Toronto Road Pricing:
The good, the bad and the complex

Optimized Time-Dependent Congestion Pricing System for Large Networks

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Outline

- Motivation
- Theory
- U of T's Reusable Framework and System
- Application to the GTA
- Conclusions

What is Congestion Pricing?

- Road pricing is any system that directly charges motorists for the use of a road or network of roads.

- Congestion pricing refers to road tolls intended to *reduce* traffic congestion or to *distribute* it more evenly over time and space.

Congestion Pricing Inevitable

- Much like traffic lights are!
- Viable congestion control tool
- Revenue is a (welcomed?) by product
- Why inevitable?
  - Demand/Supply > 1.0 ---→ Congestion
  - Spills over longer periods and larger space
  - Constrained supply (space, $, environment)
  - Ever increasing demand
  - Ever increasing congestion until it chokes the metropolis
- Not a matter of if, but when, where and how

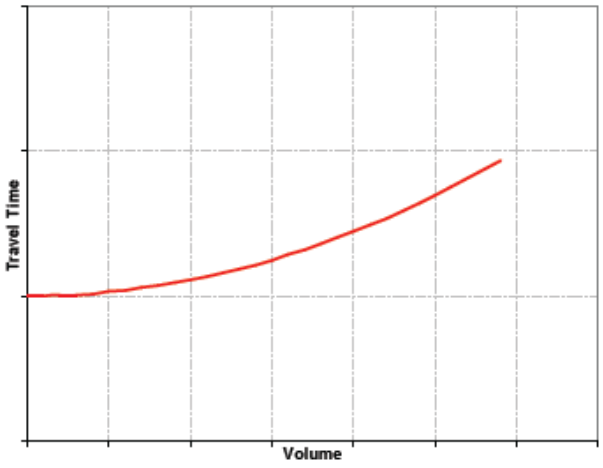
Evidence Why Congestion Pricing?

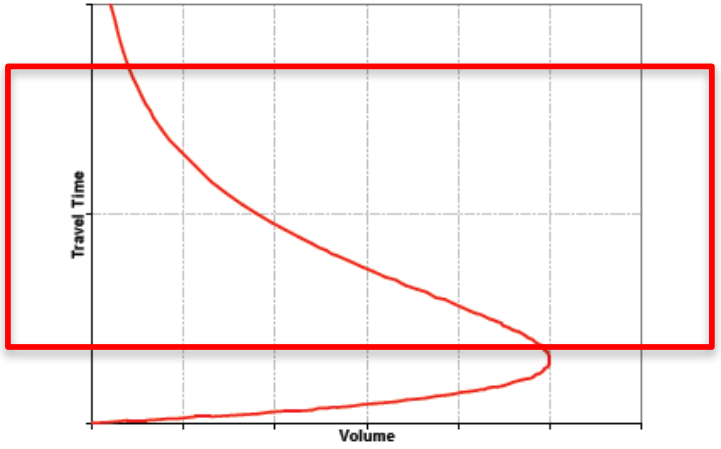
Tragedy of the commons *(Hardin, 1968)*.

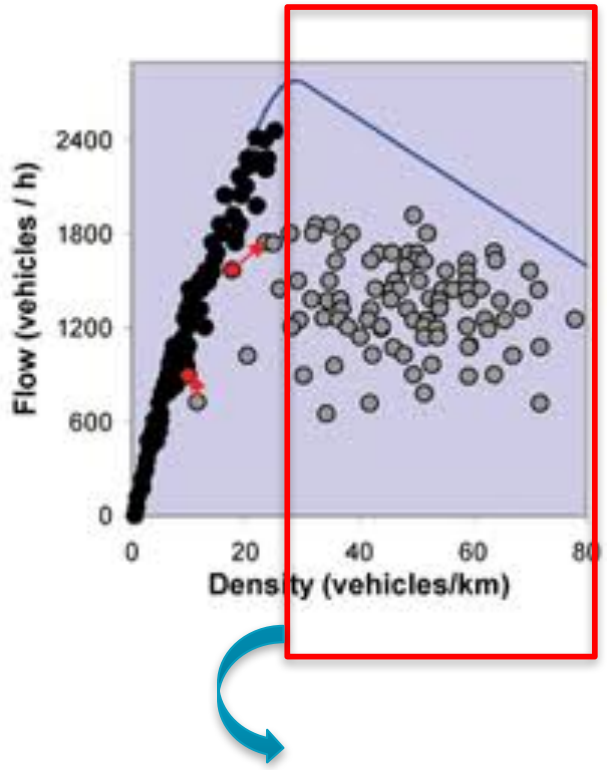
VKT is quite responsive to price, as opposed to transit/capacity expansions *(Duranton and Turner, 2011)*.

Therefore, policy makers should emphasize *not only* on improving the supply of alternative modes *but also* on financial disincentives for auto use.

Traffic 101: what is congestion?



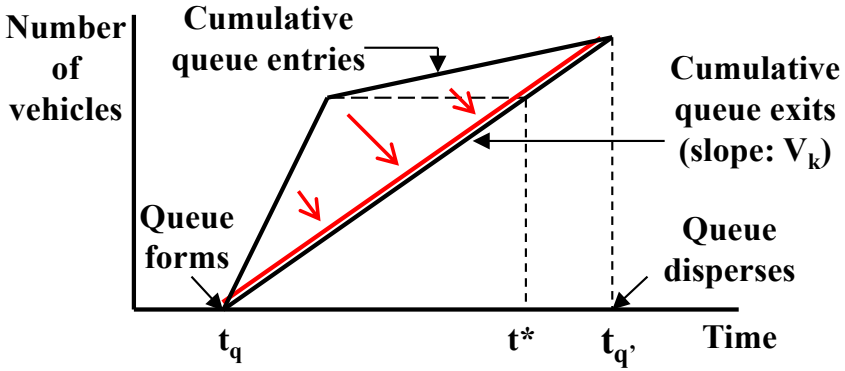


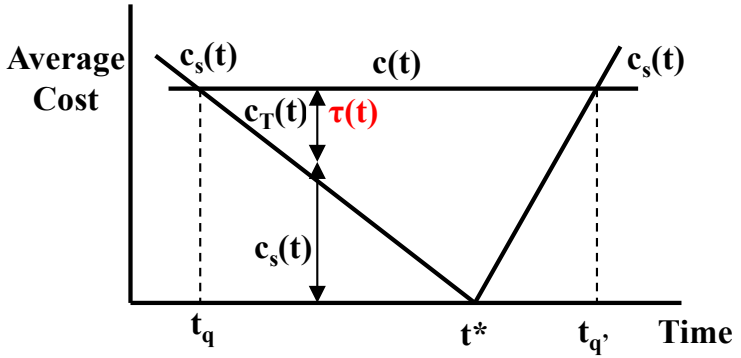


- Hyper-congestion, or
- Supercritical congestion

Dynamic Hyper-Congestion Pricing

The Basic Bottleneck Model



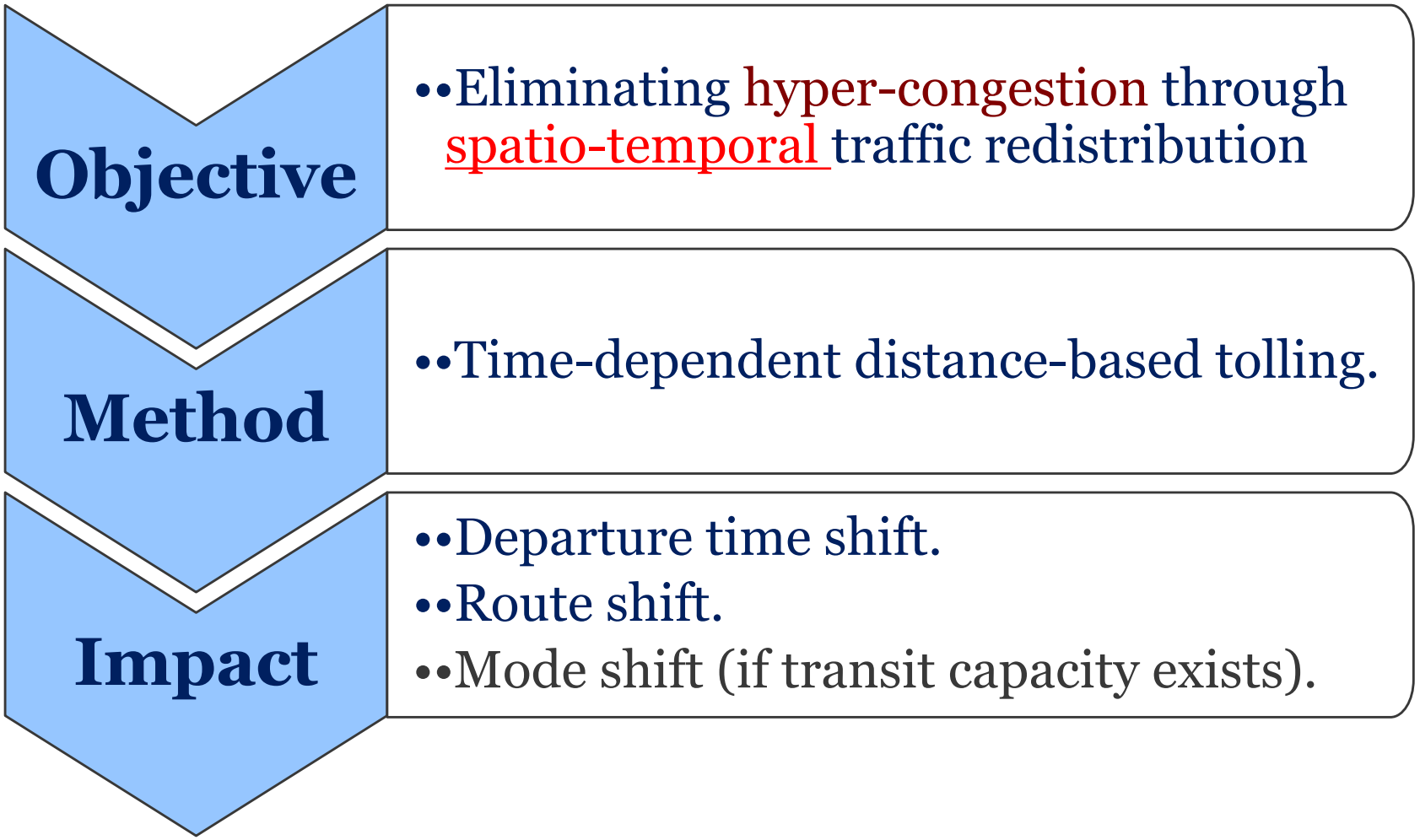


Optimal pricing in the Bottleneck Model

→

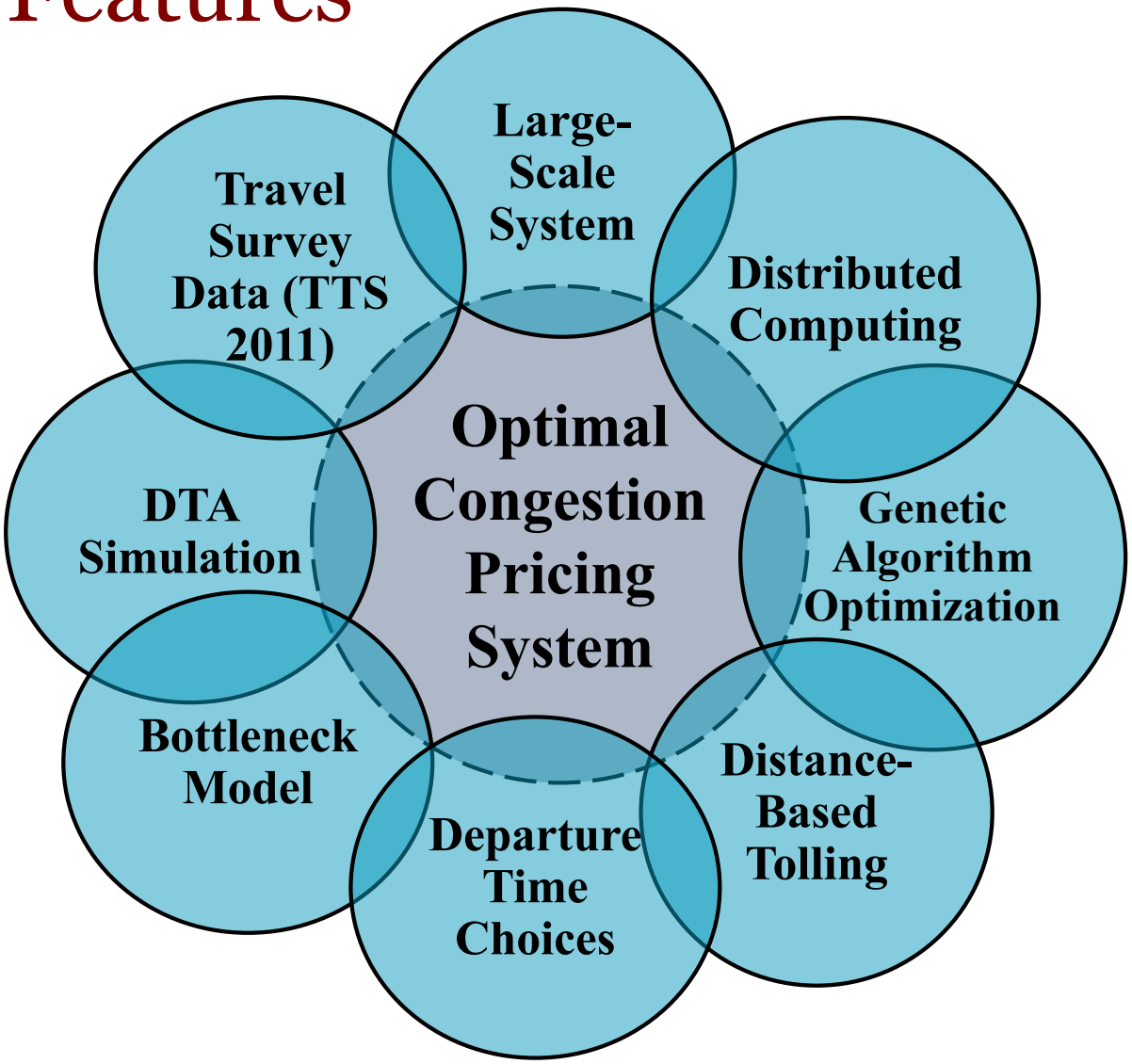
Departure-time rescheduling.

Generalized Dynamic Congestion Pricing

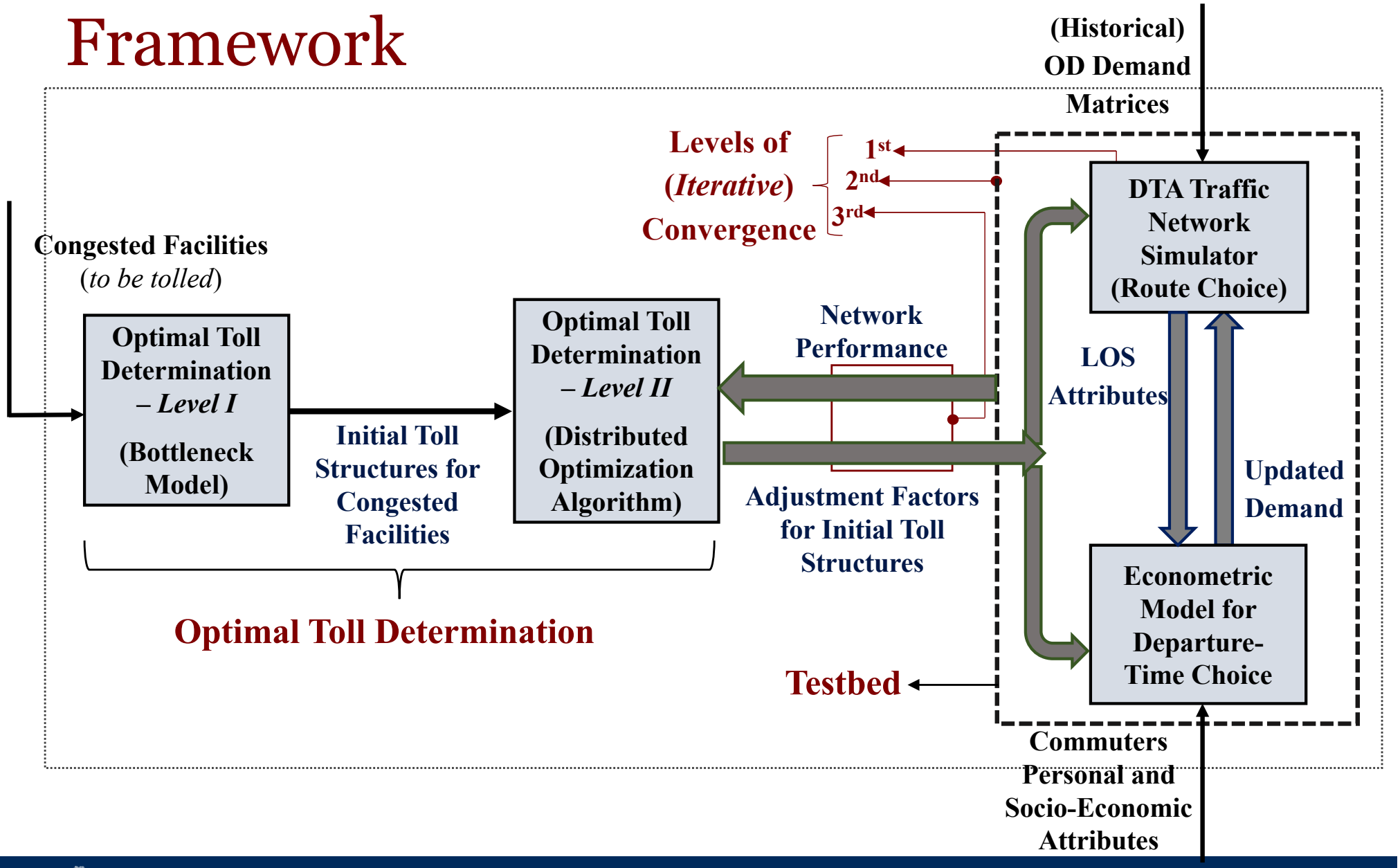


Optimal Congestion Pricing System

Design Features



Optimal Congestion Pricing System Framework



Greater Toronto Area Case Study

Toll Determination – Level I: The Bottleneck Model

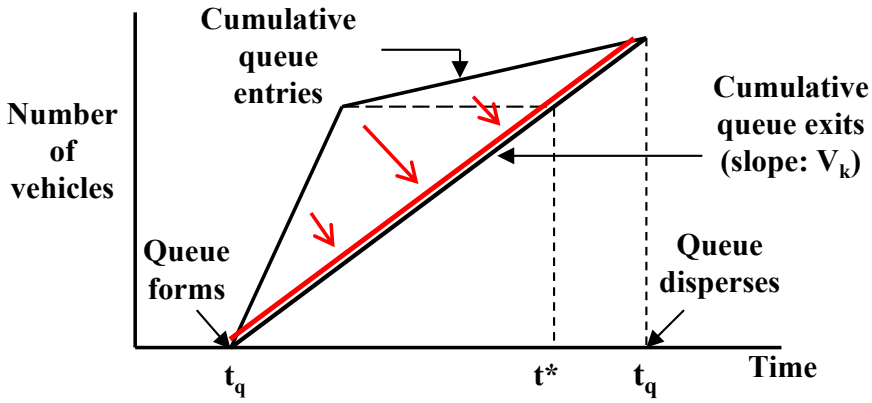
Initial (sub-optimal) step-toll structure determination procedure:

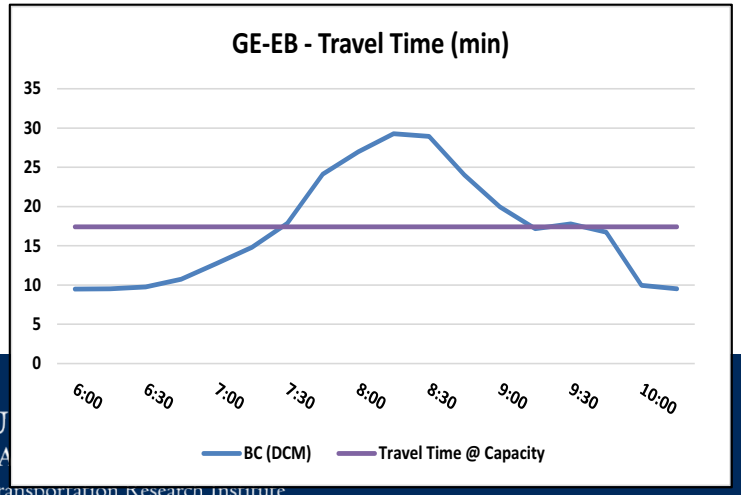
1- Travel time (hence queueing-delay) estimation.

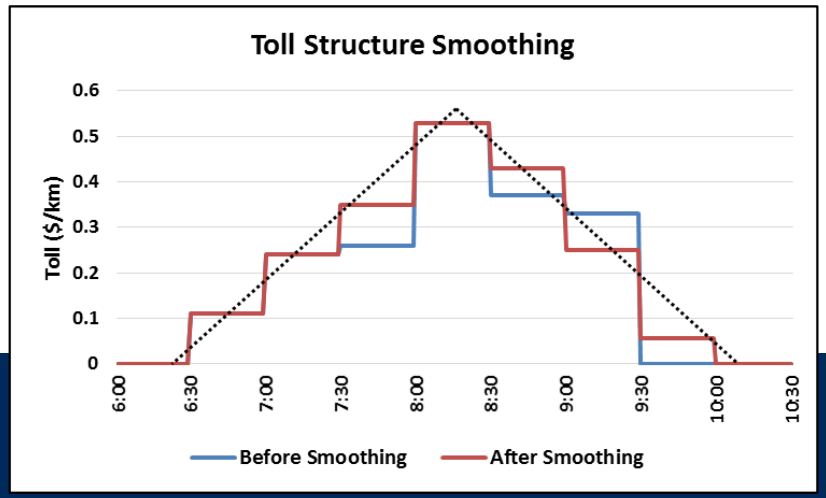
2- Identify the tolling period and set the max toll value.

3- Determine the full toll structure.

4- Toll structure smoothing.



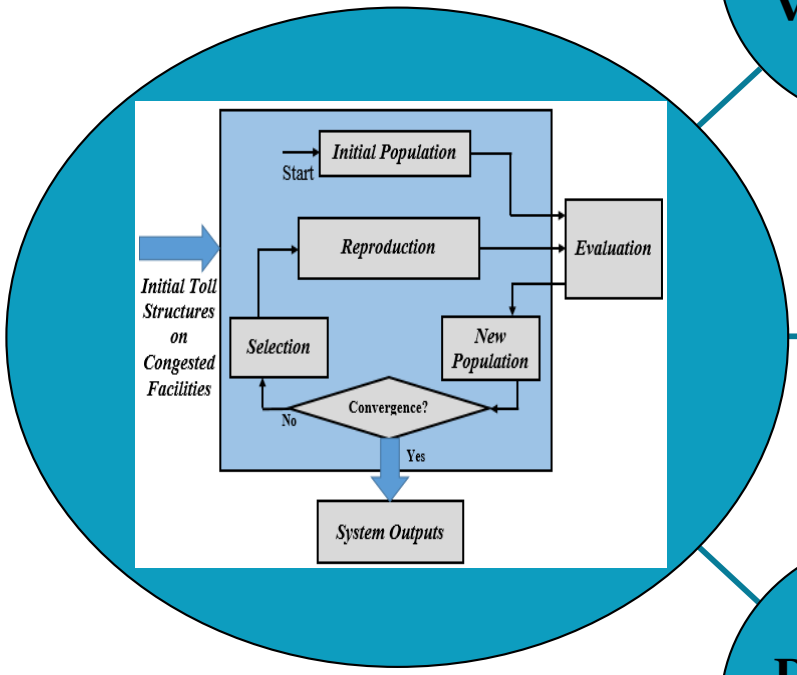




Toll Determination – Level II: Distributed Genetic Algorithm *(Mohamed, 2007)*

Decision Variables

- Scale factors for initial toll structures.
- Variables' ranges.



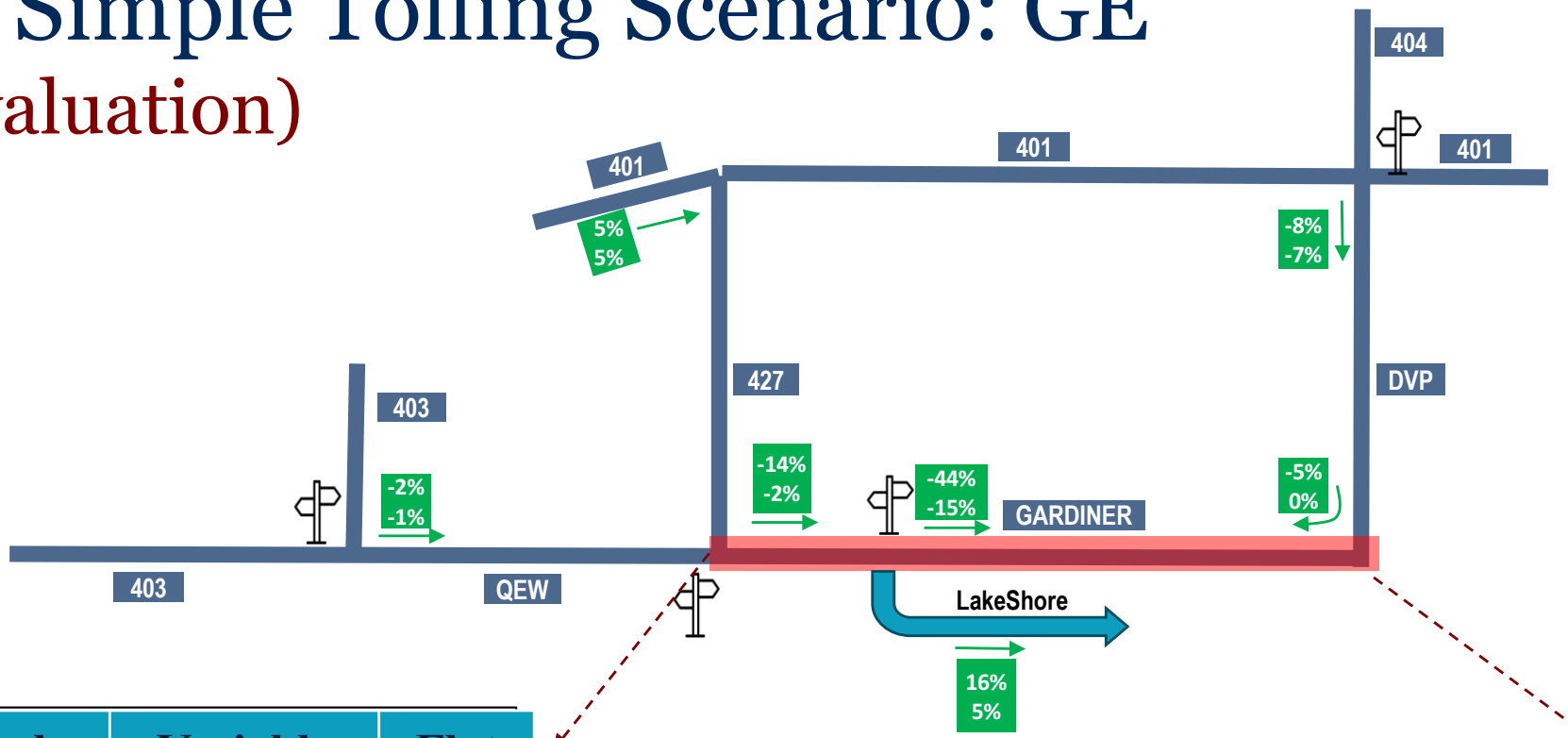
Objective Function

- Total travel times then utilization levels (flow*speed).
- Optimization problem segmentation for "quasi-flat" fitness phenomenon.

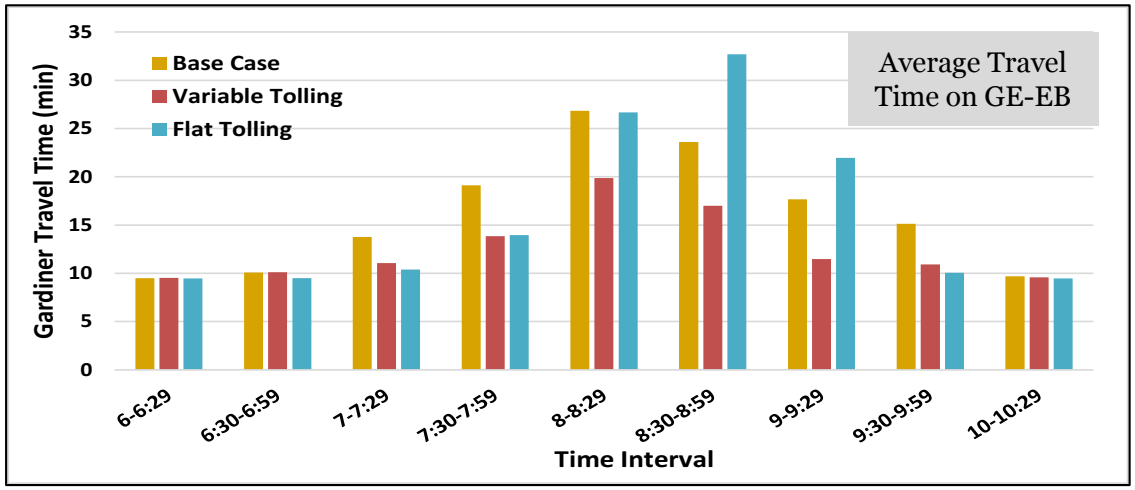
Distributed Computing

- Apache Ignite: Map-reduce paradigm.
- Calibration of Parallel cluster.
- Linear speedup.

(I) Simple Tolling Scenario: GE (Evaluation)



% Travel Time Savings	Variable Toll	Flat Toll
GE-EB (tolled route)	25% (8-8:30 am)	-ve ?
GE Corridor	9.5%	2%
Network-Wide	1.7%	0.6%



(II) Extended Tolling Scenario: GE, DVP, and 401 Express

1

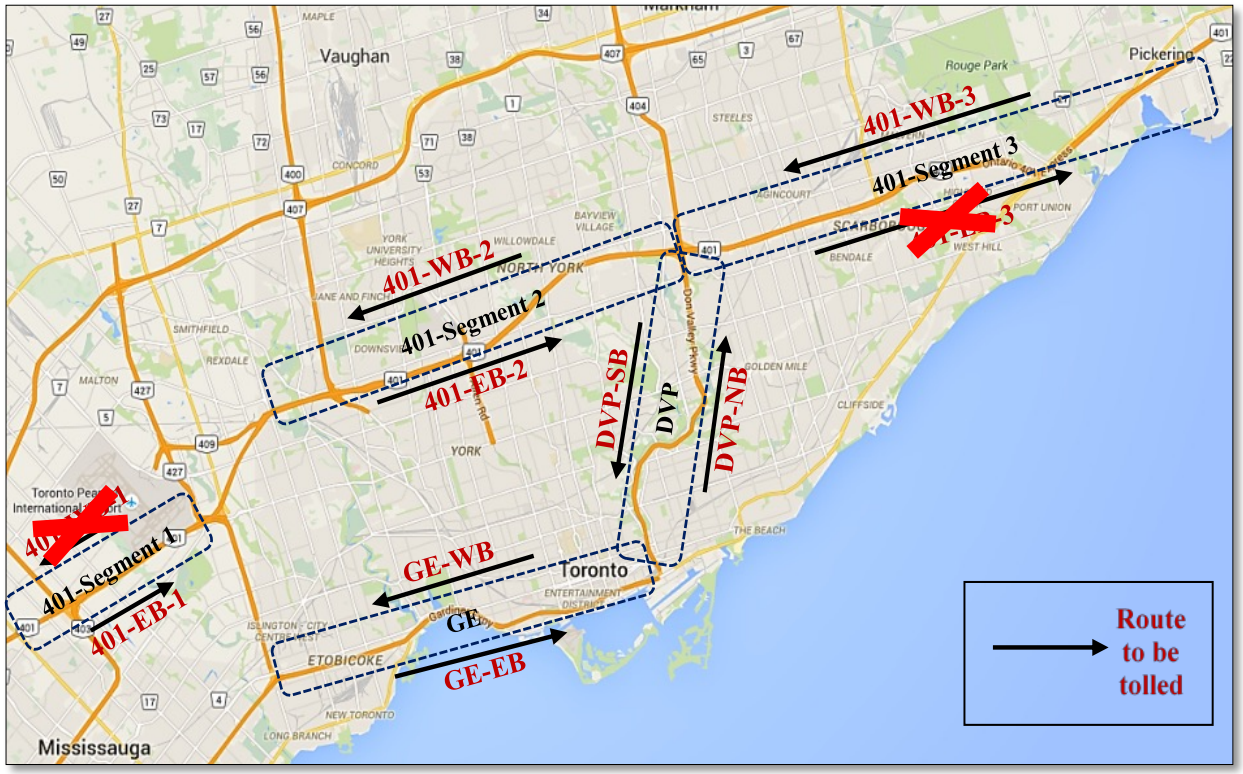
GE-EB
DVP-NB

2

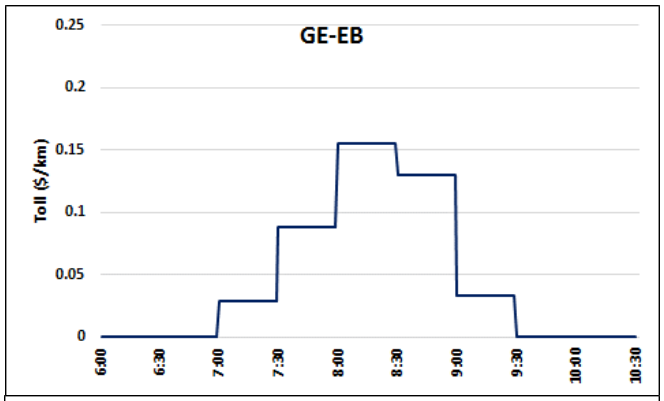
401-EB-1
401-EB-2

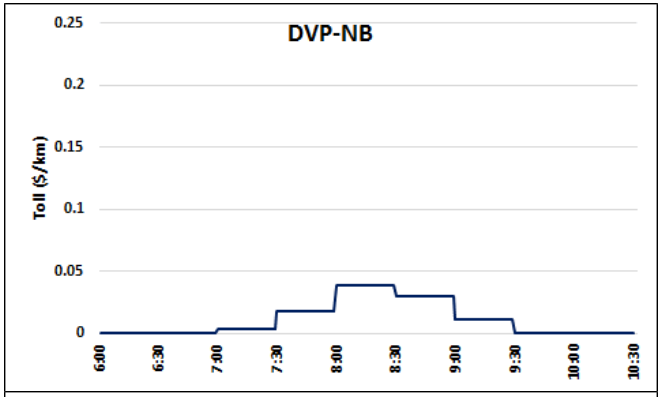
3

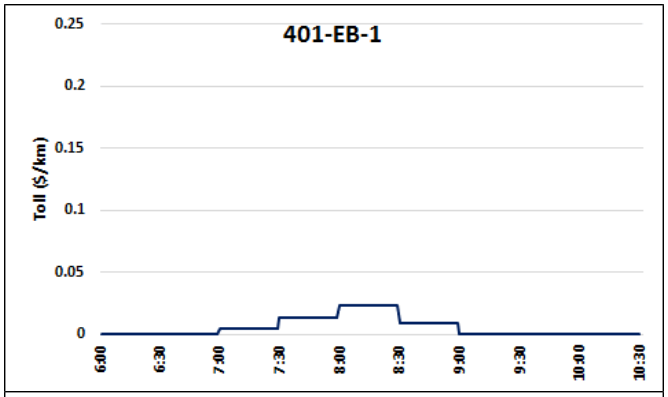
401-WB-3
401-WB-2
DVP-SB
GE-WB

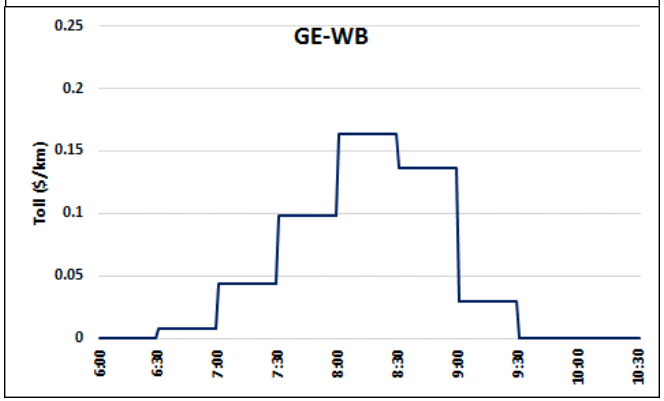


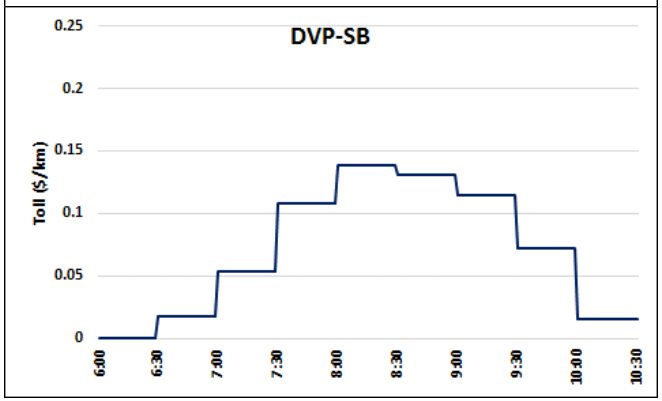
(II) Extended Tolling Scenario: GE, DVP, and 401 Express (Optimal Toll Structures)

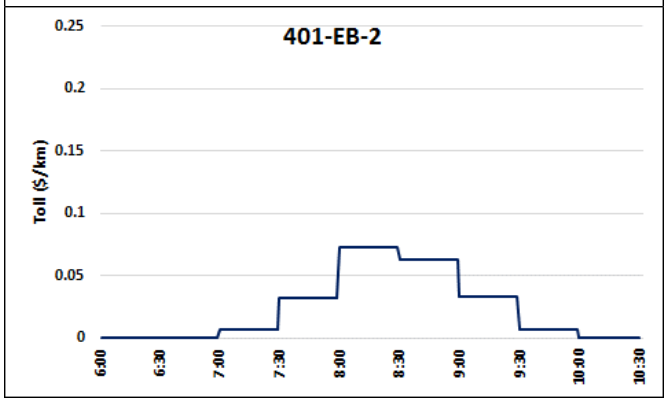


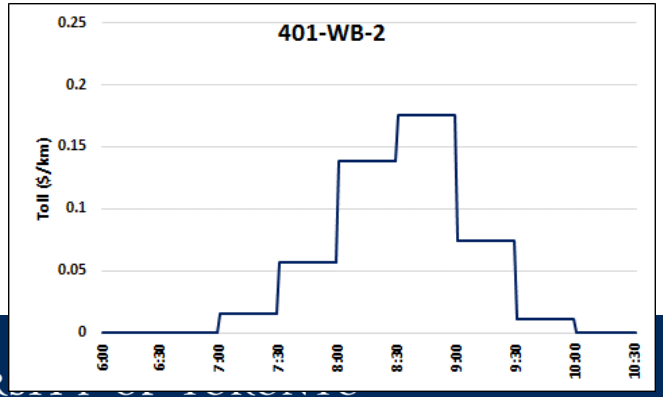


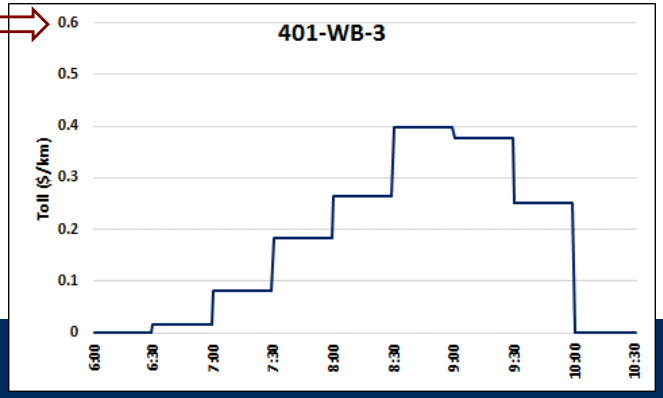












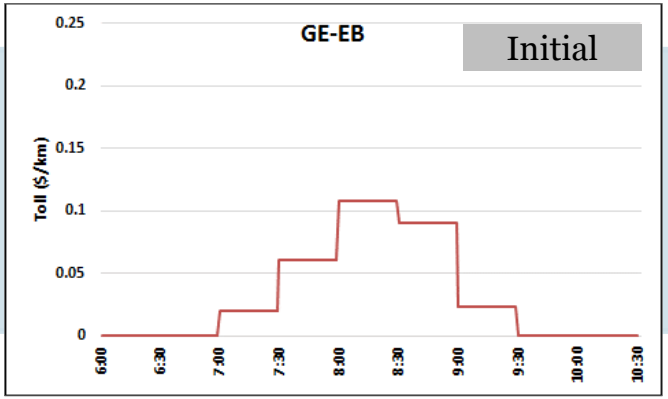
(II) Extended Tolling Scenario: GE, DVP, and 401 Express (Total Travel Time Savings)

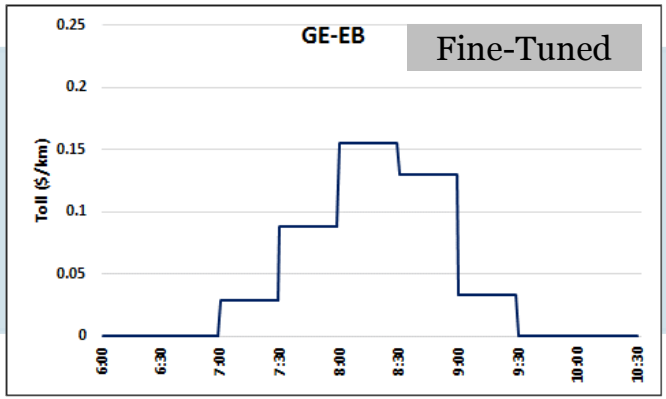
Network-Wide (2 million trips)	• 10,313 hr. (1.7%)*
Trips using tolled corridors (455,000 trips)	• 7831 hr. (2.91%)*
Trips using tolled routes (220,000 trips)	• 12,457 hr. (7.5%)*

** percentages are calculated relative to the total base case travel times of each group.*

(II) Extended Tolling Scenario: GE, DVP, and 401 Express (Corridor Analysis Ex. 1: GE-EB)

Toll Structure

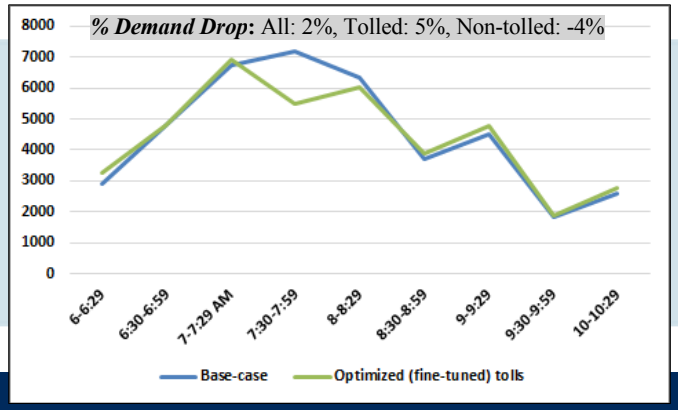


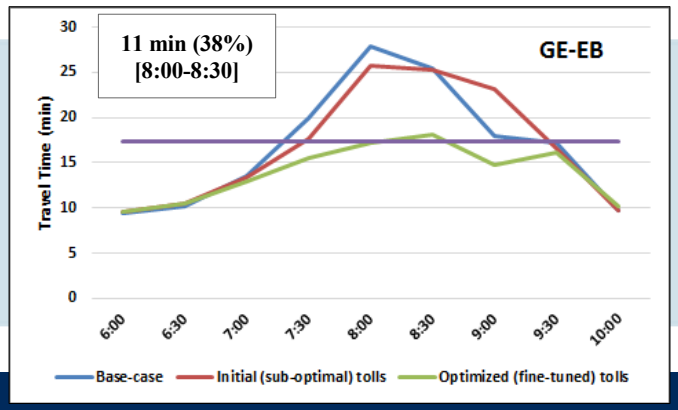


Utilization Level

Route	Base-Case	Initial Toll Structures	Fine-Tuned Toll Structures
GE-EB (*Tolled*)	7.20E8	7.39E8 ▲	7.58E8 ▲▲
GE-EB (*Parallel*)	9.48E8	9.69E8 ▲	9.57E8 ▲▼
GE-EB (*Corridor*)	**1.67E9**	**1.71E9 ▲**	**1.71E9 ▲▲**

Tolled Route





(II) Extended Tolling Scenario: GE, DVP, and 401 Express (Annual Benefit-Cost Analysis)

<table>
<tr><th>Entity</th><th colspan="2">Overall Costs ($ Millions)</th><th colspan="2">Overall Benefits ($ Millions)</th><th>Benefit-Cost Ratio</th></tr>
<tr><td rowspan="3">Government (Producer)</td><td>Capital Cost:</td><td>Annual Cost:</td><td>Toll Revenues</td><td>Travel Time Savings</td><td rowspan="3">2.15
(after 1st year)</td></tr>
<tr><td>88.5</td><td>73.2</td><td>76.8</td><td>80.5</td></tr>
<tr><td colspan="2">Total Producer Costs:
1st year: 161.7
After 1st year: 73.2</td><td colspan="2">Total Producer Benefits: 157.3</td></tr>
<tr><td rowspan="3">Toll Payers (Consumers)</td><td colspan="2" rowspan="3">Toll Paid: 76.8</td><td>Travel Time Savings</td><td>Schedule-Delay Savings</td><td rowspan="3">1.61</td></tr>
<tr><td>97.2</td><td>26.4</td></tr>
<tr><td colspan="2">Total Consumer Benefits: 123.6</td></tr>
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Conclusions

- Comprehensive tool for optimal time-dependent tolling strategies in large-scale networks.
- The results demonstrate that:
  - optimal variable pricing mirrors temporal and spatial congestion
  - induces proper departure-time re-scheduling and rerouting
  - improved average travel times and schedule-delays at all scales in addition to benefits to toll payers.
  - more benefits are attained from variable tolling due to departure-time rescheduling as opposed to re-routing only in flat tolling.
  - optimal toll levels intended to manage traffic demand are significantly lower than those intended to maximize toll revenues.

Thank you

Questions?