Segregating Buses and Cars in a Congested, Non-Steady State Network

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Motivation: Effects of Bus-only Lanes on Car Traffic

- Bus-only lanes to enable buses to bypass car queues
- In settings where space is limited, convert regular use lanes to bus-only
Downside of Lane Conversions

- Lane conversions can be damaging to car traffic
- Fear of negative impacts on car traffic has led to opposition to lane conversion proposals
Previous Research Findings

• Yet, previous research (ISTTT 18) has shown that such lane conversions can diminish car delays due to the smoothing effect.

• This previous work assumed:
  • network traffic operated in steady-state conditions
  • bus lanes are reserved for the entire duration of the analysis
Present Work

• We further explore impacts of lane conversions in non-steady state conditions:
Findings

We find that both car and bus traffic can benefit from converted bus lanes, if:

• The conversion persists only for the duration needed to serve rush-period bus schedules,

• And if beyond the end of bus tours, lanes are returned to general use
Findings

The favorable predictions hold even without accounting for the smoothing effect, and even if no travelers shift from cars to buses.
Why Do Benefits Arise?

Benefits arise because once all lanes are returned to cars, they enjoy higher trip completion rates. This occurs because:

(1) Buses move faster → Buses complete their tours earlier in the day → Cars enjoy a network free of buses early on in the day

(2) Bus lane conversions cause more cars to queue outside the network → During the rush, the car accumulation inside the network is smaller → Cars confront lower network accumulations
Outline

1. Model
2. Numerical Analysis
3. On-going Work
City Structure

2 superimposed grid networks of arterial and local roads

Example Origin for Car Trips
(Local Roads)

Example Origin for Bus Trips
(Bus Depot along the Arterial)
Demand Pattern

Rush Period $t_r$ is the period of peak demand

For simplicity:

- Low Demand
- High Demand $\lambda$
- Low Demand

Cumulative Count (pce)

- $\lambda t_r$
- $\lambda$
- $\lambda_{Bus}$

Total Demand

Bus Demand
The Bin Model

Flow of vehicles entering (merge model)

Trip Origins on Local Roads and in Bus Depots

Arterial Roads

Destination on Arterial Roads

Flow of vehicles exiting (Network Exit Function)
Existence of a MFD in the network (e.g., Geroliminis and Daganzo, 2009)

Average Link Flow in the Network $q$ (pce/h)

Average Link Density in the Network $k$ (pce/km)

$v_f$: free-flow speed in a signalized network
The MFD can be rescaled to a NEF (Daganzo, 2007)

- Average Link Flow in Network $q$ (pce/h)
- Trip Completion Rate $f$ (pce/h)
- Total Accumulation $n$ (pce)

Mathematical expressions:

- Average Link Density $k$ in Network (pce/km)
- Average Link Flow in Network $v_f$ (pce/h)
- Trip Completion Rate $f_m$ (pce/h)
- Total Accumulation $n_m$ (pce)
Implicit Assumptions

1. Same average vehicle trip length across both vehicle classes
   → problematic, to be addressed later

2. Same average speed across both vehicle classes
   → conservative
Flow of Vehicle Entering the Arterial Network

Grid Network

Building Block Representation

Arterial Roads

Trip Origins on Local Roads and in Bus Depots

Destinations on the Arterial

Merge Model (Daganzo, 1996)
Determining Accumulation in the Network

With the entry flows onto the arterial network determined from the merge model:

Trip Completion Rate \( f \) (pce/h)

Total Accumulation \( n \) (pce)

\[ f_m \]

\[ f(t) \]

\[ n_m \]

\[ n(t) \]
Queuing Diagram: Non-Segregated Case

Cumulative Number (pce)

Total Demand Curve (given)

Total flow exiting the network (pce/hr)

Arterial Entry Curve (predicted)

Time (h)

\( \lambda \), \( t_r \), \( n(t) \), \( n_m \), \( f_m \), \( n_e \)
Queueing Diagram: Non-Segregated Case

- Cumulative Number (pce)
- Total Demand Curve (given)
- Arterial Entry Curve (predicted)
- Trip Completion Curve (predicted)

$\lambda \cdot t_r$

$t=0$

Trip time $t_r$

$n(t)$
Queueing Diagram: Non-Segregated Case

- Cumulative Number (pce)
- Total Demand Curve (given)
- Arterial Entry Curve (predicted)
- Trip Completion Curve (predicted)
- Pce-Hours Spent outside the arterial network
- Pce-Hours Spent inside the arterial network

Parameters:
- \( \lambda \)
- \( t_r \)
- Time (hr)

Time points:
- \( t=0 \)
- Trip time \( t_r \)
Segregated Case

- Use integer number of bus lanes
- Follow similar methodology with rescaled models

![Graph showing Total Flow of Vehicles Exiting f (pce/h) vs Total Accumulation n (pce). The graph includes points f_m and n_m.]
Queuing Diagram: Segregated Case

Cumulative Number (pce)

\( \lambda_{\text{car}} t_r \)

Car Demand after Segregation (given)

Trip Completion Curve after Segregation (predicted)

Total PCE-Hours Spent in the system in the segregated case

Time (h)

Trip time

t=0
Compare Segregated and Non-Segregated Case

Total Pce-Hours Spent in the system in the segregated case (Cars Only since Bus Delay=0)
Recall Why Benefits Arise:

- Buses move faster
- Buses complete their tours earlier in the day
- Cars enjoy a network free of buses early on in the day
- Bus lane conversions cause more cars to queue outside the network
- During the rush, the car accumulation inside the network is smaller
- Cars confront lower network accumulations
Benefit to Transit Agencies

Transit agencies also benefit from the lane conversions because:

- As buses move faster
- Buses complete their tours earlier in the day
- Fewer buses are needed to maintain target service frequency
Numerical Analysis

Parameters for Downtown San Francisco borrowed from (Geroliminis and Daganzo, 2007)

\[ f_m = 15660 \text{ pce/h} \]
\[ n_m = 3000 \text{ pce} \]
\[ n_c = 9500 \text{ pce} \]

Assumed:
Number of lanes = 3
Bus proportion is 20% of \( \lambda \) (pce/h)

- Not beneficial in total passenger-hours or car-hours travelled
- Beneficial in total passenger-hours but not car-hours travelled
- Beneficial in both total passenger-hours and car-hours travelled

Gridlock boundary for the segregated case
Gridlock boundary for the non-segregated case
On-going Work

• Adapt the model for non-zero demand outside the rush
• Account for different vehicle trip lengths
• Perform a sensitivity analysis of inputs
• Develop a microsimulation as ground truth to test findings
Extending our Work

This work can be extended to carpool lanes and most special use lanes
Thank you