

Dedicated lanes, tolls and ITS technology

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**The Future for Interurban Passenger Transport
Bringing Citizens Closer Together**

SESSION 4: TRANSPORT SYSTEM INTERACTIONS AND INNOVATION

Outline

1. **Overview**
2. Modeling results

Potential advantages of vehicle separation

Alleviate congestion

Enhance safety

Enhance air quality, reduce noise

Economize on road construction & maintenance costs

Facilitate use of Long Combination Vehicles

Constraints on vehicle separation

Lane capacity indivisibilities

Lack of continuous right-of-way

Limited access may increase total travel distance

Complete separation impractical or infeasible

Lane weaving

Outline

1. Overview
- 2. Modeling results**

Scope of model

De Palma, A., M. Kilani and R. Lindsey (2008), “The merits of separating cars and trucks”, Journal of Urban Economics 64(2), 340–361.

Analytical

Infrastructure

Fixed

Driver choices

Route (or lane)

Regulatory regimes

Unregulated user equilibrium

Tolls: comprehensive, partial

Route (or lane) access restrictions

System optimum

Externalities

Congestion, accidents; pollution, noise, road damage

Model

Trip matrix: One origin-destination pair

Routes: $r - 1, 2$. Perfect substitutes

Route capacities: Fixed

Demand:

Types: *Lights* and *Heavies*

Inelastic volumes: N_L, N_H

Route allocation:

$$N_{L1} + N_{L2} = N_L$$

$$N_{H1} + N_{H2} = N_H$$

Model (cont.)

Private trip costs

$$C_r^L = F_r^L + c_{Lr}^L N_{Lr} + c_{Hr}^L N_{Hr} + \tau_r^L, \quad r = 1, 2$$

$$C_r^H = F_r^H + c_{Lr}^H N_{Lr} + c_{Hr}^H N_{Hr} + \tau_r^H, \quad r = 1, 2$$

Own-cost coefficients: $c_{Lr}^L, c_{Hr}^H, \quad r = 1, 2$

Cross-cost coefficients: $c_{Hr}^L, c_{Lr}^H, \quad r = 1, 2$

Unregulated equilibrium (UE)

Types of equilibrium route allocations

1. Integrated
2. Partially separated
3. Segregated (fully separated)

7 possible configurations. 56 toll combinations.

Equilibrium depends on:

- Relative numbers (N_L, N_H)
- Relative capacities of the routes

Necessary condition for integrated UE:

$$\left(c_{L1}^L + c_{L2}^L\right)\left(c_{H1}^H + c_{H2}^H\right) > \left(c_{H1}^L + c_{H2}^L\right)\left(c_{L1}^H + c_{L2}^H\right)$$

or $c_{L\bullet}^L \cdot c_{H\bullet}^H > c_{H\bullet}^L \cdot c_{L\bullet}^H$

System optimum (SO)

Average system trip costs

$$ASC_r^L = F_r^L + c_{Lr}^L N_{Lr} + c_{Hr}^L N_{Hr} + e_{Lr}, \quad r = 1, 2$$

$$ASC_r^H = F_r^H + c_{Lr}^H N_{Lr} + c_{Hr}^H N_{Hr} + e_{Hr}, \quad r = 1, 2$$

Marginal system trip costs

$$MSC_r^L = \left(C_r^L - \tau_r^L \right) + \underbrace{c_{Lr}^L N_{Lr}}_{\text{Own}} + \underbrace{c_{Lr}^H N_{Hr}}_{\text{Cross}} + \underbrace{e_{Lr}}_{\text{Environ.}}, \quad r = 1, 2$$

$$MSC_r^H = \left(C_r^H - \tau_r^H \right) + \underbrace{c_{Hr}^H N_{Hr}}_{\text{Own}} + \underbrace{c_{Hr}^L N_{Lr}}_{\text{Cross}} + \underbrace{e_{Hr}}_{\text{Environ.}}, \quad r = 1, 2$$

System optimum (cont.)

Types of optimal route allocations

1. Integrated
2. Partially separated
3. Segregated (fully separated)

Necessary condition for integrated SO:

$$c_{L\bullet}^L c_{H\bullet}^H > c_{H\bullet}^L c_{L\bullet}^H + \frac{1}{4} (c_{H\bullet}^L - c_{L\bullet}^H)^2$$

Condition for UE:

$$c_{L\bullet}^L c_{H\bullet}^H > c_{H\bullet}^L c_{L\bullet}^H$$

Analytical results

1: Unregulated equilibrium is “biased” towards integration

Even if the unregulated equilibrium is integrated, the system optimum may be partially separated or segregated.

Examples

1. *Heavies* impose disproportionately high crash risks on *Lights* \Rightarrow desirable to keep *Heavies* away from *Lights*.
2. *Heavies* have disproportionately high values of travel time \Rightarrow desirable to give *Heavies* lots of road space.

Analytical results (cont.)

2: The System Optimum can coincide with User Equilibrium

Example

If the own-cost, cross-cost and environmental externalities all balance across routes.

Analytical results (cont.)

3: Differentiated tolls suffice to support the System Optimum

The system optimum can be decentralized using tolls that are differentiated by vehicle type and route.

Analytical results (cont.)

4: Route access restrictions may be ineffective

Assume

Unregulated equilibrium is integrated.

System optimum is partially separated or segregated.

Then [under plausible assumptions]

Restricting one vehicle type to one route raises total system costs if the other vehicle type uses both routes.

Numerical examples

Cost coefficients include congestion and accident externalities:

$$c_{hr}^g = \text{cong}_{hr}^g + \text{acc}_{hr}^g, \quad g = L, H; \quad h = L, H; \quad r = 1, 2$$

Numerical examples (cont.)

(a) Congestion coefficients

Values of time:	v^L, v^H
Generic passenger car equivalent:	PCE_{cong}
Impedance factor:	λ

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		Cost incurred by	
		<i>Light</i>	<i>Heavy</i>
Cost imposed by	<i>Light</i>	1	
	<i>Heavy</i>		

Numerical examples (cont.)

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	<i>Heavy</i>		

Numerical examples (cont.)

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Numerical examples (cont.)

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Cost imposed by	<i>Light</i>	1	v^H / v^L
	<i>Heavy</i>	$\lambda \cdot PCE_{cong}$	$(v^H / v^L) PCE_{cong}$

Numerical examples (cont.)

(b) Accident coefficients

Accident cost for a *Heavy* relative to *Light*: μ^H

Generic passenger car equivalent: PCE_{acc}

Hazard factor: ϕ

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Cost imposed by	<i>Light</i>	1	μ^H
	<i>Heavy</i>	$\phi \cdot PCE_{acc}$	$\mu^H PCE_{acc}$

Base-case parameter values

Studies of PCE, lane restrictions, differential speed limits. Empirical evidence is mixed:

PCE of trucks varies with

- Mix of cars and trucks

- Terrain

- Weather

Crash rates for trucks

- Lower: overall, rear-end

- Higher: fatal, sideswipe

Car drivers

- Dislike presence of trucks

- Increase headways which reduces capacity

Base-case parameter values

	Route 1	Route 2
Capacities	4,000 PCE /hour	2,000 PCE /hour
Speed limits	65 mph (105 kph)	65 mph (105 kph)
Lengths	32.5 miles (52 km)	32.5 miles (52 km)
Total trips by <i>Lights</i> and <i>Heavies</i>	40,000	
Proportion of <i>Heavies</i>	20%	
Travel costs		
	<i>Light</i> vehicles	<i>Heavy</i> vehicles
Fixed costs	\$0.194/mile (€0.08/km)	\$0.42/mile (€0.17/km)
Values of time	\$12/hour (€8/hr)	\$50/hour (€33/hr)
Congestion PCE for <i>Heavies</i> (PCE_{cong})		2
Relative impedance of <i>Lights</i> by <i>Heavies</i> (λ)	1	
Accident PCE for <i>Heavies</i> (PCE_{acc})		0.75
Relative crash hazard for <i>Lights</i> (ϕ)	1	
Relative cost of accident for <i>Heavies</i> (μ^H)		1
Environmental costs	\$0.0223/mile (\$0.009/km)	\$0.2153/mile (\$0.09/km)

Base-case-parameter solution

Unregulated equilibrium is integrated

Compared to *Lights*, *Heavies* cause more congestion than accidents but are more averse to congestion than accidents.

⇒ *Heavies* prefer to travel with *Lights*

⇒ *Lights* prefer to travel with *Heavies*

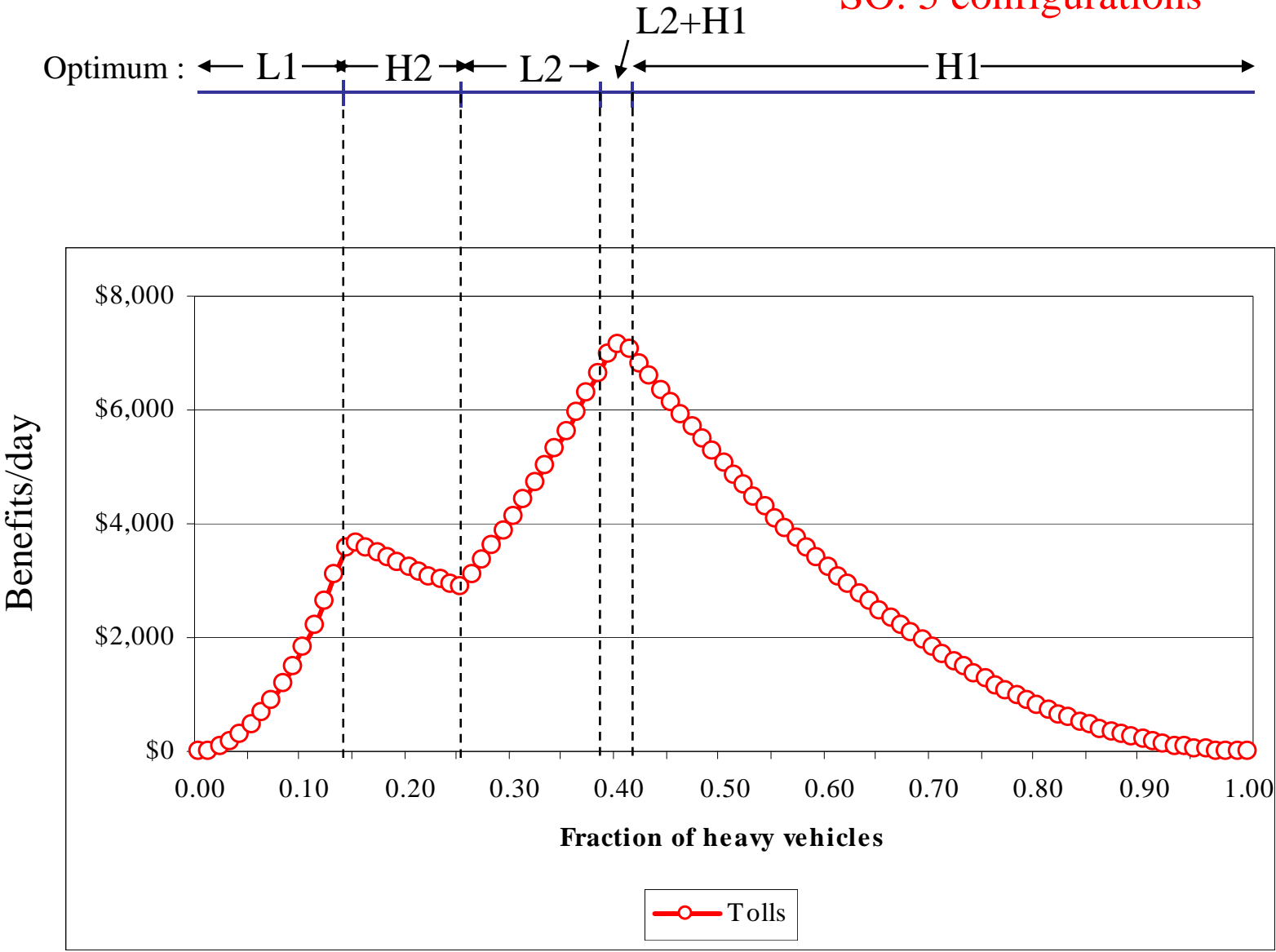
System optimum same as Unregulated equilibrium

Conditions of Result 2 satisfied

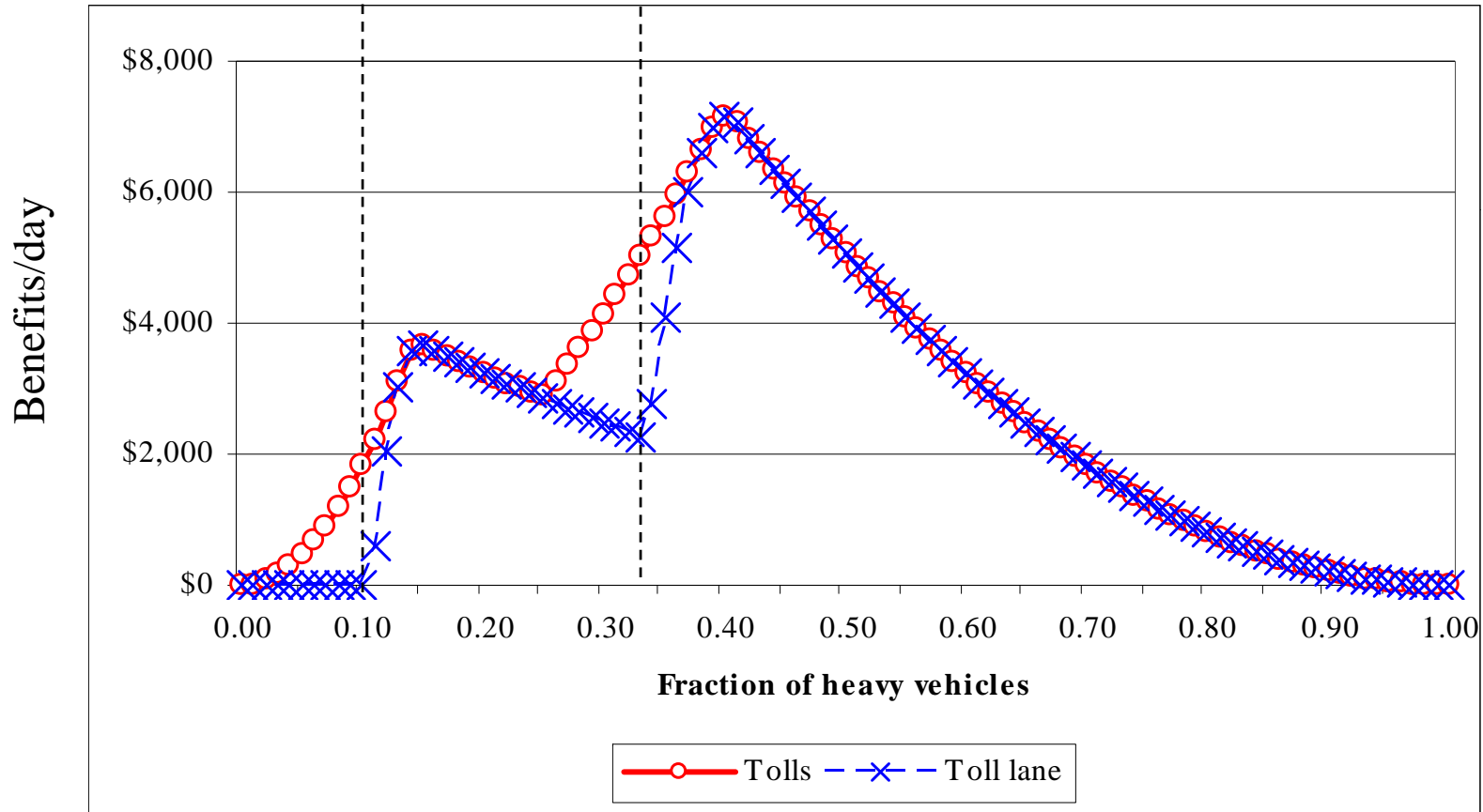
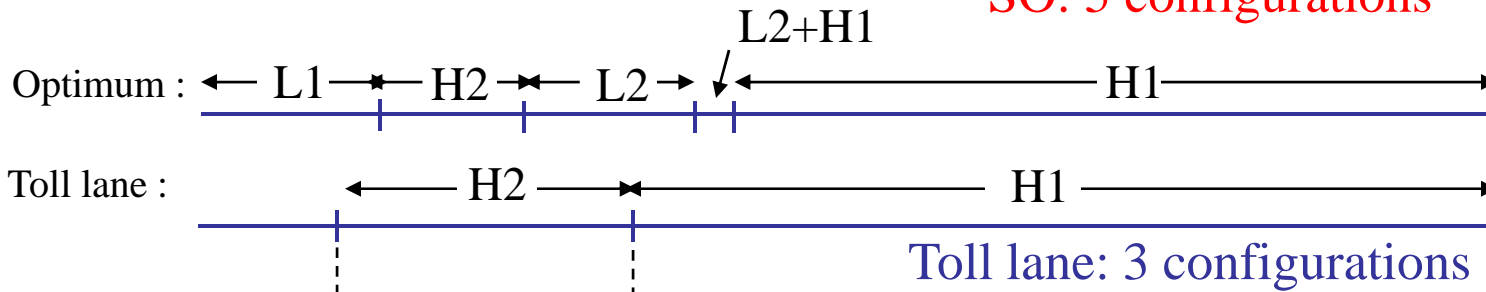
Variant 1: $v^H = \$75/h$

Base case: $v^H = \$50/h$

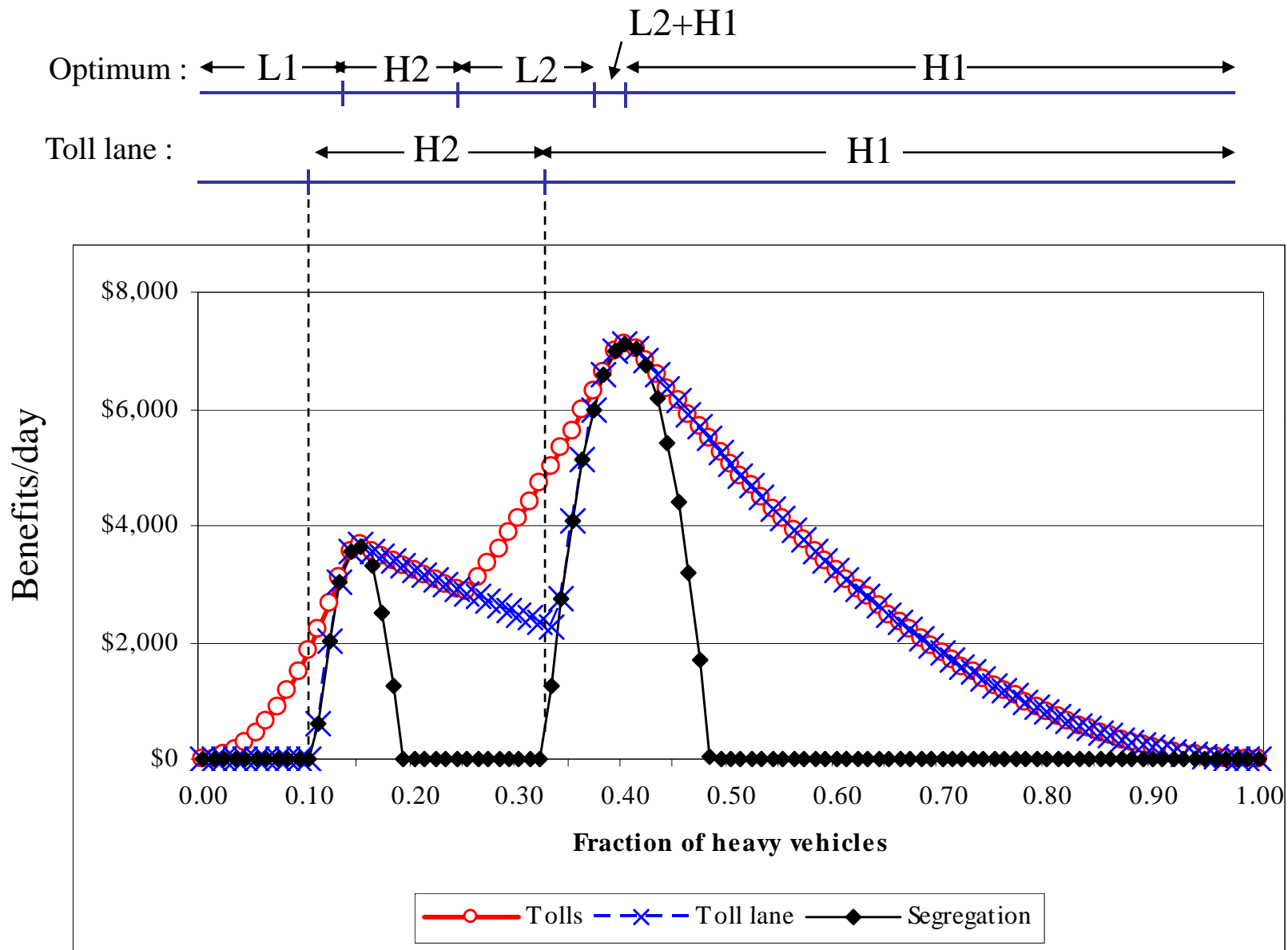
SO: 5 configurations

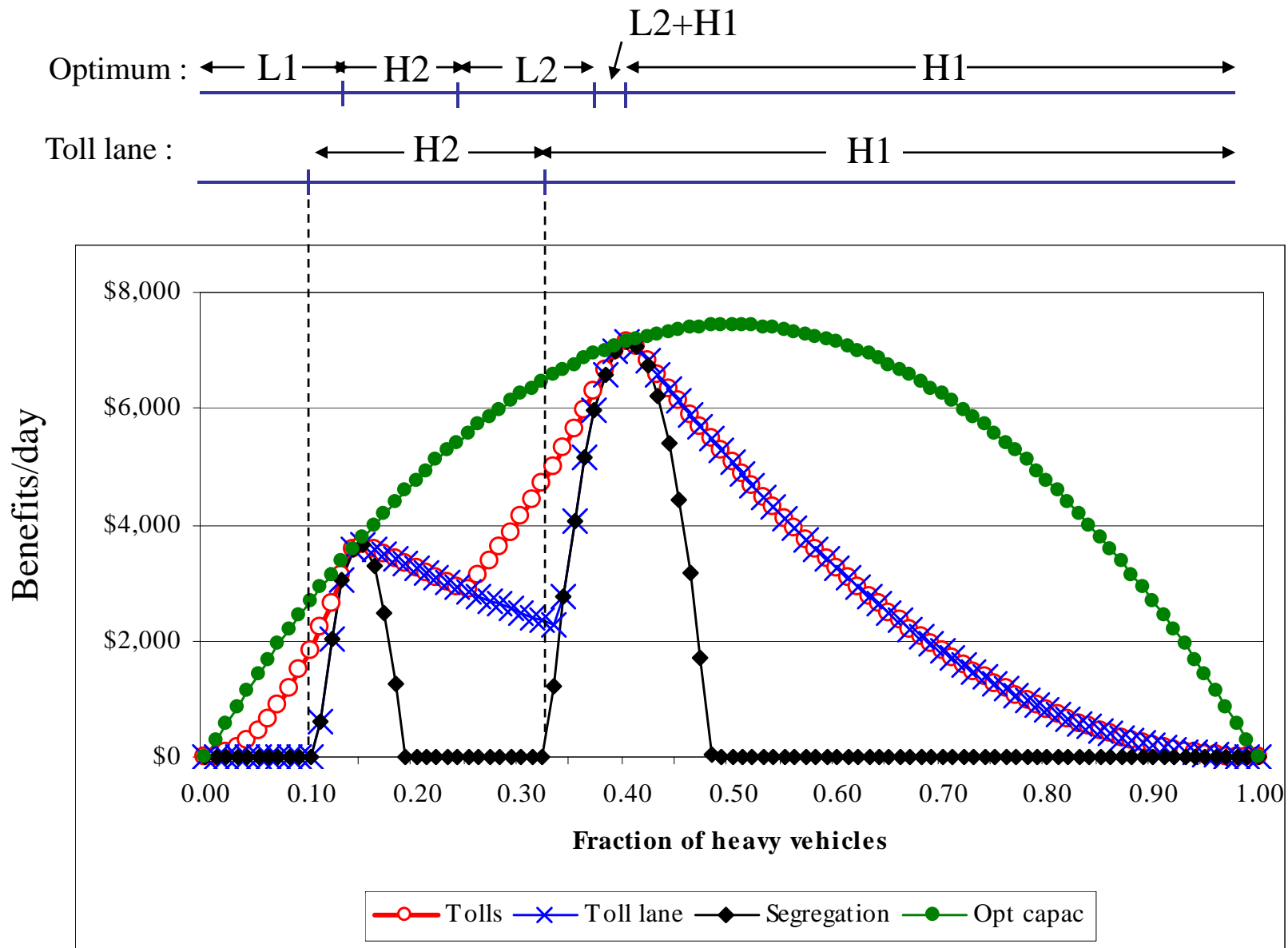


SO: 5 configurations



Route/lane access restrictions useless

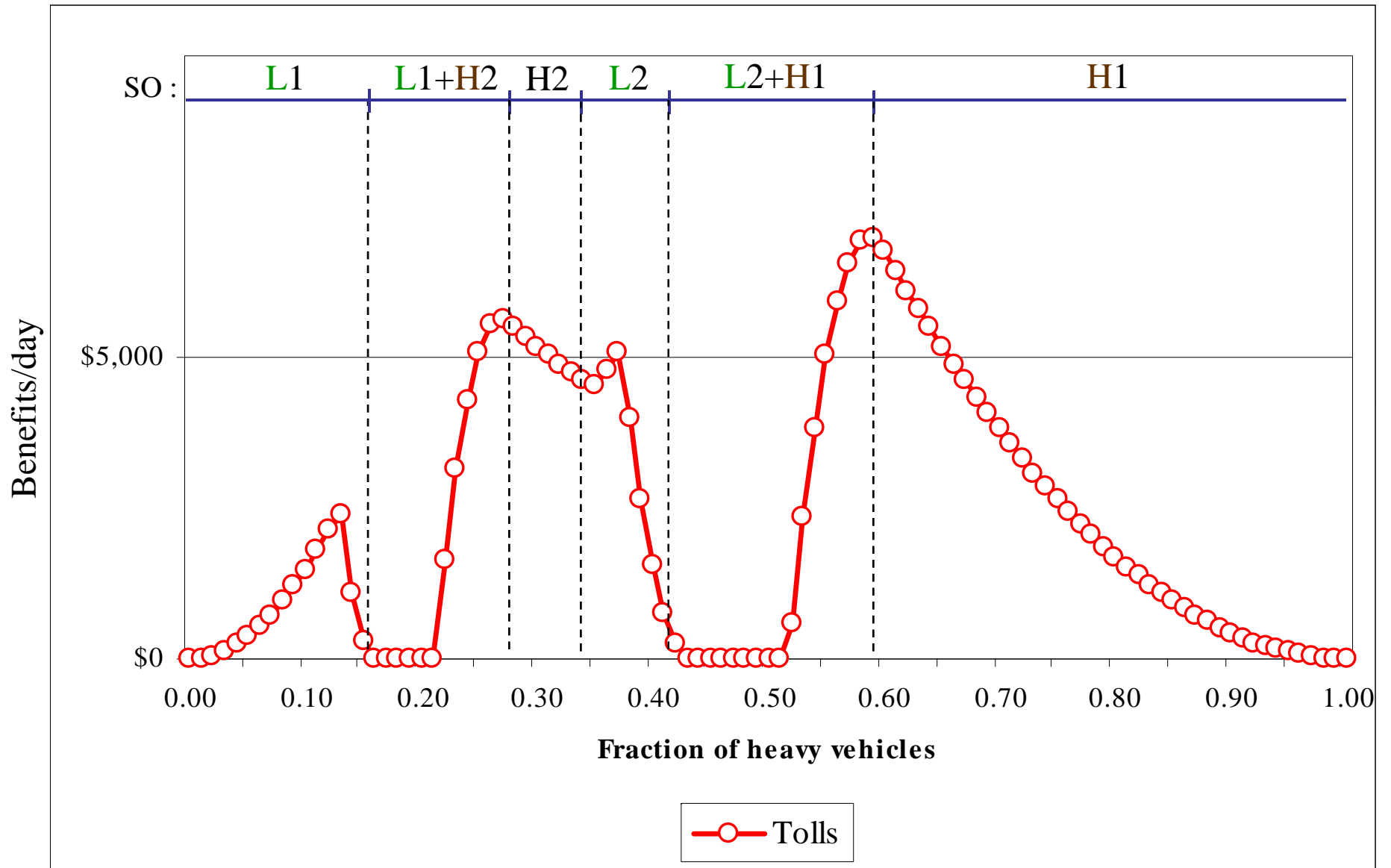




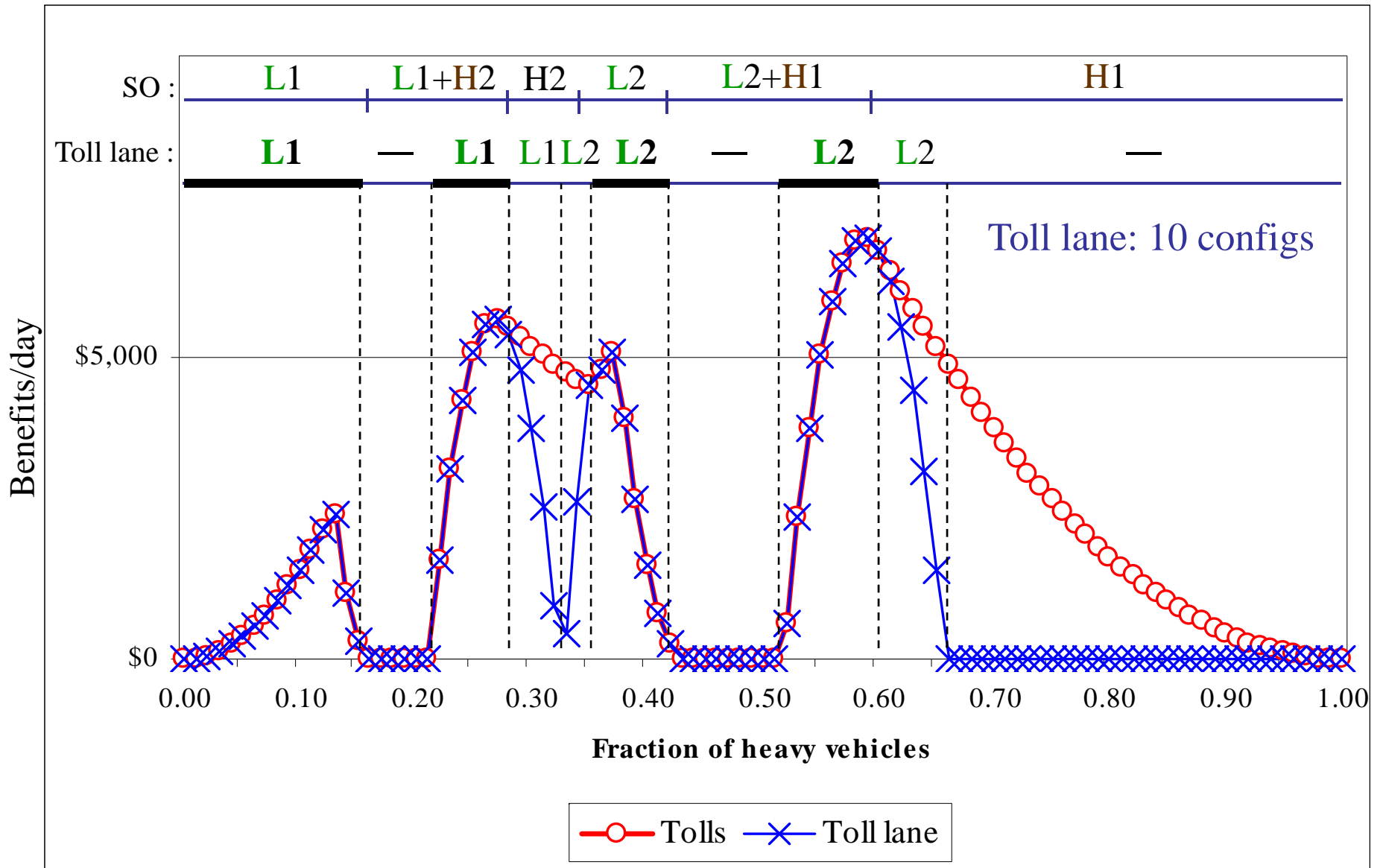
Variant 2: $v^H = \$25/h$, $\lambda = 2$

Base case: $v^H = \$50/h$, $\lambda = 1$

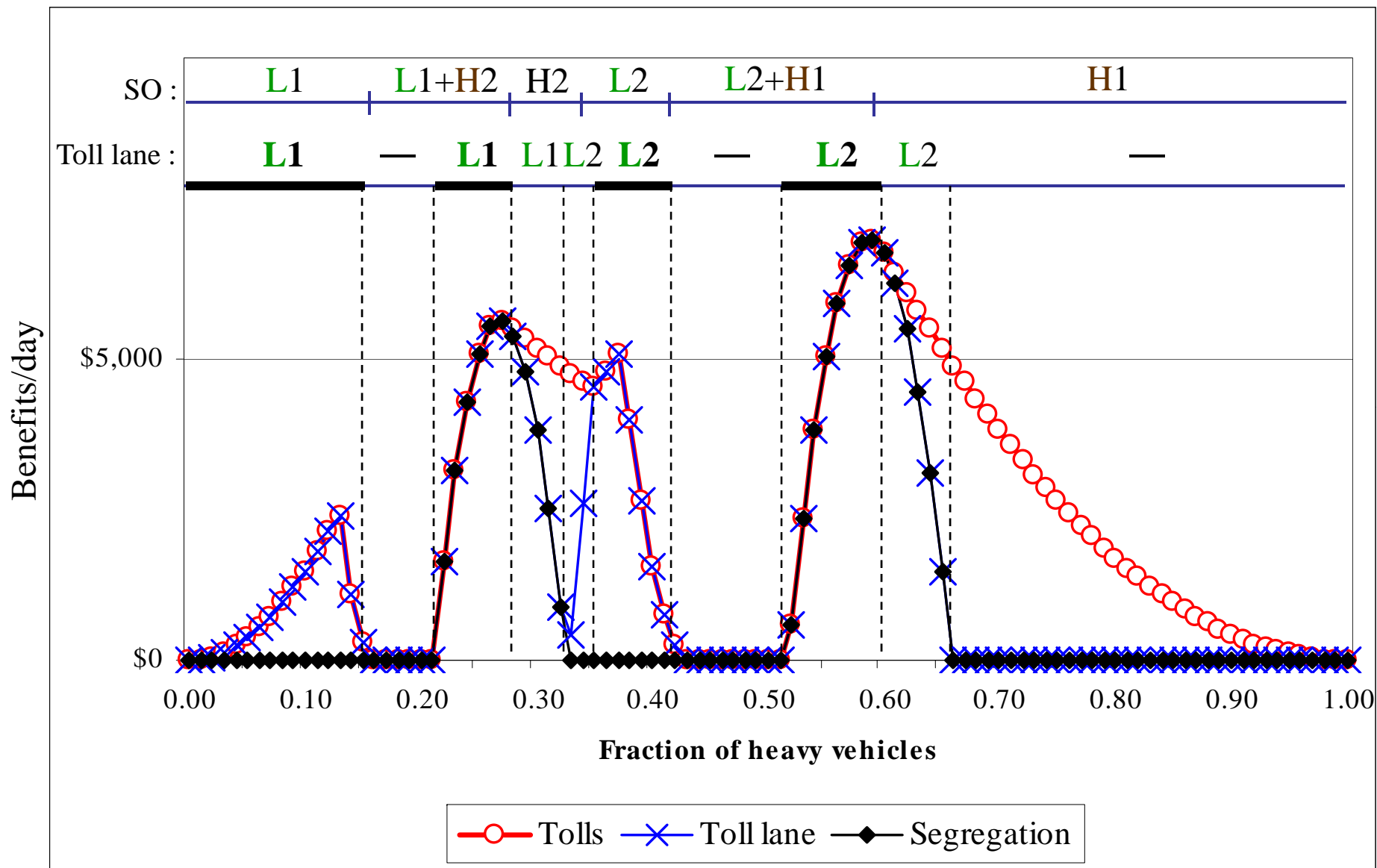
SO: 6 configurations



SO: 6 configurations

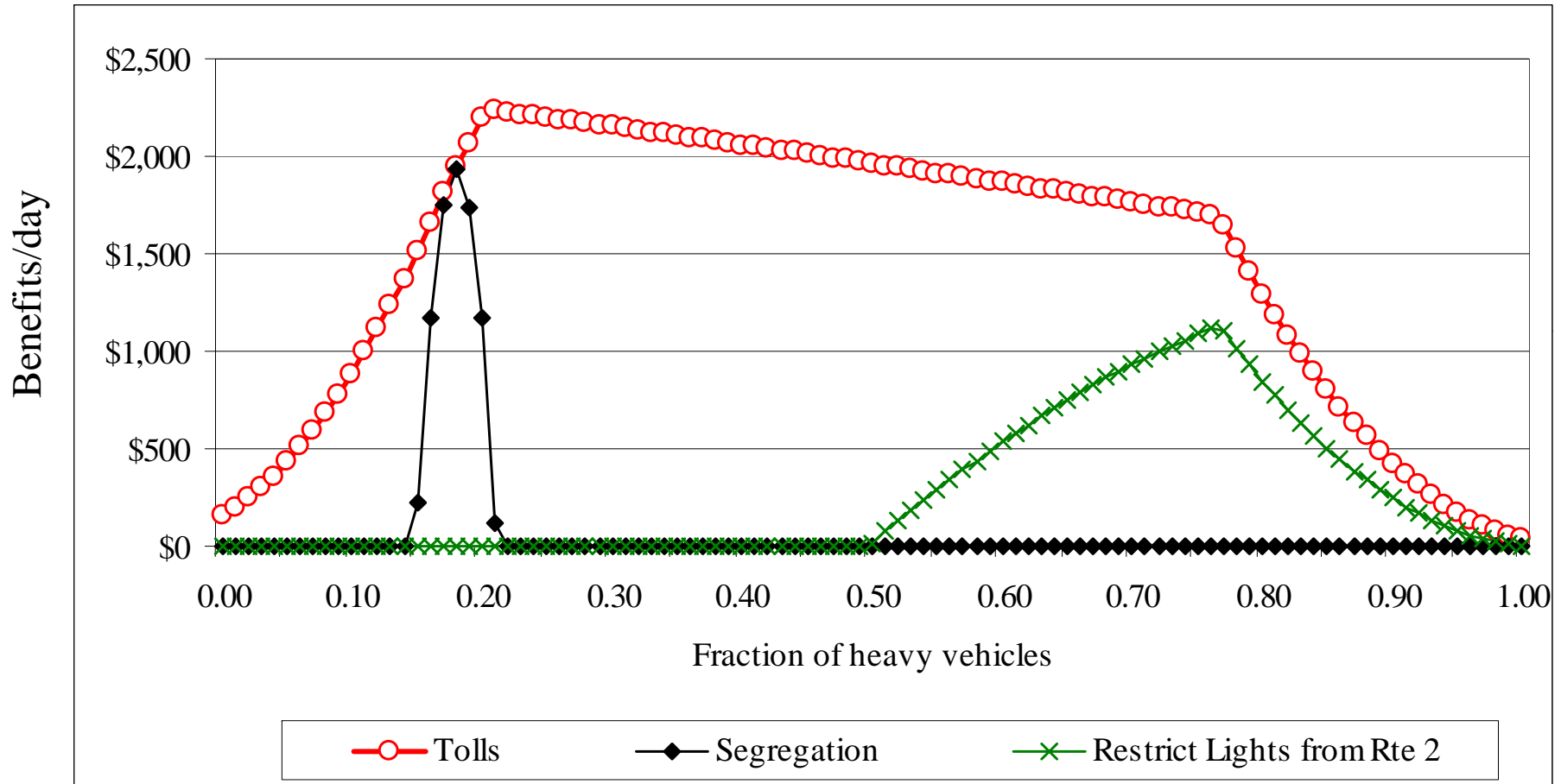


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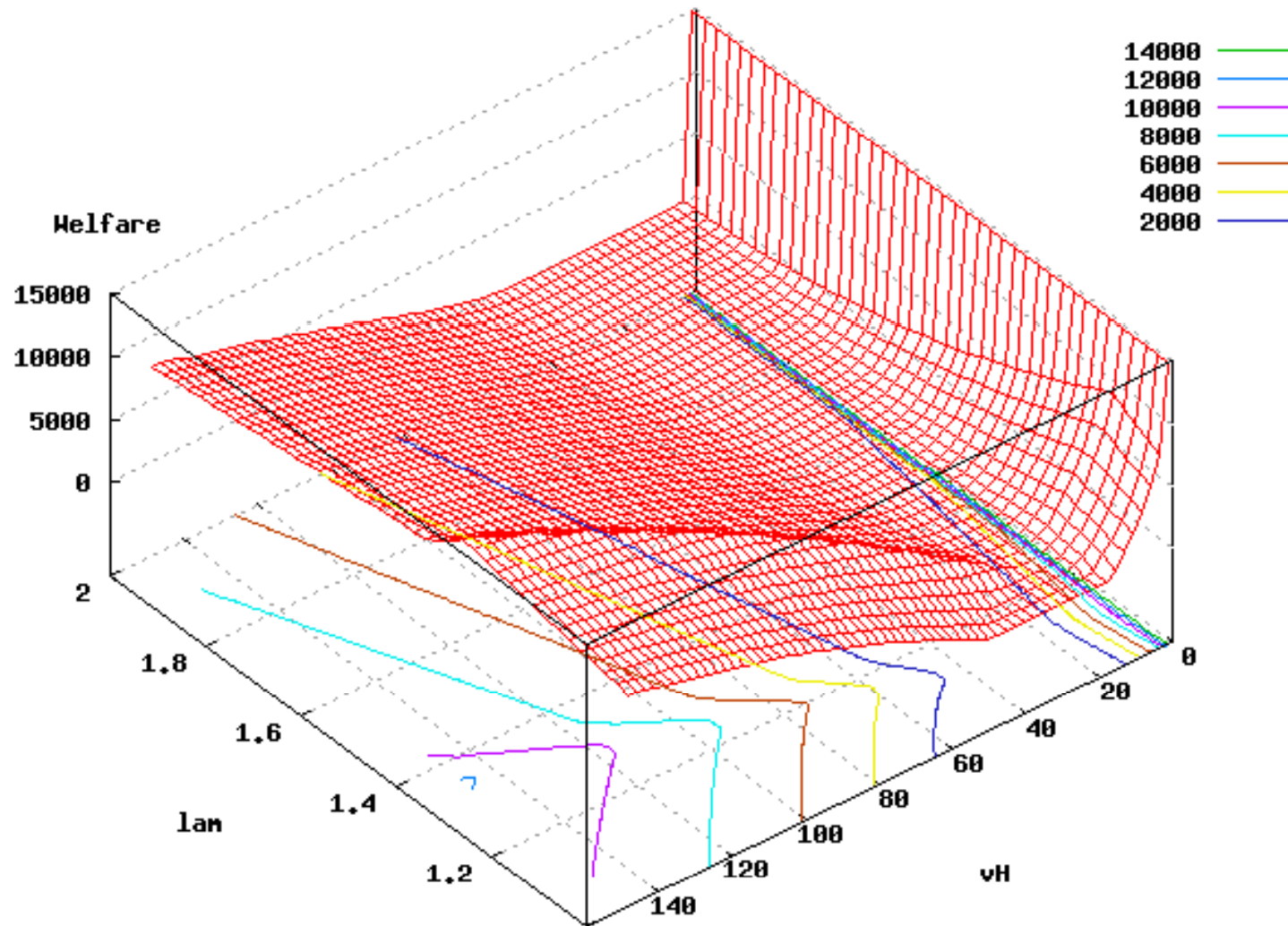


Segregation: 5 configurations

Variant 3: Route 2 is 2.5 miles shorter



Variant 4: Two-way variation



Conclusions from model

- 1) Benefits from intervention sensitive to various parameters:

Proportions of *Lights* and *Heavies*

Lane capacity indivisibilities

PCEs for congestion and PCEs for accidents

Values of travel time (relative and absolute)

- 2) Nonmonotonic variation of benefits with parameters;
e.g. fraction of *Heavies*, VOT for *Heavies*
- 3) No presumption that separation is desirable

Model extensions

Elastic demand

- Alternative toll-free corridors (traffic diversion problems)

Trip-timing preferences

- Truck and auto flows peak at different times.
- Constraints on trucks: Hours of service regulations, maritime terminal operating hours, neighborhood curfews, shippers' hours, delivery tours.

Heterogeneity within types

VOT, PCE, road damage

Desired vehicle speeds \Rightarrow scale economies with respect to number of lanes

Need simulation models