High-Occupancy-Toll (HOT) lanes: potential benefits and modeling challenges

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Outline

- Case study (the "fast lane" to Tel-Aviv)
- Traveler choice models (LOGIT/VOT)
- Toll algorithms
- Basic stochastic model
- Departure time choice

The “fast-lane to Tel-Aviv” package

- Dedicated bus lane
- High occupancy vehicles (HOV)

- Low occupancy vehicles pay toll (HOT)

- Auxiliary lane
- Carpool parking lot
- Free parking & downtown shuttle

Potential Pareto $\Rightarrow$ Full Pareto

Dates and costs

- Government decision: 1997
- Construction started: January 2009
- Opened to the public: January 7, 2011

- Construction cost: 300-500 MNIS (~150 M$)
- BOT winning offer: -182 MNIS (~ -50 M$)

  i.e. operator pays the government

Toll system specifications

Public statement: one lane (of three) will carry half of the people and quarter of the vehicles.

Contract:

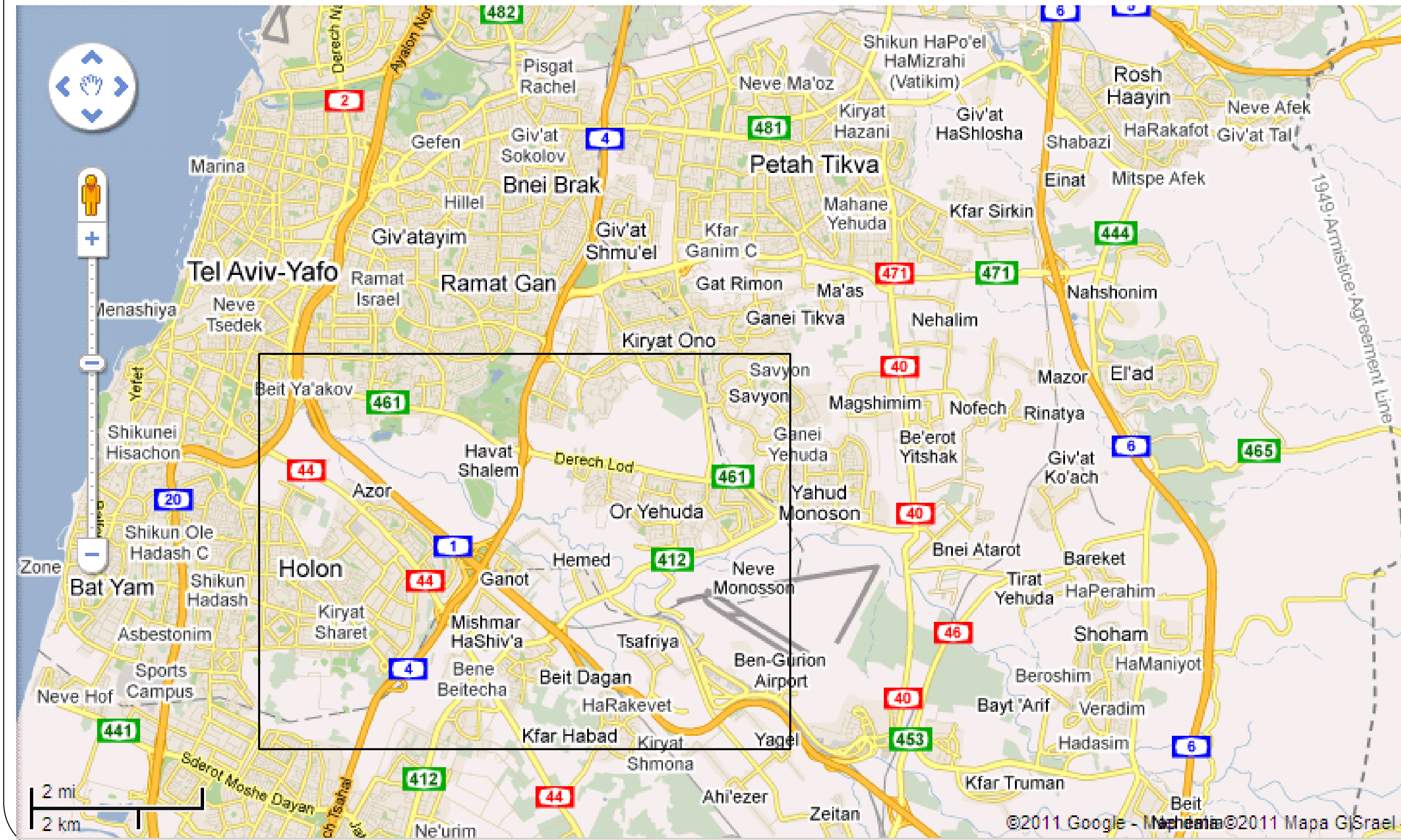
Speed above 70 km/h

Flow above 1600 vehicles per hour

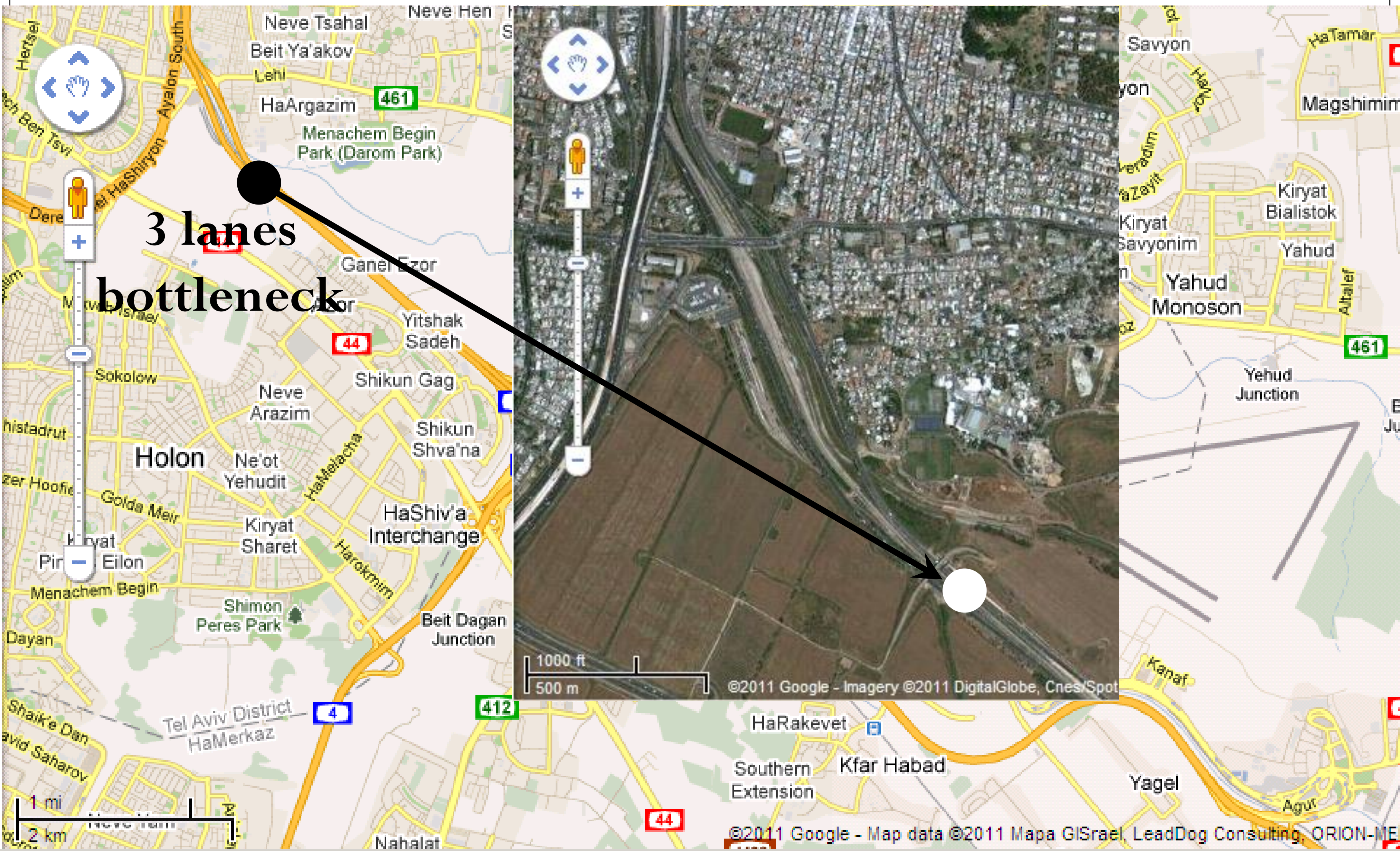
$\Downarrow$

Real-time responsive toll

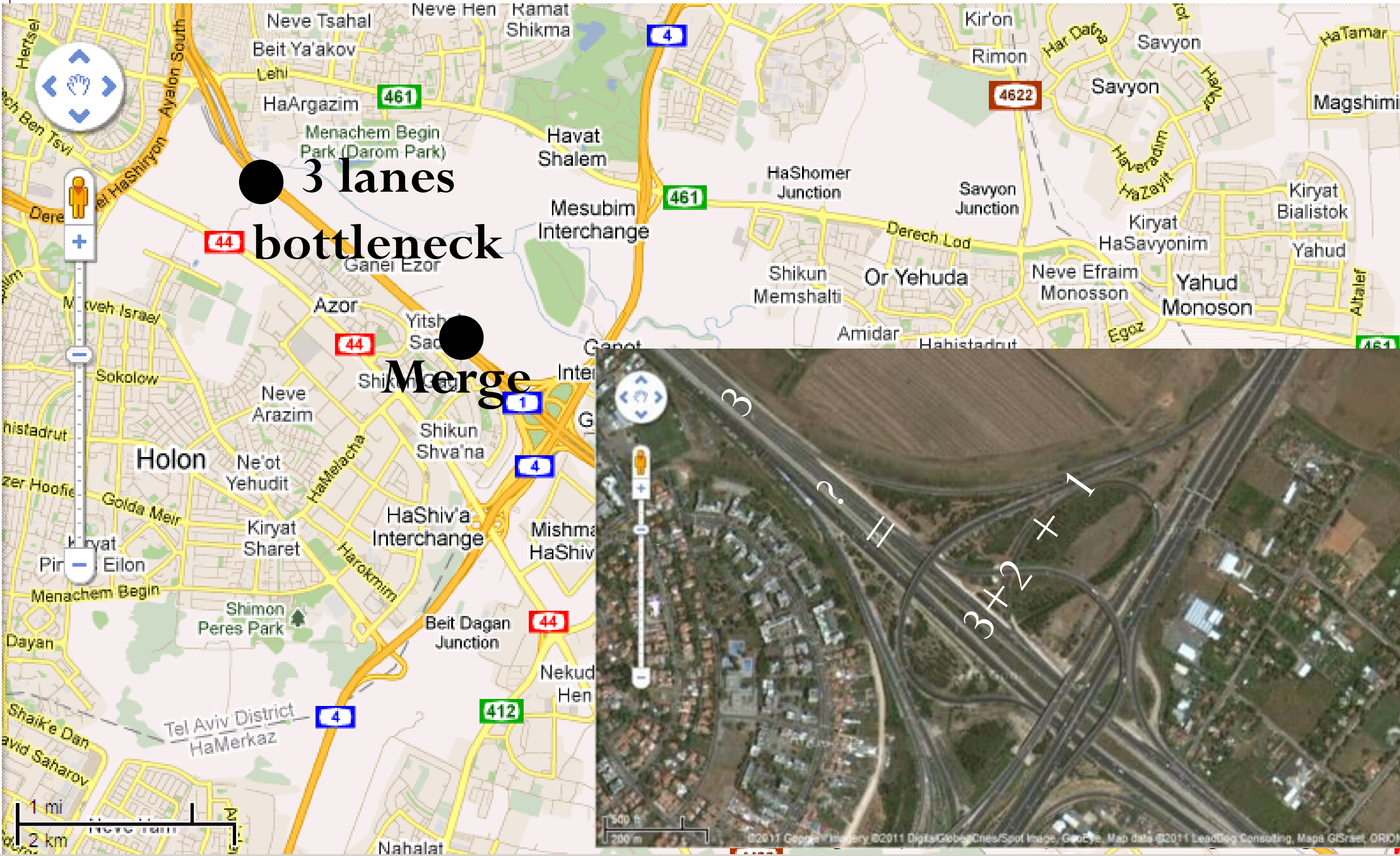
The location



The corridor



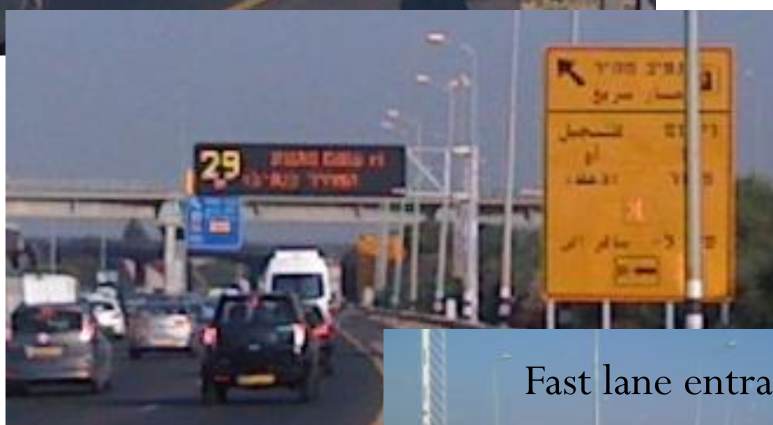
The corridor



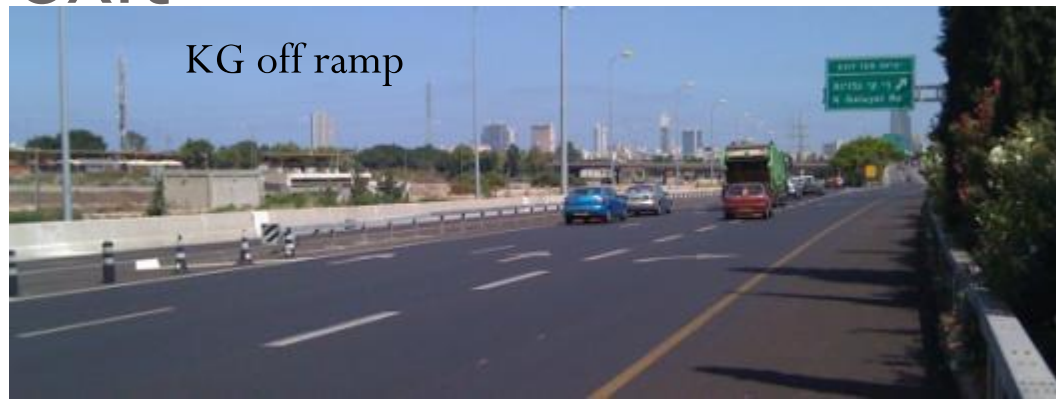
The corridor

The corridor: 13 km length

Entrance and exit



Fast lane entrance



KG off ramp

Fast lane exit

Entrance rules

- Public transport, mainly busses, 200/h
- HOV – 4 (or 3) persons or more, 100/h
- Responsive toll: 7-75 shekels (~2-20$)
- E-toll (zero delay) for registered users

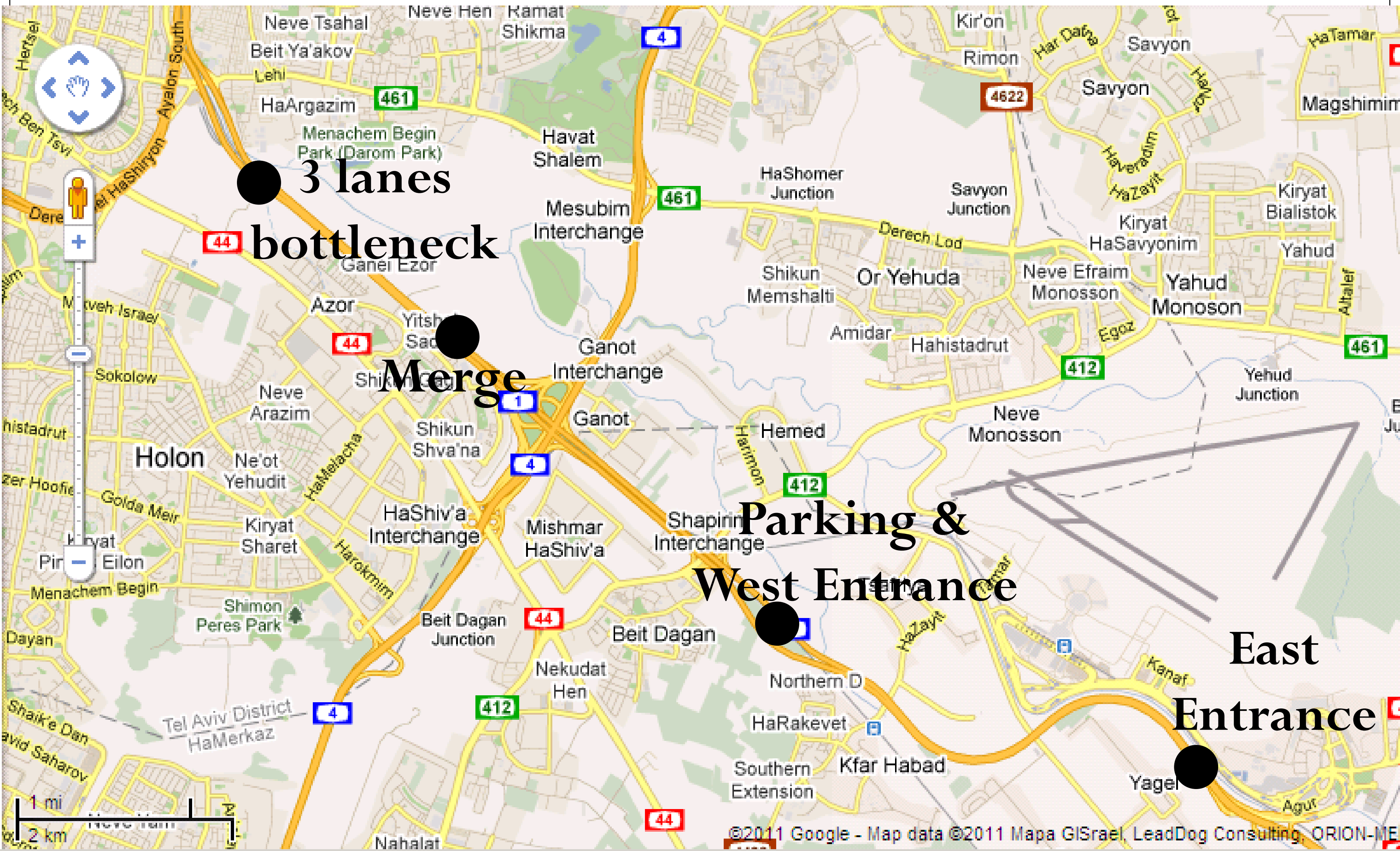
Manual HOV inspection and cash toll booths

Access control at wide cross sections

"Soft" access control at the bottleneck

Pictures taken from the west bridge

The parking lot



The parking lot

Photograph by Rodi Almog

2000 spots parking & West Entrance

The downtown shuttle

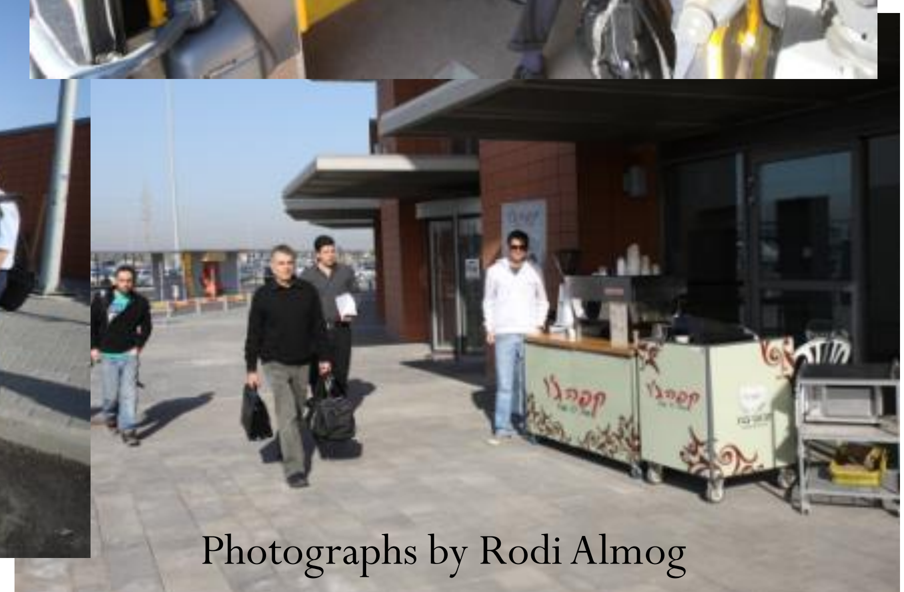
Every 5 minutes

6:30-9:30 & 15:30-19:00

Every 15 minutes

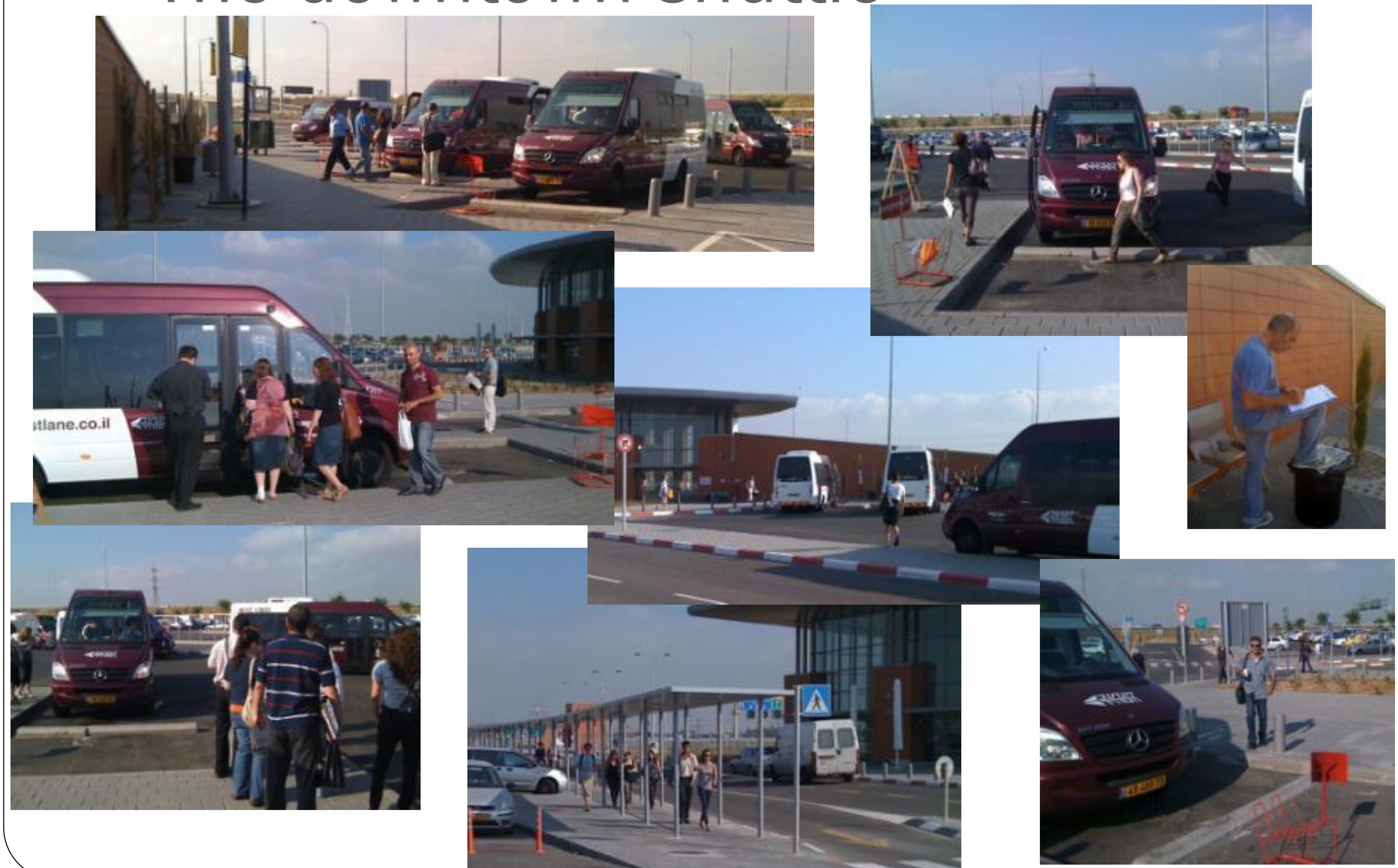
6:00-23:00

The downtown shuttle



Photographs by Rodi Almog

The downtown shuttle



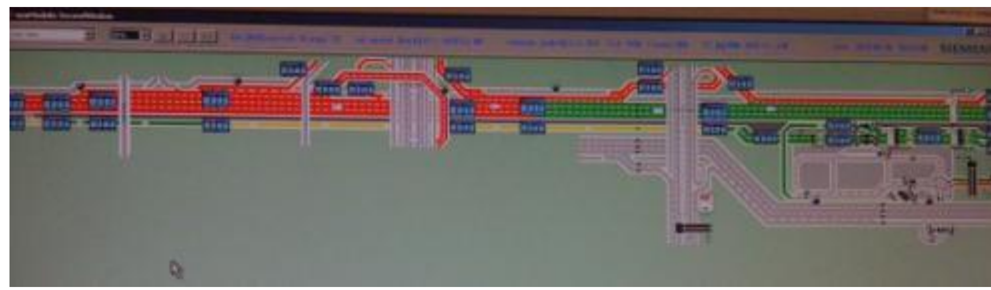
The parking lot

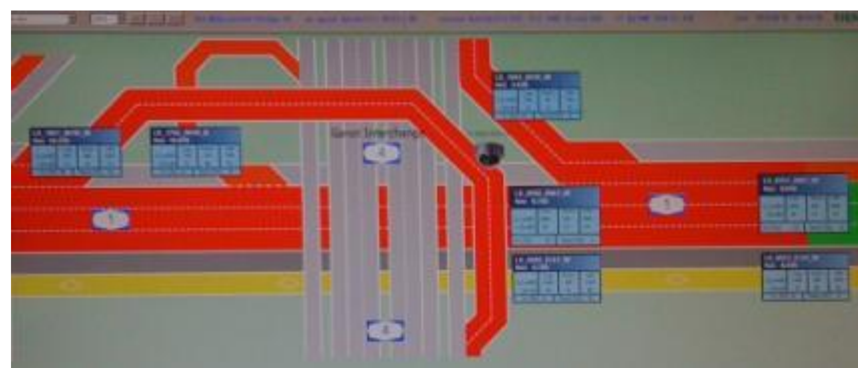
In the first months, on a typical day **by 12:00AM** there were about **900 vehicles** in the parking lot

Before

Photographs by Rodi Almog

After (Thursday, June 16, 2011)



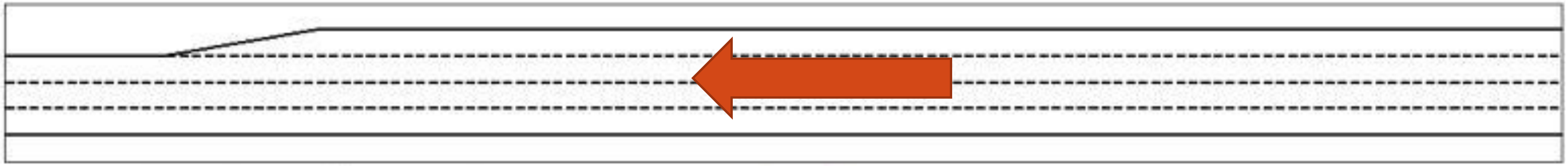


Research Motivations

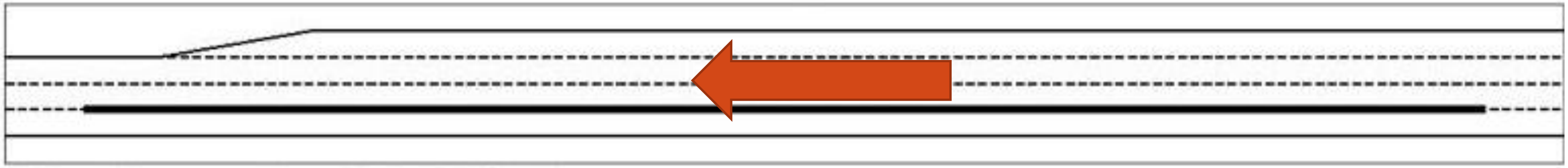
- The use of high-occupancy-toll (HOT) lanes increases continuously.
- A key challenge in HOT operation is how to set the tolls.
- Variability in travel demand creates additional complexity.
- A successful tolling scheme, whether fixed or time-varying, must be robust to changes in travel demand.

Case Study Facility

- Freeway with two lane groups: general purpose (GP) lanes, and a managed lane.
- Managed lane scenarios: GP (Base), HOV or HOT.
- Bottlenecks exist at the downstream end (deterministic point queue model).



(a) Base case



(a) Bottleneck with Managed Lane

Case Study Inputs

	Average Occ.	7:00-8:00	8:00-9:00	9:00-10:00
LOV	1.2	6300	5100	3900
HOV	4	600	600	600
Transit	40	300	300	300
Total		**7200**	**6000**	**4800**

HOT capacity: 1800 vphpl; GP capacity: 2100 vphpl; Length: 10 km; Free flow speed: 100 km/h.

Modeling Travelers' Lane Choice

LOGIT (conventional):

- Assumes choice probability is dictated by an i.i.d. random additive cost component per route, due to imperfect information for example.

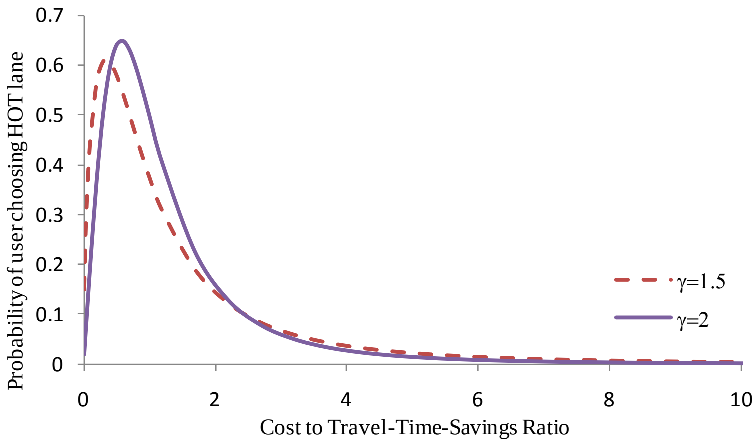
Value Of Time – VOT (proposed):

- Assumes primary variation in lane choice is due to VOT distribution (e.g. Burr).
- The proportion of travelers choosing the HOT lane is exactly the proportion of travelers whose VOT exceeds the current ratio of cost to time difference.

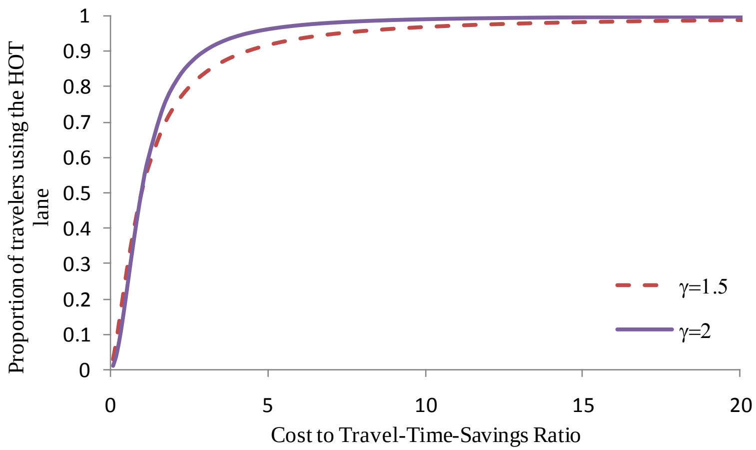
VOT-Based Distribution

Burr Distribution: Used to model household income distribution in a population

$$P_v^{VOT}(\Delta\tau, c) = 1 - F_v(c/\Delta\tau) \qquad \text{where} \qquad F\left(\frac{c}{\Delta\tau};\zeta,\gamma\right) = 1 - \frac{1}{\left[1+\left(\frac{c}{\zeta\cdot\Delta\tau}\right)^{\gamma}\right]}$$



The *probability* of a traveler choosing the HOT lane

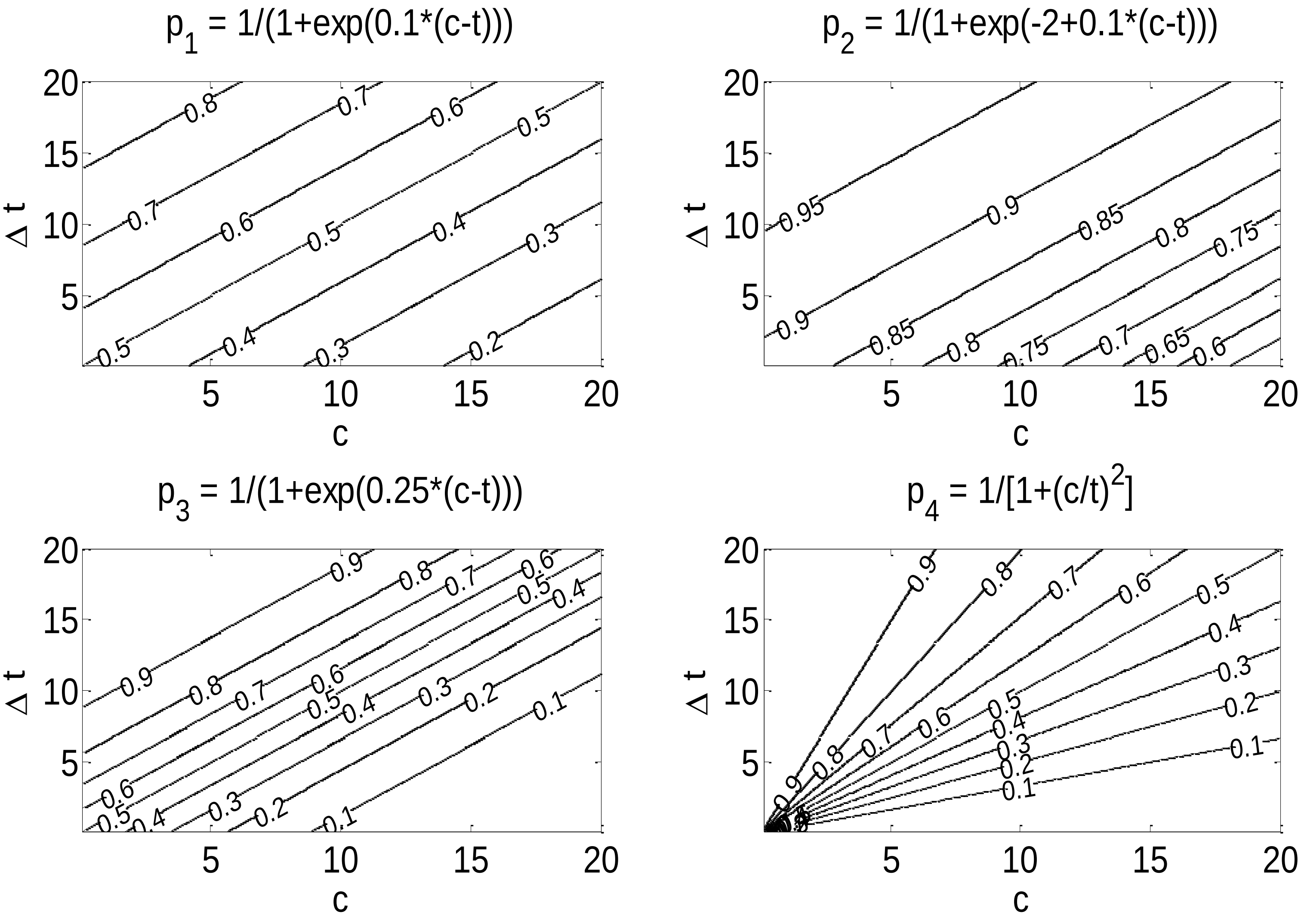


The *proportion* of travelers choosing the HOT lane, relative to the cost to travel-time-savings ratio

Travelers Indifference Curves

LOGIT 1

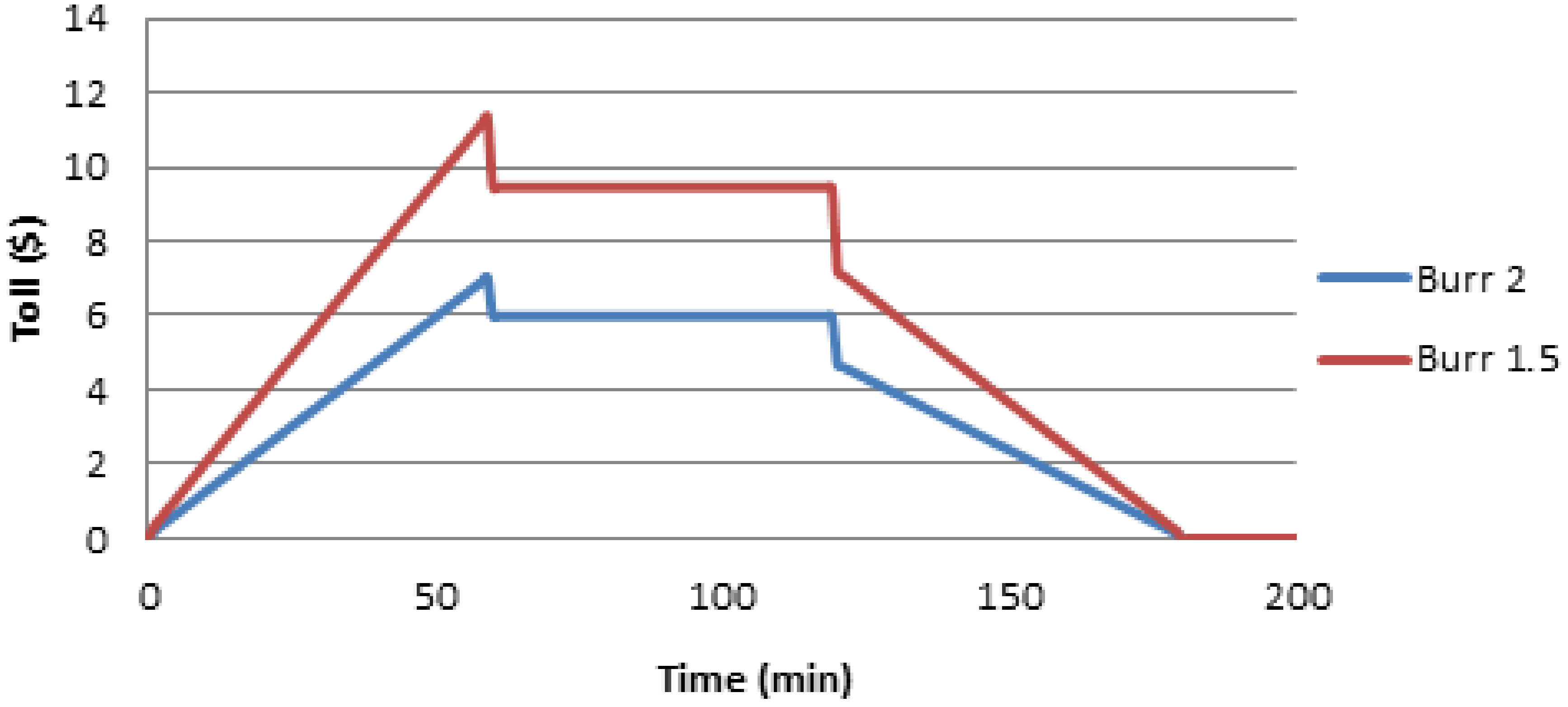
LOGIT 2



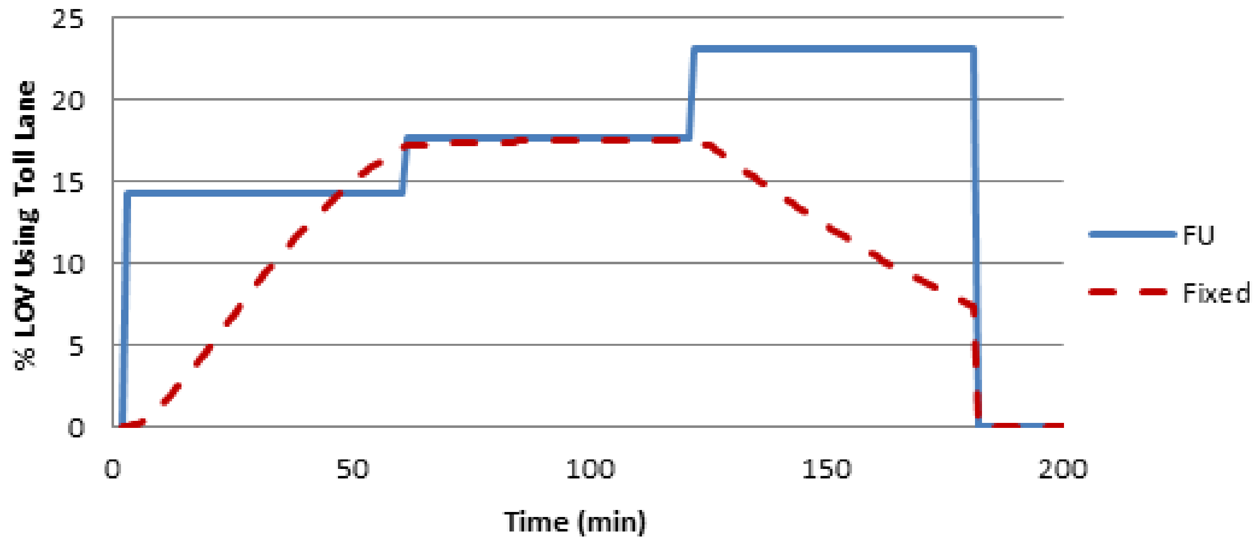
LOGIT 3

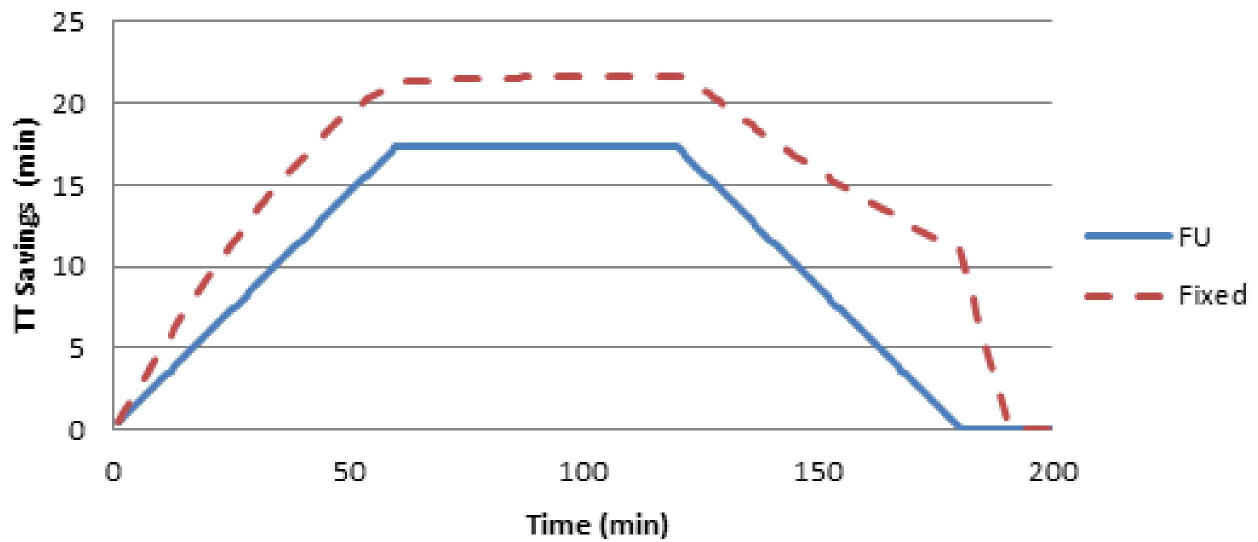
VOT

Full Utilization (Optimal) Tolls

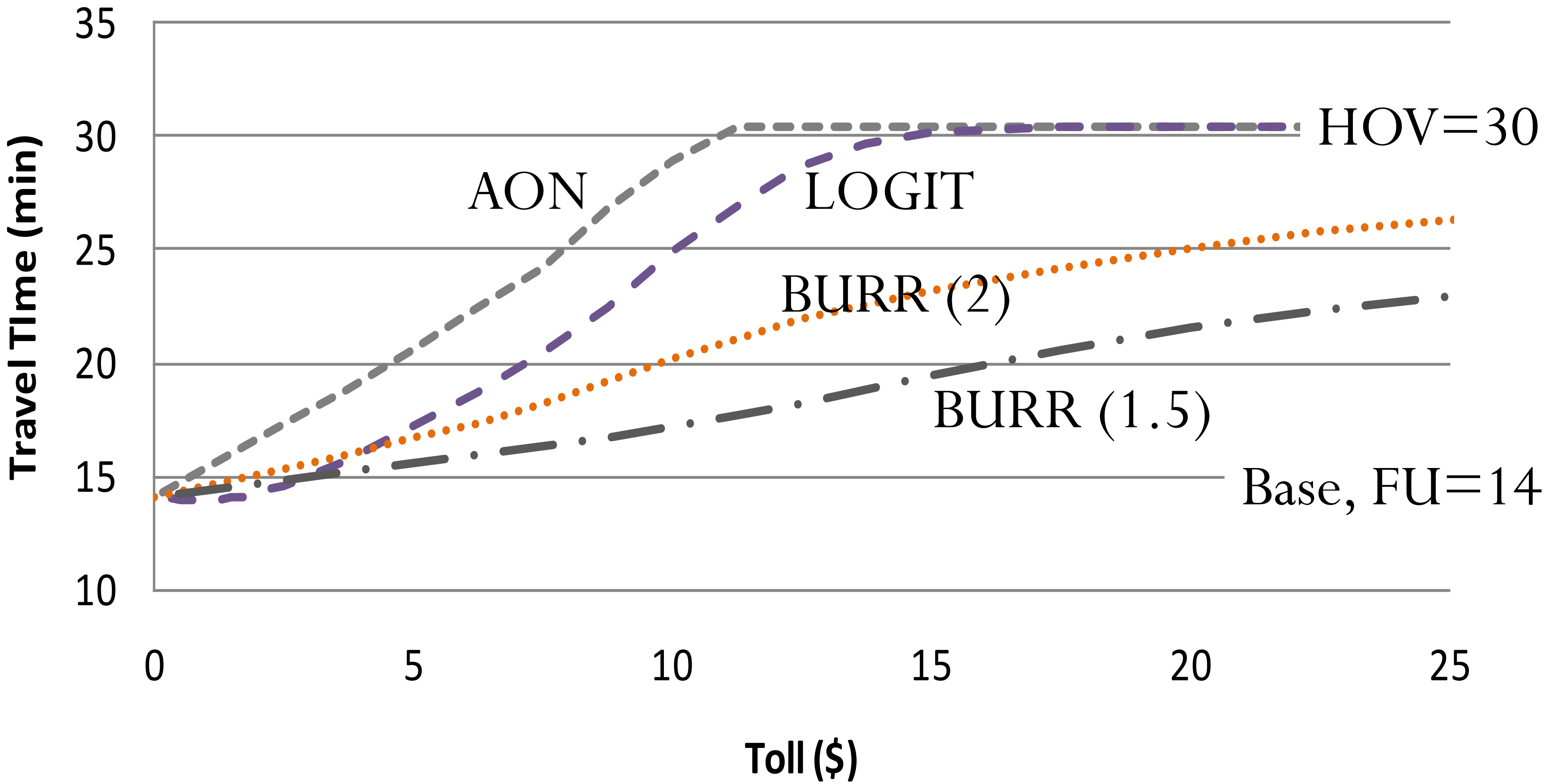


HOT lane usage and time saving

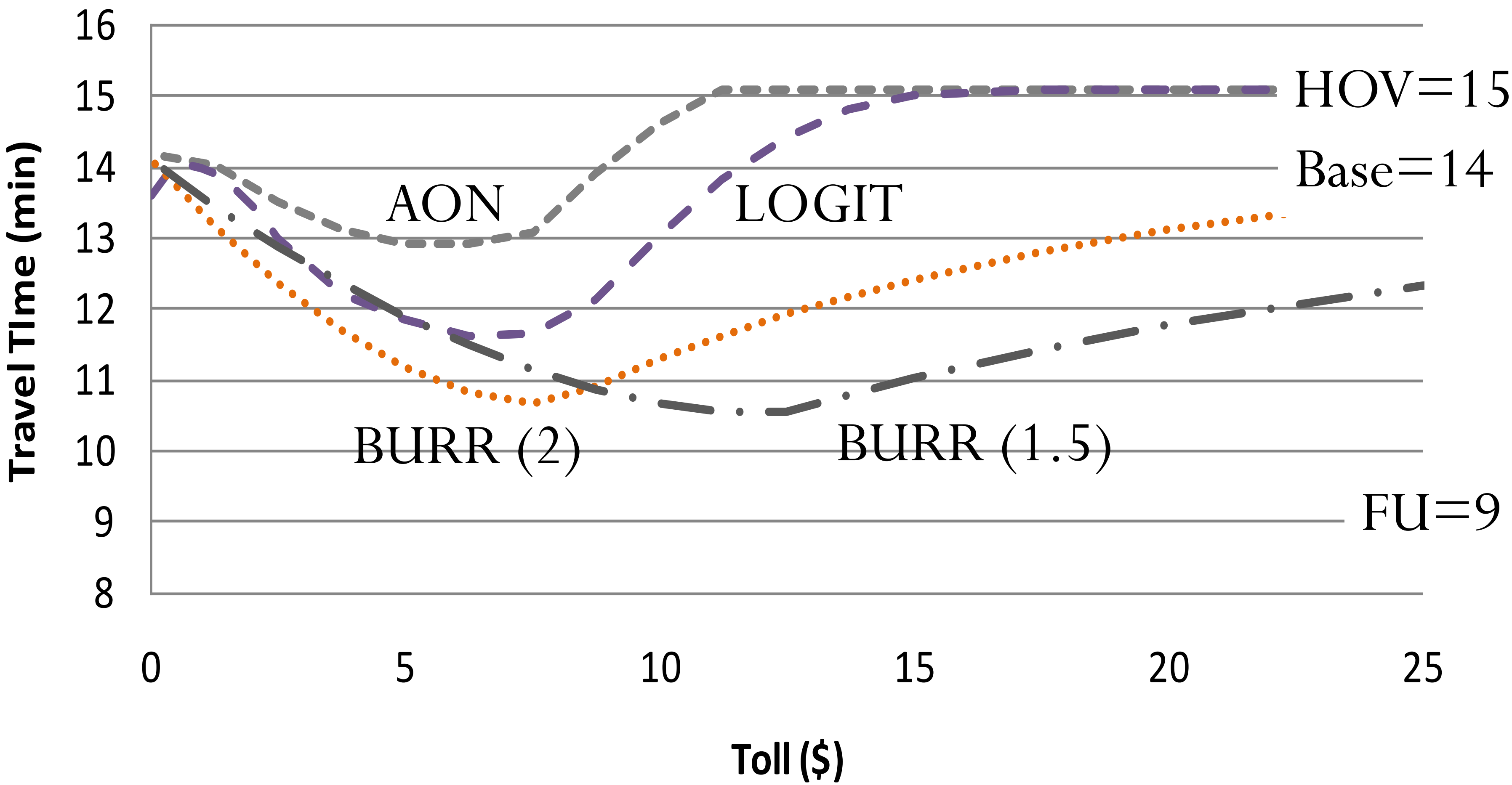




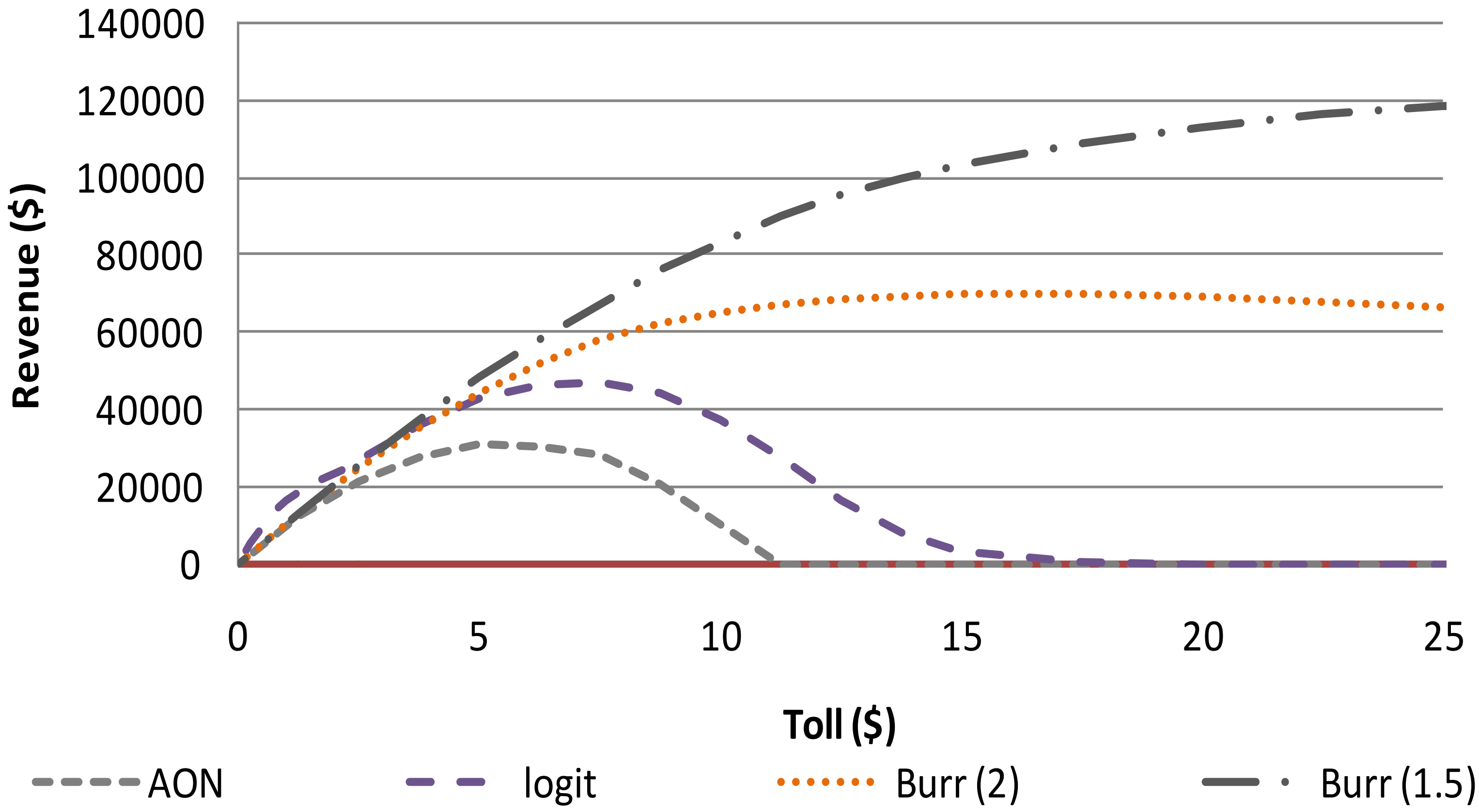
Average Vehicle Travel Time (AVTT)



Average Person Travel Time (APTT)



Revenue



140000
120000
100000
80000
60000
40000
20000
0
Revenue ($)
0
5
10
15
20
25
Toll ($)
AON
logit
Burr (2)
Burr (1.5)

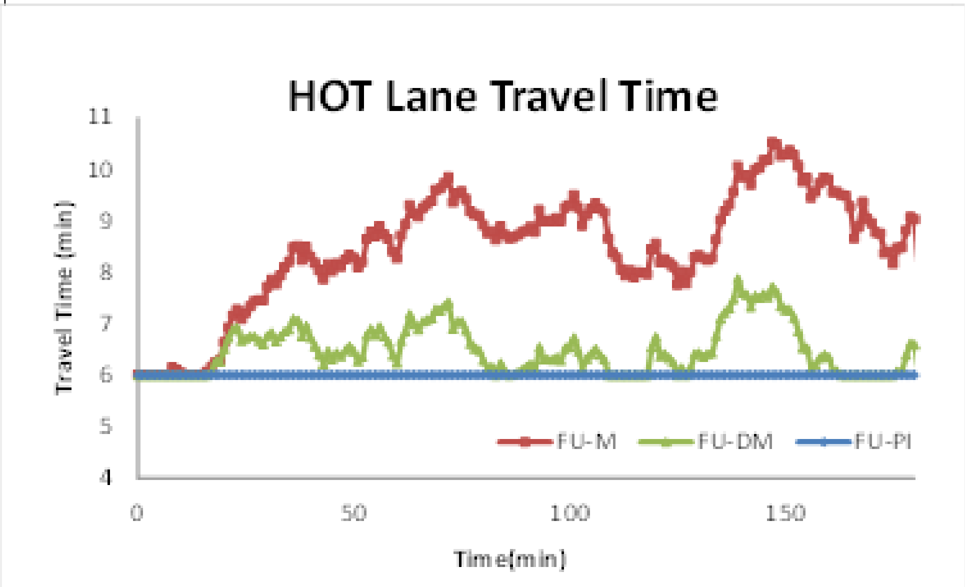
Stochastic Context

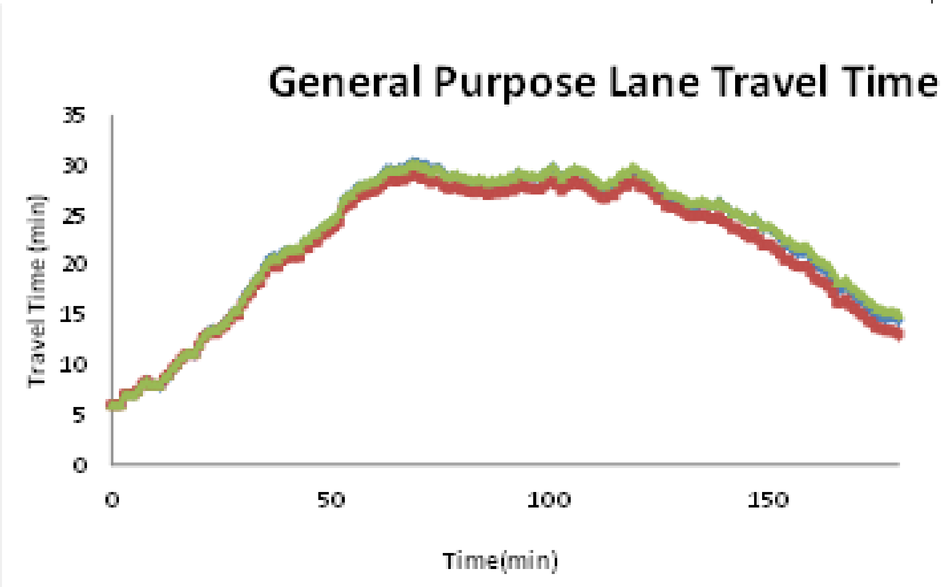
- Focus on demand uncertainty.
- Assume non-correlated day-to-day demand uncertainties.
- Implementation:
  - Arriving flow per minute is an independent random variable
  - Normally distributed.
  - The mean is determined by the time of day.
  - Scenario-specific Coefficient of Variation (CV).
- Assume a deterministic traffic flow model.

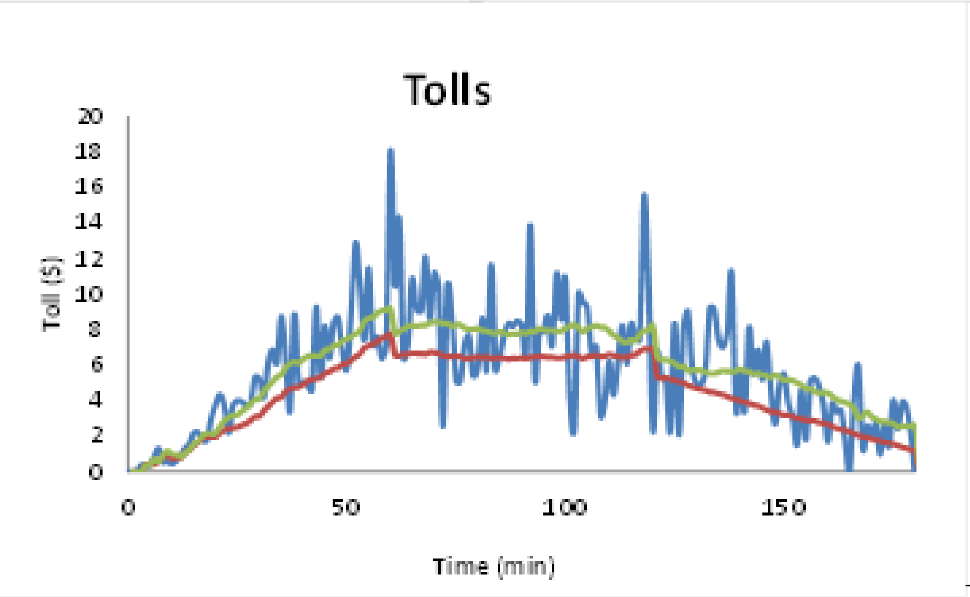
Dynamic Tolling Schemes

1. Fixed tolls (constant across time)
2. Pre-scheduled full-utilization tolls based on the mean demand values (**FU-*M***).
3. Real-time density-modified full utilization toll (**FU-D*M***). Tolls are set in ignorance of the current demand value, but modified based on the number of vehicles in the HOT lane.
4. Perfect information full-utilization tolls (**FU-PI**), where the demand realization is known to the operator before tolls are set.

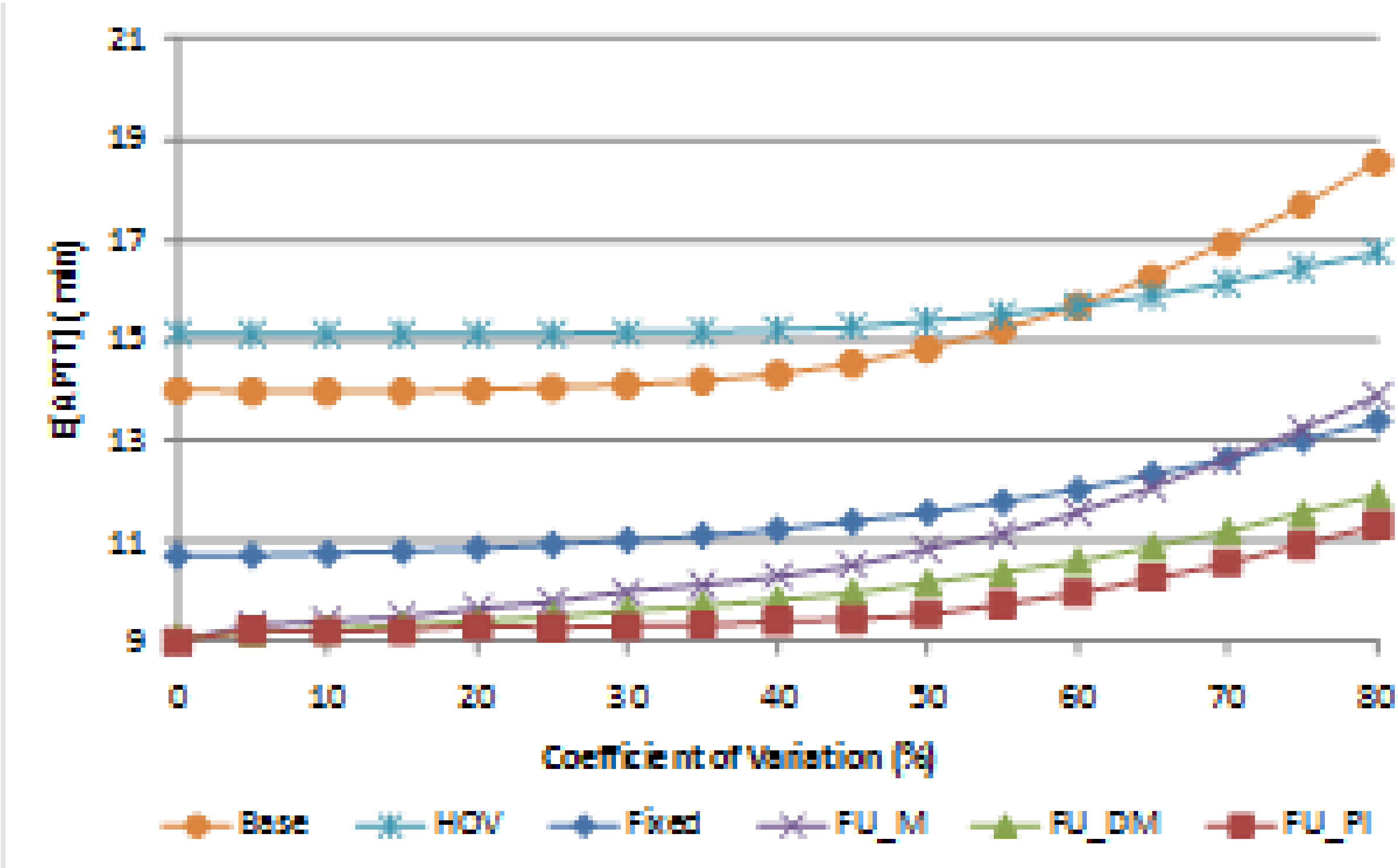
Behavior (CV=0.3)



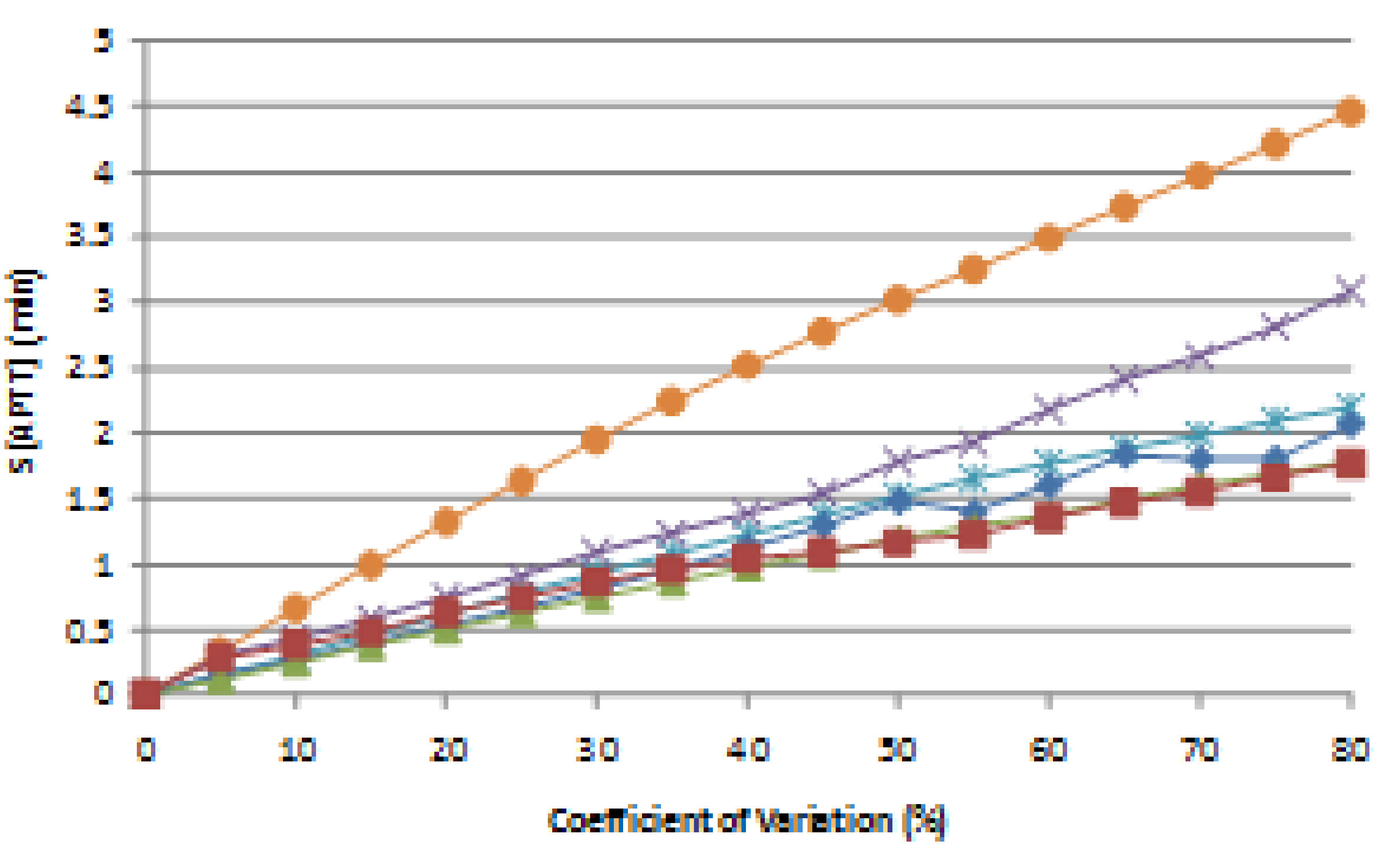




Expected Average Person Travel Time



Performance Measures (Stochastic)



Departure Time Choice Model

- Travelers are either “strategic” or “captive”
- Captive drivers can only use the GP lanes. Their demand can be stochastic.
- Strategic drivers can choose between GP lanes and the HOT lane. Their demand is deterministic.
- Strategic drivers are divided into discrete “classes” by VOT and target arrival time.
- 1 min early arrival penalty = 0.5 min travel time
- 1 min late arrival penalty = 1 min travel time
- Two-stage decision process: departure time in view of expected generalized cost, lane by revealed conditions.

Scenario

- Overall demand profile equivalent to case without departure time choice.
- Captive demand C.V is 0.4.
- 10 discrete VOT values, representing percentiles (counted from the top) according to Burr distribution.
- Target arrival time resolution is one minute.
- Full utilization toll schemes: Perfect Information (PI); Mean (factor=1.0); Density Modified (DM, factor=5).
- 300 MSA iterations of departure time choice.

Main Metrics

Metric	All GP	Fixed ($30)	Mean	DM	PI
AVTT	19.6	21.8	17.9	17.7	17.5
APTT	20.1	13.8	10.5	10.4	10.3
ANTD	24.1	22.7	18.3	18.1	17.9
Revenue ($\times 10^3$)	0	144	143	146	140

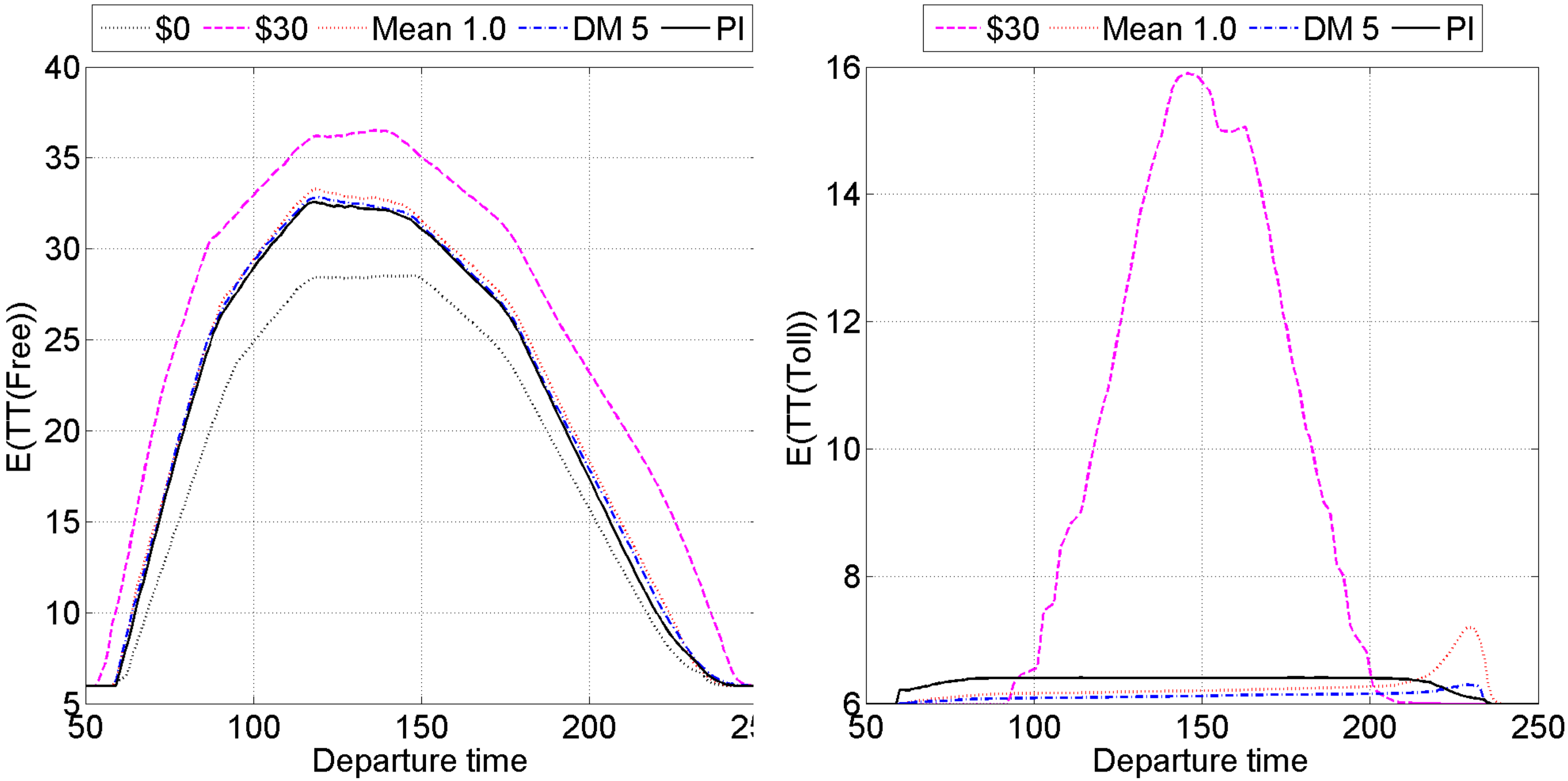
AVTT: Average vehicle travel time

APTT: Average person travel time

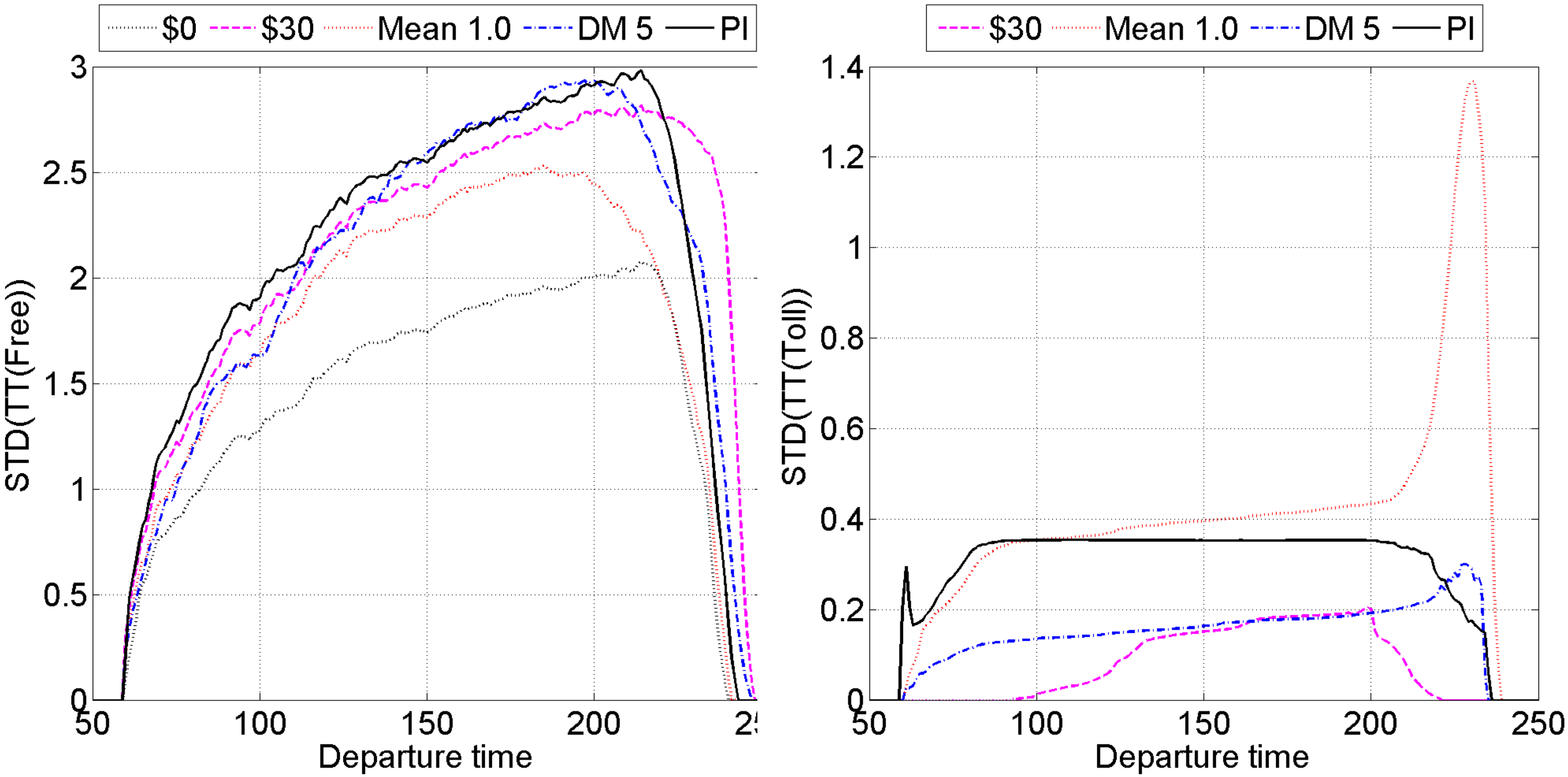
ANTD: Average non-transfer disutility

Calualtions are based on 200 Samples

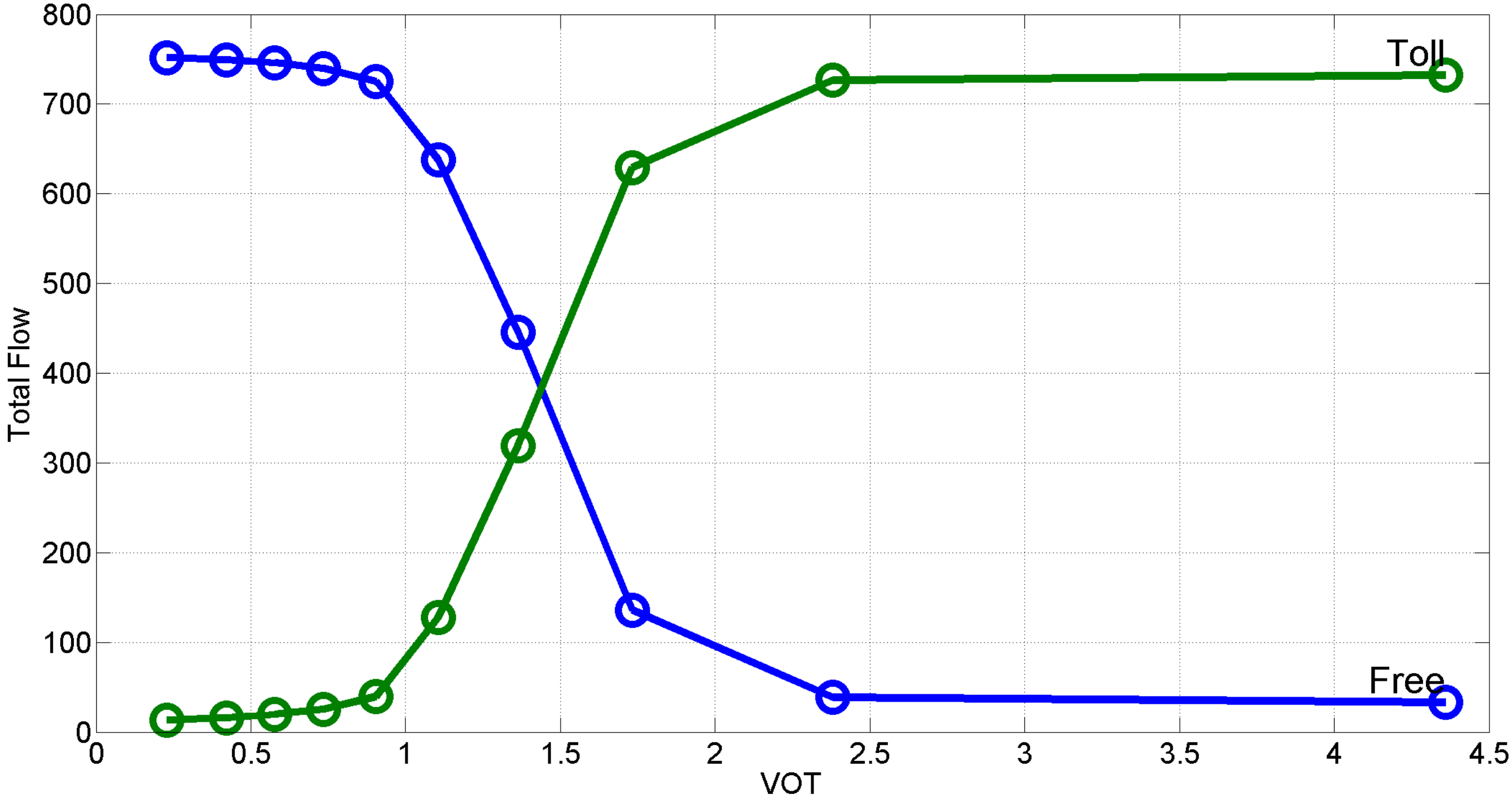
Travel Time Profile



Travel Time Variability

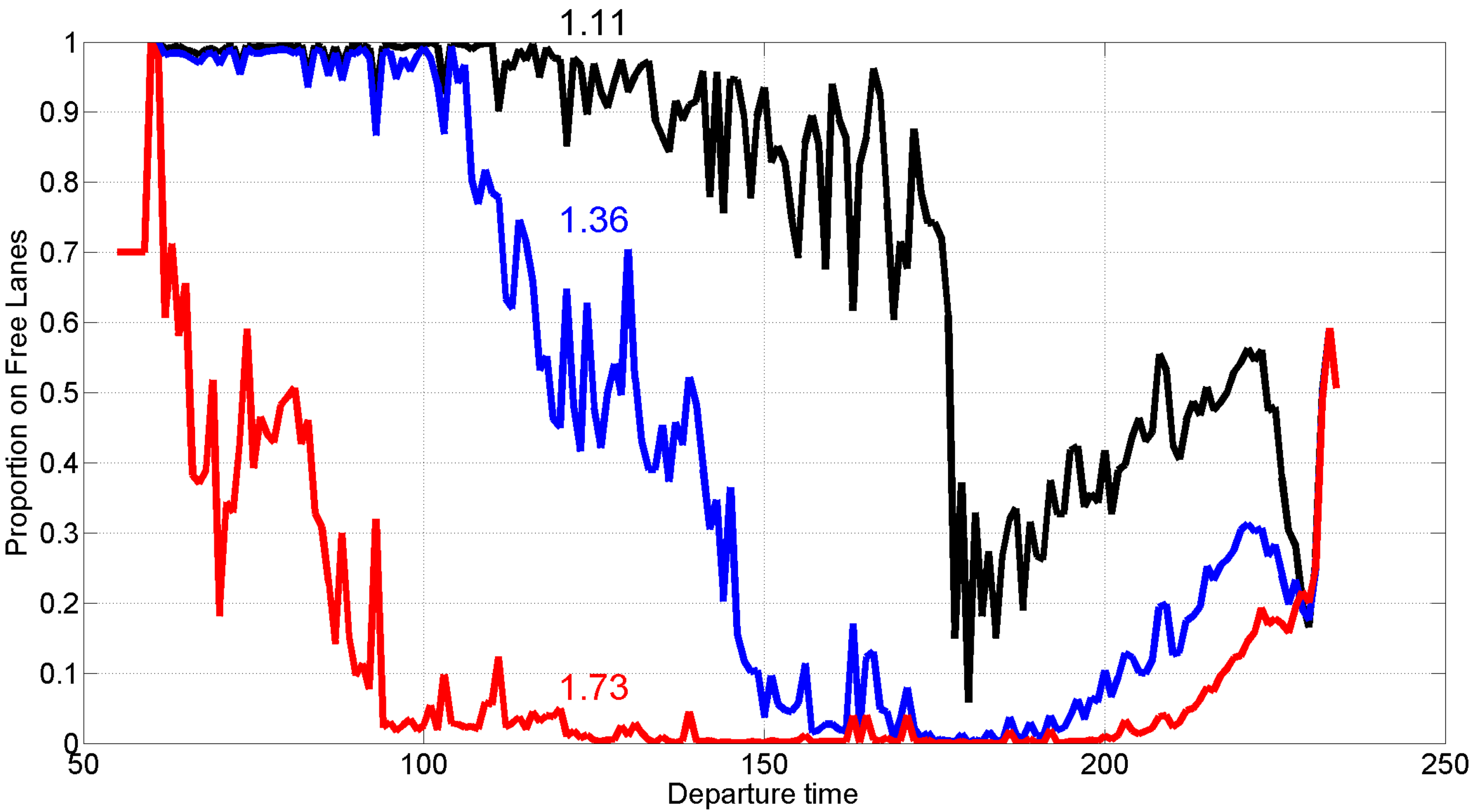


Overall lane choice by VOT



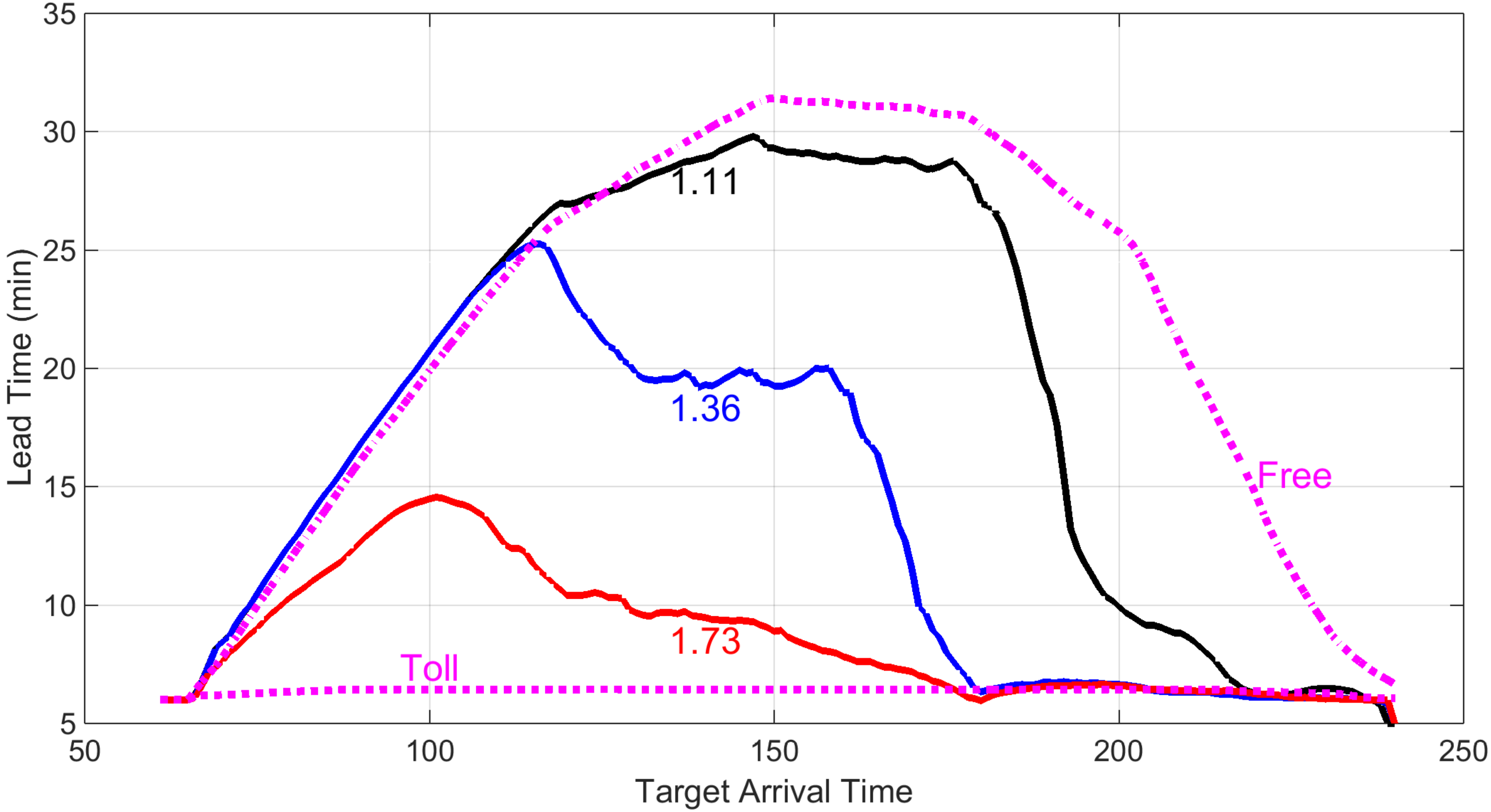
Toll scheme is PI

Free lane usage by departure time and VOT



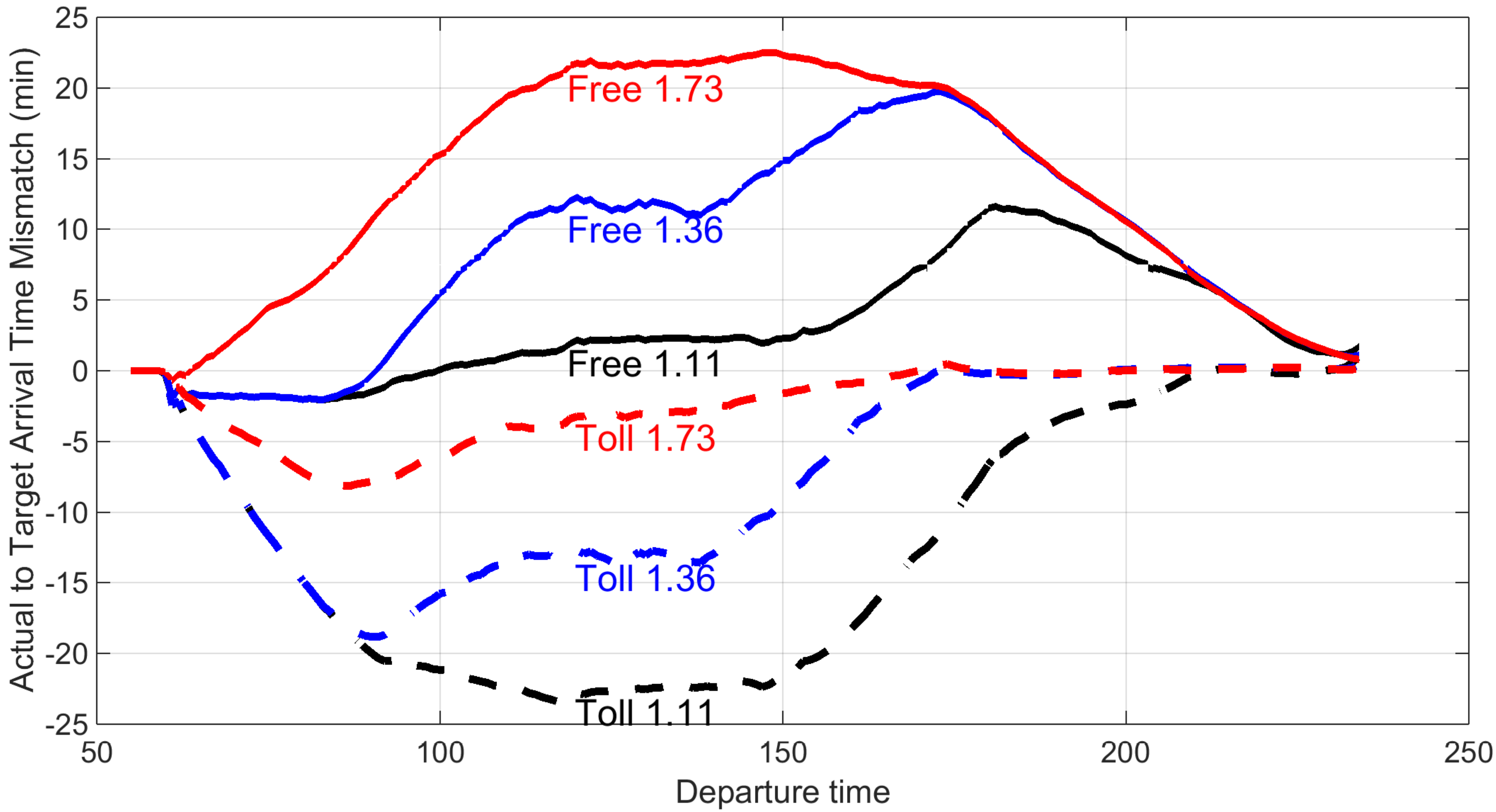
Toll scheme is PI

Lead time by target arrival time and VOT



Toll scheme is PI

Arrival time mismatch by lane and VOT



Toll scheme is PI

Conclusions

- HOT lanes are a promising option for Pareto improvements of freeway corridors.
- A fixed toll value (24/7) may achieve a decent portion (2/3 in the examined case studies) from the theoretical potential benefit in terms of average passenger travel time.
- Pre-determined toll profile can handle reasonably well non-trivial uncorrelated demand uncertainties (up to CV=0.3).
- Departure time choice reduces real time toll elasticity.