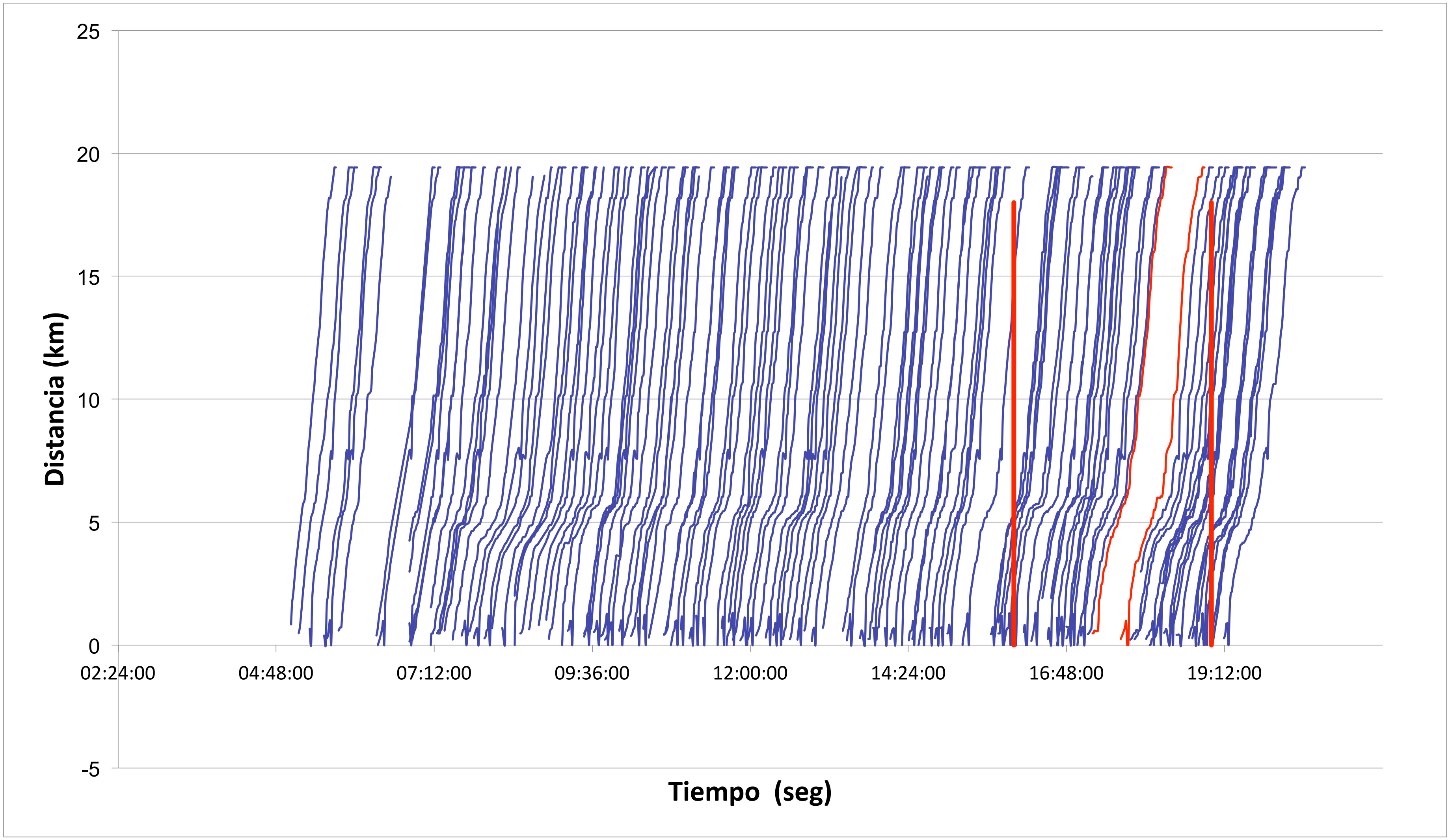
- May 26th with Control vs. May 25th without Control



# Trajectories C84 May 25th: No Control

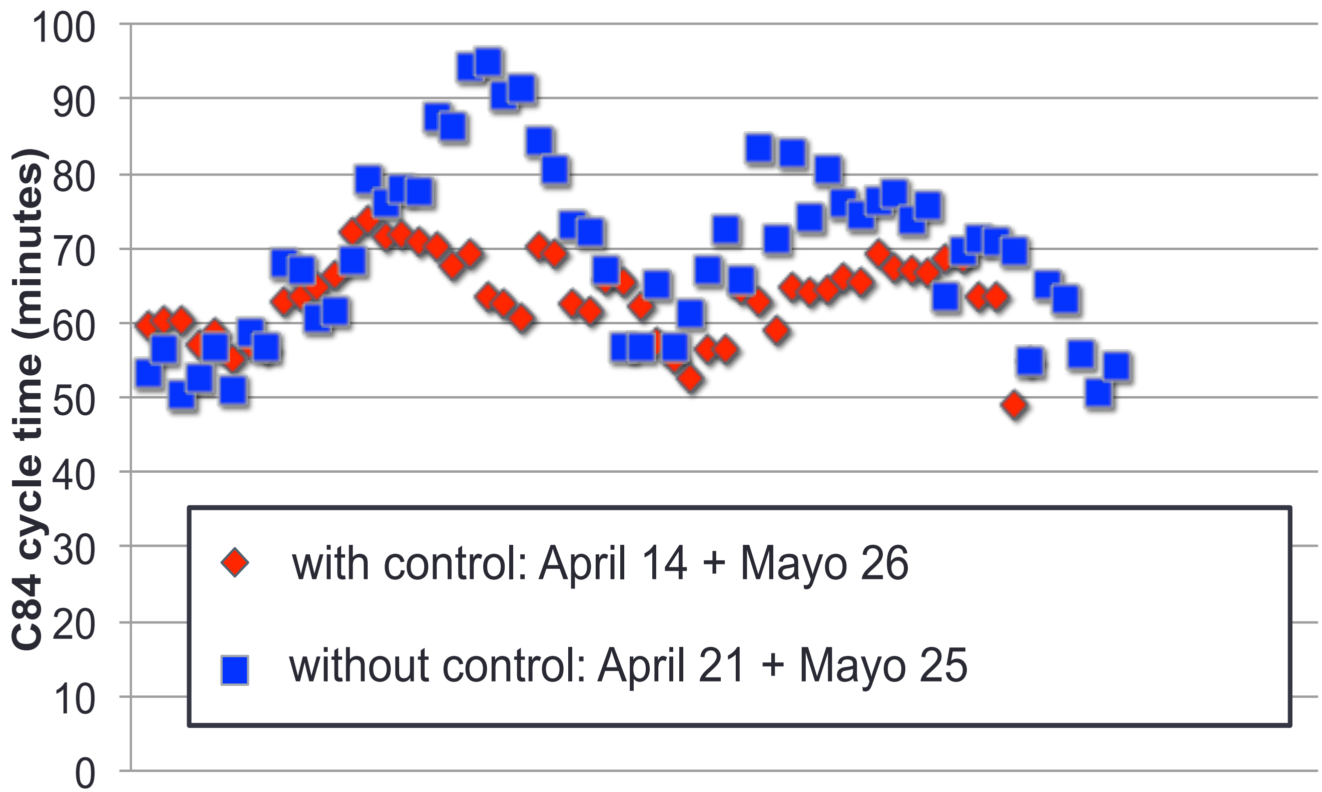


# Trajectories C84 May 26th With Control



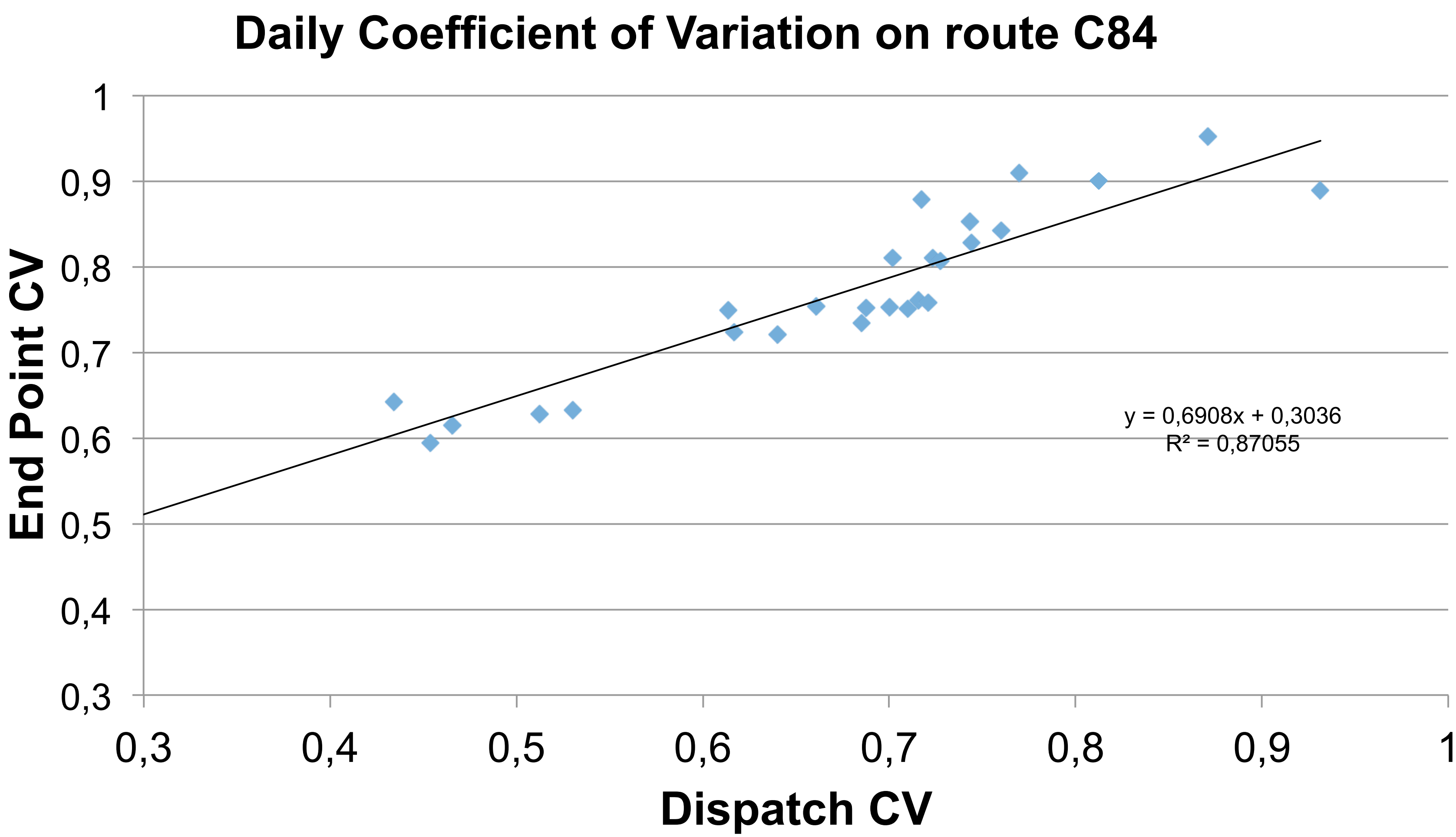
# Results: Transmilenio Pilot tests

- Cycle times distribution




With control: Average cycle time = 63.4 min and standard deviation = 5.6 min
Without control: Average cycle time = 69.5 min and standard deviation = 11.8 min

# Need to control dispatches!

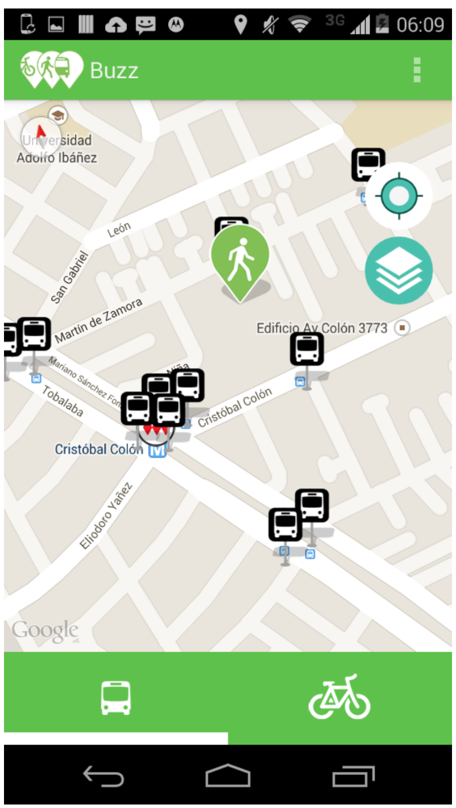


# Conclusions

- We have a tool for effectively controlling buses in a BRT
- Waiting times were maintained (even decreased) along the route
- Reduction on vehicle cycle times and their variability allow for reductions on fleet size or improvements on level of service
- Implementation challenges:
  - Severe irregularity at the dispatching buses at terminal
  - Some buses operated without operative communication device
  - Driver compliance

# Complementary technologies

- Android Mobile App for dispatching buses in terminals
- Android Mobile App for counting passengers in buses
- Buzz Santiago: sustainable mobility App (transit+bike)






BUZZ
SANTIAGO

# Thank you!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