Credit-Based Congestion Pricing for Win-Win Traffic Solutions by Kara Kockelman

10/21/22

Spencer McDonald

Part I. Literature Citations

Arash Behestian, Richard Geddes, Omid Rouhani, Peter Cramton, Kara Kockelman, Axel Ockenfels, & Wooseok Do. Bringing the Efficiency of Electricity Market Mechanisms to Multimodal Mobility across Congested Transportation Systems. Transportation Research Part A 131: 58-69 (2020), https://doi.org/10.1016/j.tra.2019.09.021.

Vivian (Weijia) Li, Kara Kockelman, and Yantao Huang. Traffic and Welfare Impacts of Credit-Based Congestion Pricing Applications: An Austin Case Study. Transportation Research Record 2675(1):10-24 (2020).

K. Murthy Gurumurthy, Kara Kockelman, & Michele Simoni. Benefits & Costs of Ride-sharing in Shared Automated Vehicles across Austin, Texas: Opportunities for Congestion Pricing. Transportation Research Record No. 2673 (issue 6) (2019).

Jooyong Lee and Kara Kockelman. Development of Traffic-based Congestion Pricing and Its Application to Automated Vehicles. Transportation Research Record No. 2673 (issue 6) (2019).

Lewis Clements, Kara Kockelman, & William Alexander. Technologies for Congestion Pricing. Research in Transportation Economics 90, 100863 (2021).

Michele Simoni, Kara Kockelman, K. Murthy Gurumurthy & Joschka Bischoff. Congestion Pricing in a World of Self-Driving Vehicles: An Analysis of Different Strategies in Alternative Future Scenarios. Transportation Research Part C 98: 167-185 (2019).

Part II. Recent News and Articles

Greising, David. “Commentary: A Congestion Tax Won't Solve Chicago's Budget Jam.” Chicago Tribune, Chicago Tribune, 5 Sept. 2019, https://www.chicagotribune.com/opinion/commentary/ct-opinion-congestion-tax-lori-lightfoot-greising-20190905-u3e627fon5e4lesiqthrfytqxy-story.html.

Iivonen, .css-1i2ud9c-CreditTag{font-weight:400;text-transform:uppercase;}Illustration: Janne. “Congestion Pricing Could Give Lift to Some Home Values.” The Wall Street Journal, The Wall Street Journal, 1 May 2019, https://www.wsj.com/articles/congestion-pricing-could-give-lift-to-some-home-values-11556719681.

Ley, Ana. “Yellow Cabs Are Struggling. Congestion Pricing Could Deal a New Blow.” The New York Times, The New York Times, 11 Oct. 2022, https://www.nytimes.com/2022/10/11/nyregion/nyc-traffic-yellow-cab-tolls.html.

Part III. Questions and Answers

Jinhua questions

Q: Behavior – Do we assume each driver knows up front what their "charge" will be or will they find out after their trip is over?

A: People love certainty, they want to know the tolls beforehand. Luckily, technology allows us to be able to know beforehand. As such, we assume that drivers know up front how much they would have to pay.

Q: Technology – Implementation of the charging, how is it done? Historically, we had toll booths, but now we have many more technological systems available to enable tolling, how are they being used? Also, how do we change pricing for different transportation modes (e.g., electric cars)?

A: Some vehicles have a lot of technology already (e.g., Tesla's). The technology is embedded in newer vehicles to embed congestion pricing. Most people will fight to not have the tolling agencies know where people are at all times. It is likely there will exist "dongles" that will act as a monitoring tool to measure where you end up traveling.

Q: Technology – When autonomous vehicles enter the market, how do we change our congestion pricing strategy to reflect that it is no longer a human driving?

A: Supposedly the value of time will decrease with the adoption of autonomous vehicles, as such we expect that people would be willing to spend longer while traveling to avoid congested areas.

Q: How do you see academic research evolving in the congestion pricing literature?

A: I would like to see more implementation and technology deployment. Actually, creating the dongles, apps, other equipment that are being sold. Phone based apps are somewhat done, but not to the level that we would like it to be.

General Questions

Q: Do you take into consideration the origin and destinations of the passengers when determining the fees?
A: Every links are treated the same. All links pricing is found based off the congestion ratio used to determine the pricing of the link. May be some stipulations for carpooling or considering taking other transportation modes?

Q: How does the assumptions of Value of time and wealth distribution change when you consider other cities?

A: Austin is very expensive city to live in, meaning that there are quite wealthy people already living there. In New York, you have better options of other transportation modes. One thing that will likely be the case is that shared rides will become more prevalent.

Q: Marginal social cost calculation – does the cost estimate consider air quality, global warming, etc?

A: I try to consider everything, but emissions is really low and does not move the needle on the decision to take a different transportation mode.

Q: Politically this is a hard sell in the US, price of freedom, what would your elevator pitch be from a political point?

A: Credit based is a good approach, people can strategically make decision based off of pricing. We are just making the prices more explicit. Congestion tolls can also be used to help local transit systems.

Q: Will congestion pricing make lower income transit providers worst off initially?

A: What we have seen is that lower value of time travelers are better off with congestion pricing systems. Especially when riding sharing methods are used.

Q: Talking of zipcar, Robin Chase – A lot of the technology does not specifically require infrastructure investments. Could you say a few more words on does congestion pricing work when talking to policy makers?

A: Yes it makes sense to me. It's a guaranteed budget for those who qualify, but its hard to determine who does qualify. This would be a big research project. The tolls help provide more reliability when you need to travel.

Part IV. Summary of Memos.

Themes from Other Memos

1. The study presented in the lecture was based on the city of Austin specifically. How do we expand the research to consider the benefits of congestion pricing in a more systematic way across multiple cities? Are there general trends that make certain cities more susceptible to positive change from congestion pricing?
2. Overall, some disappointment and surprises with the fact that VMTs and VHTs actually increased as a result of implementing congestion pricing. Also, many speculated that increases in VHT and VMT will make it harder to get adoption of the system. Are there ways to think about a different objective function to minimize other characteristics other than purely just minimizing congestion?

3. More emphasis on understanding what the true impacts would be in terms of equity and fairness. Specifically, quantifying behaviors and decisions by just "value of time" assumptions does not quantify many of the challenging real-world challenges and decisions that many people have to live with. Trying to get a better grasp of these decisions may show that the congestion pricing is not as positive for certain groups of people.

My Reflection

For our sixth seminar of the semester, we were honored to have Kara Kockelman from the University of Texas speak to us about Congestion Pricing for the city of Austin Texas, and specifically discuss the results a simulation conducted inside her group. The seminar started with a brief background of the simulation setup, including all assumptions and modelling decisions. One of the important assumptions made is that the Congestion Pricing simulation will be Revenue Neutral, as in, all revenue will be redistributed back to the citizens of Austin, TX uniformly. The simulation additionally had different variations, most notably was the number of links that tolling's was actually enforced and by how much. The specific amount that tolls were charged was found from a combination of actual demand and had to be iterated on to arrive at an equilibrium. From there, Kara then spent most of the time discussing the results of the simulation in terms of effects on congestion, effects on commuters, and aggregate metrics such as Vehicle Mileage Total (VMT) and Vehicle Hour Total (VHT). Overall, her results found that peak congestion pricing did indeed reduce demand for capacitated road segments and improved overall congestion numbers. Additionally, she found that most all commuters (across different Value of Time metrics) saved money through use of this service. One surprising result was that VMT and VHT actually raised due to the congestion pricing. This is the result of people taking alternative routes to avoid the toll but spend more time and mileage driving. However, Kara pointed out that this could likely be improved by giving people the flexibility to adjust their departure time.

I very much enjoyed Kara's lecture. I think the research of Congestion Pricing is super relevant, as it is one of the most immediate levers, we have to influencing our current transportation system. One major idea that came to my mind during Kara's lecture was really trying to understand what the objective function should be when considering congestion pricing. Math is just a tool that accomplishes exactly what you tell it to do, potentially to the detriment of factors that are not considered. Specifically, as mentioned in the lecture, maybe we should start to consider elements of global warming and how this congestion pricing can be used to improve it. Additionally, another consideration I think future congestion pricing models should capture is the nonlinear values of time. Specifically, my hypothesis is that the value of time fluctuates throughout the day for most people. It may be the case that I am more willing to be late coming home, but I need to arrive at work on time. Capturing this in a systematic manner may skew results in an interesting manner. Overall, I thought the lecture was a great synopsis of current approaches being employed and gave me great ideas to consider moving forward with my own research.

Part V. Other Information

Other questions

What effect does interstate truck and auto travel have on demand and what do you do to inform them of the dynamic tolling system? When choosing the links to toll, do you consider tolling links on alternate routes to avoid route shifting and increases in VMT? Can you speak to the reason for governments being so hesitant to implement congestion pricing when the results of your and other such studies showing such "support"?

Other literature

Selmoune, Aya, et al. "Influencing factors in congestion pricing acceptability: a literature review." Journal of Advanced Transportation 2020 (2020).

Singichetti, Bhavna, et al. "Congestion pricing policies and safety implications: a scoping review." Journal of urban health (2021): 1-18.

Emmerink, R. H. M., Peter Nijkamp, and Piet Rietveld. "Is congestion pricing a first-best strategy in transport policy? A critical review of arguments." Environment and Planning B: Planning and Design 22.5 (1995): 581-602.

CREDIT-BASED CONGESTION PRICING
FOR WIN-WIN TRAFFIC SOLUTIONS

Kara Kockelman + Vivian Li + Yantao Huang

Introduction

- **Credit-based (de)congestion pricing** (CBCP) = **revenue-neutral policy** to address **congestion losses + equity** issues.
- CBCP **redistributes revenues as credits**, by shifting traffic, & can **benefit most travelers**.
- Those driving **at peak hours regularly & over long distances** will pay out of pocket, but experience much more reliable travel times.
- **Those who shift** departure times, destinations, modes &/or routes **can make "money"** (credits to spend on taxis, TNCs, ebikes, …).
- **This work seeks best tolling strategies for Austin setting…**

Travel Demand Model Assumptions

Trip Generation

- 3 **trip purposes**: **HBW, HBNW & NHB**
- Productions & attractions based on population & jobs, incomes & vehicle ownership.

Trip Distribution/Destination Choice

- Gamma-type **impedance functions** use shortest-path generalized costs for routing (& mode choice).
- **5 value of travel time (VOTT) groups:** $5/hr, $15/hr, $25/hr, $35/hr & $45/hr (VOTT1 through VOTT5)

Mode Choices: Automobile vs. Transit

5 auto-ownership levels based on household income shares in each TAZ. **Transit user** VOTT assumed to be **$8/hr.**

- **4 Times of Day:** AM, MD, PM & NT

- **Multi-modal Multi-class Traffic Assignment:** BPR-type link performance function

$$t_l = t_{free\text{-}flow,l}(1 + \alpha(v_l/c_l)^{\beta})$$

Tolling Strategies: Where & How Much

Multiply every link's v/c by VMT /length /period duration →	**Sum these values** over the 4 times of day to ID **key links** →	Select **key links** for tolling: **Top 25, 50, 100, 500, & 1000** - *vs* **All links & 7 bridges** scenarios →	**19 scenarios simulated with Tolls of 0.5τ, τ, & 2τ** (excepting bridges)

- **Marginal cost tolls for each link l**

$$\tau_l = MSC_l - AC_l = \beta_l t_{FF,l} \alpha_l \frac{v^{\beta_l}}{c^{\beta_l}}$$

- **Traffic assignment results** (*link travel times & volumes*) → ***updated toll values*** for each iteration, until find shortest-cost paths for all user classes: $\tau_l^{iter} = \left[(1 - 1/i)\tau_l^{iter-1} + 1/i \cdot \tau_l\right] VOTT$

Computing Traveler Welfare

We compute **nested logsums** **over destination & mode** choice sets:

$$\Gamma_{ij}^{c} = \ln[\exp({V^{c}}_{ij,auto}) + \exp({V^{c}}_{ij,bus})]/\ \theta$$

$$V_{ij}^{c} = [\ln(Attr_j) - \ln(Attr_1)] - \theta\Gamma_{ij}^{c} + \varepsilon_{ij}^{c}$$

where $\boldsymbol{\Gamma}$ = **expected maximum utility** for class c's mode alternatives

ij = trip origin & destination & ***c*** = **5 traveler (VOTT) class** indices

$\boldsymbol{V_{ij,m}}$ = utility of each mode between OD pair *ij*

$\boldsymbol{Attr_j}$ = attractiveness of destination *j* (including jobs + pop)

$\boldsymbol{\varepsilon_{ij}}$ = iid Gumbel random error terms.

Welfare Changes (vs untolled base)

- **Changes** in consumer welfare or surplus (ΔCS) for each traveler type = **normalized logsum differences** between those two scenarios.
- ΔCS equation for HBW trips differs from HBNW & NHB because **travelers' work locations are assumed fixed**, at least in near term.

HBNW & NHB trips

$$\Delta CS_i^c = \frac{1}{\alpha_p}\{\ln[\sum_{j\in D}\exp(V_{ij}^{c1})] - \ln[\sum_{d\in D}\exp(\Gamma_{ij}^{c0})]\}$$

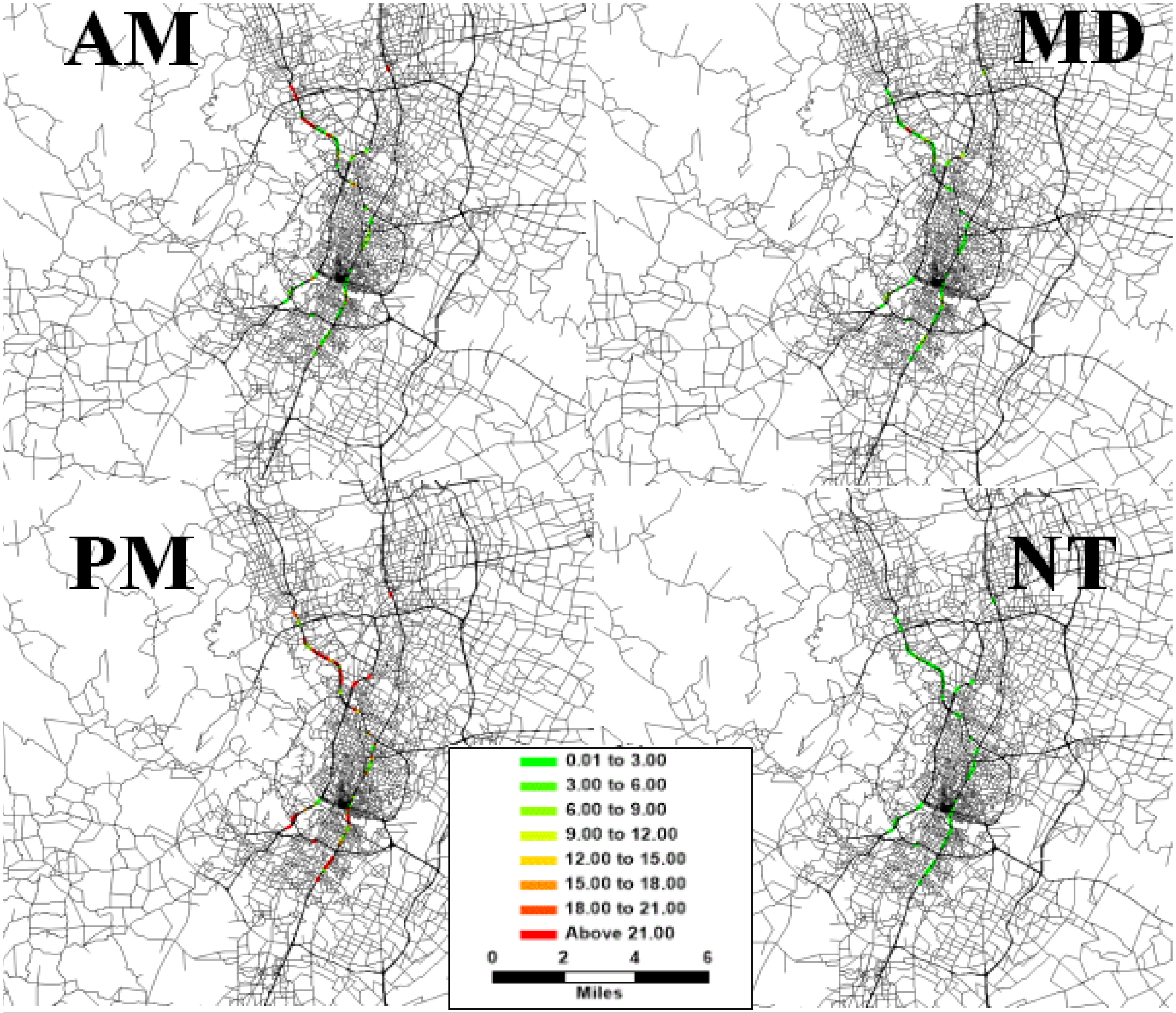
where *D* = destination alternatives for trips from zone *i* & α_p = marginal utility of money for trip purpose p

Home-based Work trips

$$\Delta CS_i^c = \frac{1}{\alpha_p}\{\sum_{j\in D}P^1(j|i)\exp(\Gamma_{ij}^{c1}) - \sum_{j\in D}P^0(j|i)\exp(\Gamma_{ij}^{c0})\}$$

where **α_p = marginal utility of money** & *P(j|i)* = probability choose destination *j* when origin is zone *i*.

Tolls on Austin's Top 100 Links' Marginal Congestion Costs (τ) in Cents/Mile



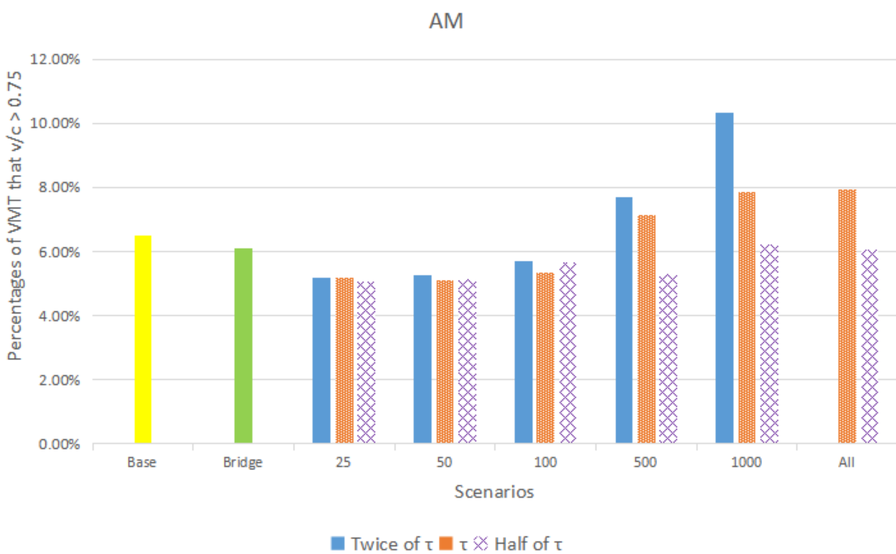
- **6 county region**
- **2,258 TAZs** & **25,176 links**
- **TransCAD 7.0** for demand modeling.

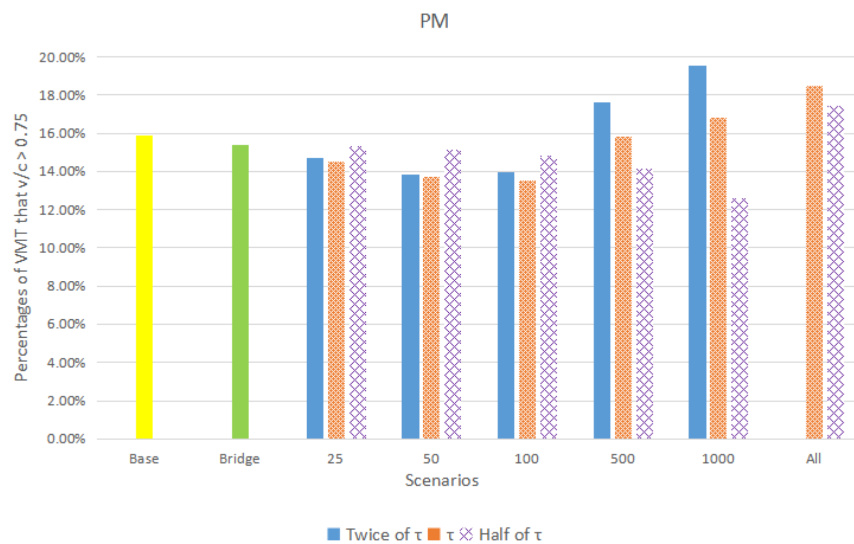
VMT, VHT & Mode Shifts

- **Total VMT & VHT** show **minor to moderate increases** (ranging from 0.5% to 7%) vs. Base Case (no-toll) scenario.
- **Biggest VMT & VHT increases** come from the **2τ scenarios** & the **1000-tolled-link scenarios.**
- **Mode choice is stagnant, without new options: 93% to 96%** of VOTT1 ($5/hr) travelers continue to rely (!) on **personal vehicles** for HBW & NHB trips, respectively. **98%** of VOTT5 ($45/hr) travelers also do so.

Congestion Impacts

%VMT with High V/C (over 0.7) in AM vs PM Peaks





%VMT at high V/C **fell** from from 7% to 5% in **AMPK.**

But ~**15% of PM Peak VMT stayed at high V/C under most CP scenarios.**

Calculating Credits

Assuming **10% revenues** → **Overhead costs** (to create & manage the system)
& **90% uniformly** given monthly to Austin's **1.16 million licensed drivers**
(for road use only/not cashable)

Toll Revenue & Travel Credit Estimates across 2τ Scenarios*

Toll Scenario	AM Peak Revenues per Day	Mid-day Revenues	PM Peak Revenues	TOTAL Revenues per Day	Credits for Distrib.	Credits per Driver per Day	Credits per Driver per Month
7 bridges*	$312K	$268K	$396K	$976K	$880K	$0.76/day	**$16.65/mo.**
25	$39K	$12.6K	$131K	$183K	$160K	$0.14/d	$3.12/mo.
50	$73K	$25.1K	$218K	$316K	$280K	$0.24/d	$5.40/mo.
100	$124K	$36.2K	$285K	$445K	$400K	$0.34/d	$7.60/mo.
500	$420K	$117K	$857K	$1.39**M**	$1.26**M**	$1.08/d	$23.82/mo.
1000	$1,164K	$255K	$2,395K	$3.82**M**	$3.43**M**	$2.96/d	**$65.12/mo.**
All Links*	$572K	$128K	$1,383K	$2.08**M**	$1.88**M**	$1.61/d	$35.57/mo.

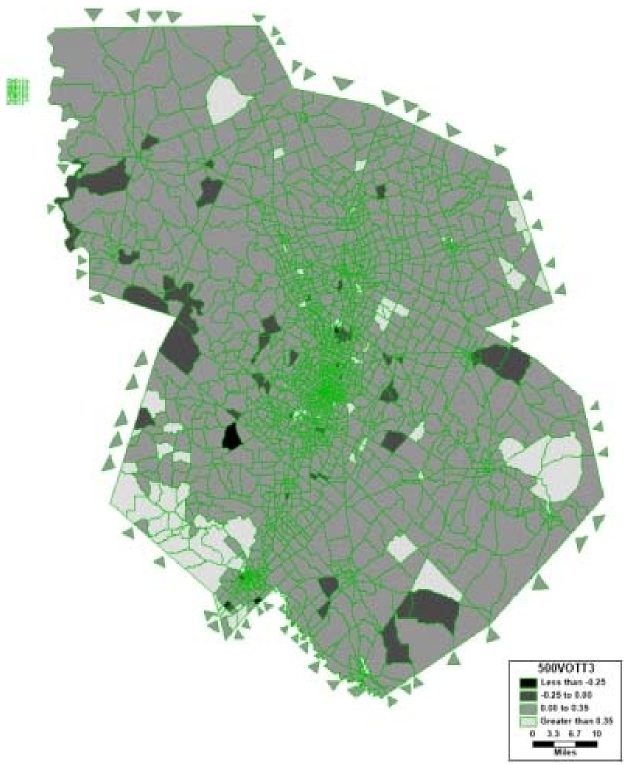
τ = 2 x Marginal Cost

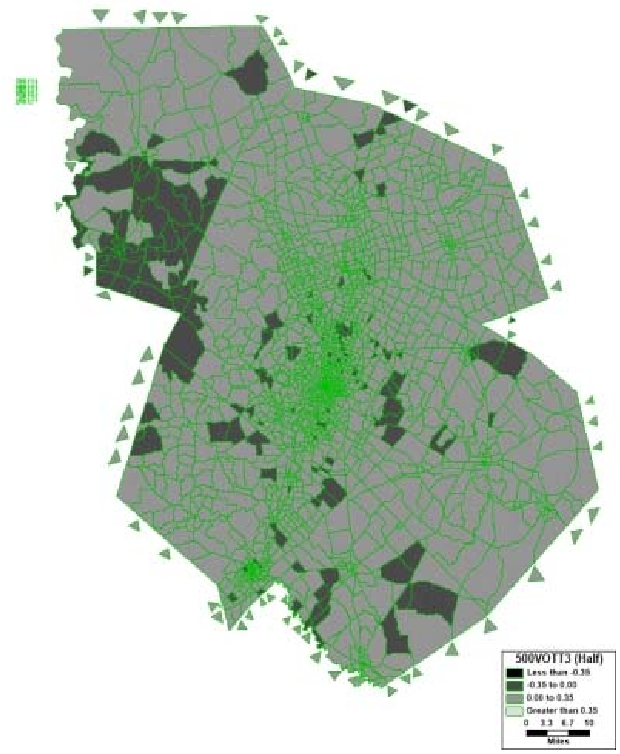
*τ = MC tolling

Welfare Impacts

- These normalized differences in nested logsums = **consumer surplus changes (ΔCS) or willingness to pay** for the different pricing policies.
- Estimates are **by location** (TAZ) & **traveler type** (VOTT) & **trip purpose**.
- Following images show within-zone average effects of CBCP policy on **HBWork** trip valuation for **VOTT3 ($25/hr)** & **VOTT5 ($45/hr) traveler types.**

500-link 2τ & 0.5τ Examples





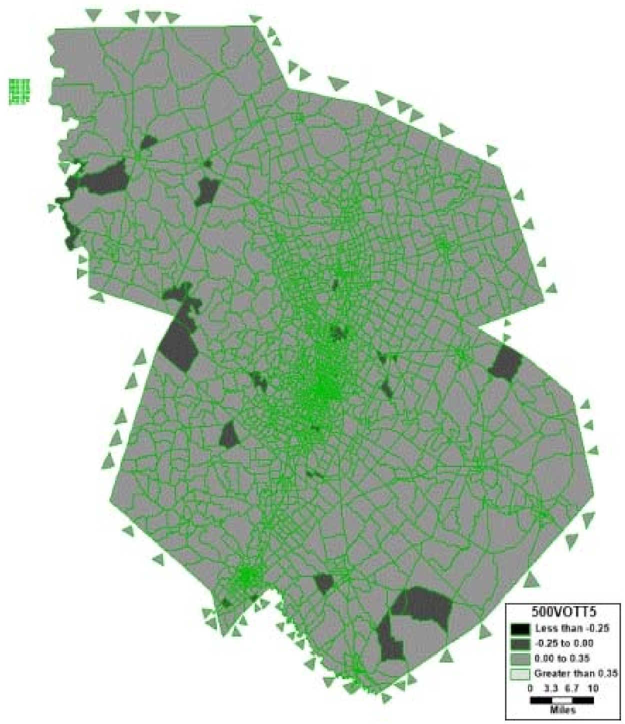
VOTT3 ($25/hr) ($2\tau$ Tolling)

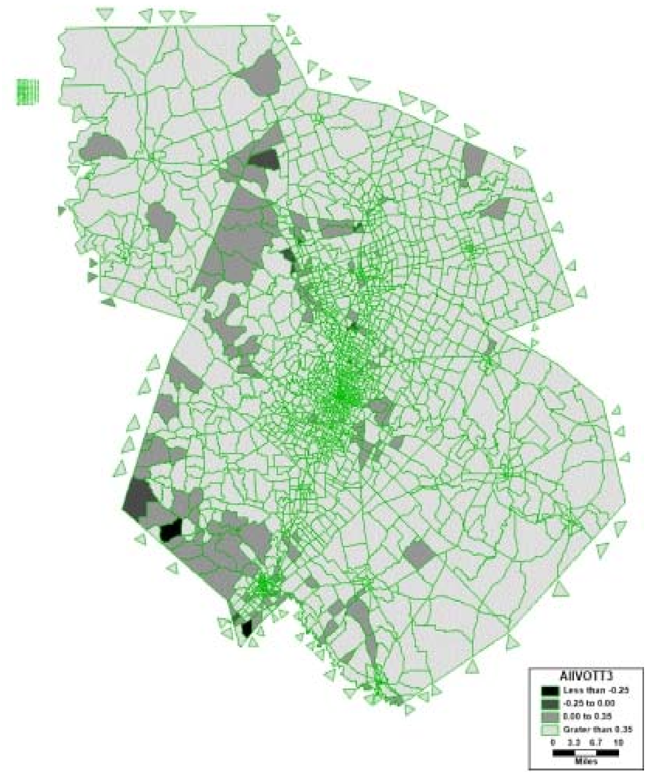
97% of the regions' TAZs' VOTT3 travelers are estimated to **benefit** from CBCP policy.

VOTT3 ($25/hr) ($0.5\tau$ = 50% MC Tolling)

91% of TAZs' **VOTT3** ($25/hr) travelers **benefit**, with losses more likely in northwest & low-density zones.

500-link vs. All-Link Tolling





500 Links
VOTT5 ($45/hr) (2τ Tolling)

98% of TAZs' VOTT5 ($45/hr) benefit

All Congested Links Tolled
VOTT3 ($25/hr) (1τ = MC Tolling)

99% of TAZs' VOTT3 ($25/hr) benefit

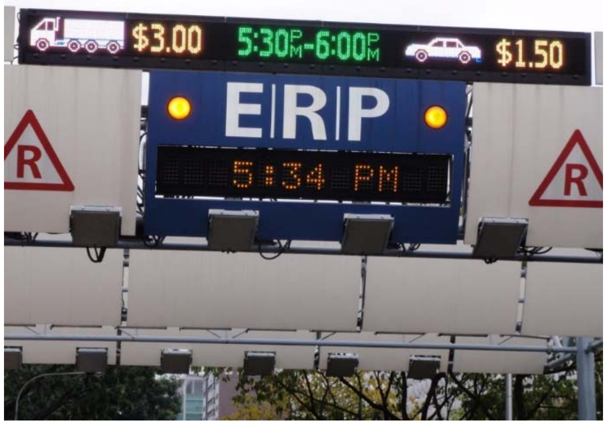
Conclusions

- **VMT & VHT rise** as more links are tolled, especially when **tolls = 2τ.**
- Yet uniform crediting of **2τ** toll revenues on just **500 links** benefits **97+% of TAZs' VOTT 3+ travelers…**

  … and benefits 85% of TAZs' **lowest VOTT1 travelers**. This rises to 95% (!) when using **MCP (tolls = τ) on all links**.
- **2τ tolls benefit more people than 0.5τ tolls**, though many links' travel times worsen (as traffic shifts).
- **Credit-based congestion pricing (CBCP) across all** congested **links** → **99% of TAZs' travelers** benefit = **Best scenario** tested.
- **Freeing up work** locations **& adding new modes** (like walk, bike, ride-sharing, tele-work) should enable **greater benefits**.

Thank you so much *for your time & participation!*

Questions + Suggestions?



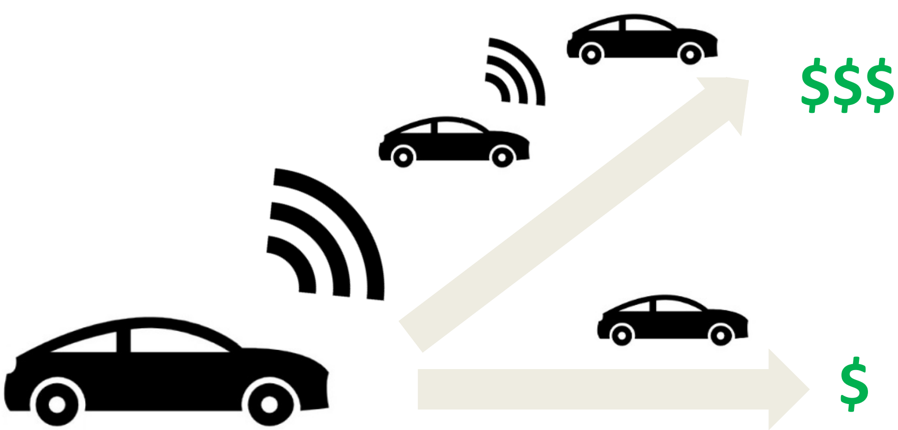
All pre-prints at https://www.caee.utexas.edu/prof/kockelman/

Related Papers

- **Congestion Pricing in a World of Self-Driving Vehicles:** Analysis of Different Strategies in Alternative Future Scenarios. *Transp Research Part C* (2019)
- Development of Traffic-based **Congestion Pricing & Its Application to Automated Vehicles.** *Transportation Research Record* (2019)
- Bringing Efficiency of **Electricity Market** Mechanisms to Multimodal Mobility across Congested Transportation Systems. *Trans Research Part A* (2020)
- Benefits & Costs of **Ride-sharing in SAVs** across Austin, Texas: Opportunities for Congestion Pricing. *Transportation Research Record* (2019)
- **Technologies** for Congestion Pricing. *Research in Transp Economics* (2020)
- **How Will Self-Driving Vehicles Affect U.S. Megaregion Traffic?** The Case of the Texas Triangle. *Research in Transportation Economics* (2020)
- *Economics of Transportation Systems: A* ***Reference for Practitioners*** (2012)

Extra Slides

Congestion Pricing in a World of Personal + Shared AVs



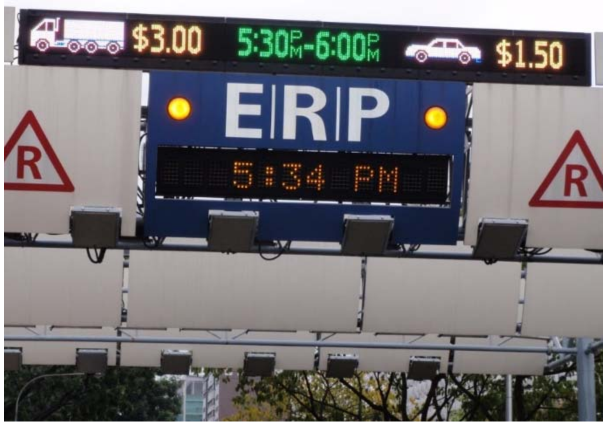
LONG-TERM expectations of **privately owned + shared AVs** (AVs + SAVs)

→

BENEFITS in road safety, accessibility, electrification of vehicles + higher link capacities **may be mostly offset by Rising Congestion?**

→

OPPORTUNITY: **Smart system management** with congestion pricing (traditional & advanced strategies)



Scenarios Evaluated

2020 Base Scenario: No AVs

- 5% sample from 1M population
- Car, transit, + walk/bike modes
- High car access (90% of travelers)

Private AV-Oriented Scenario

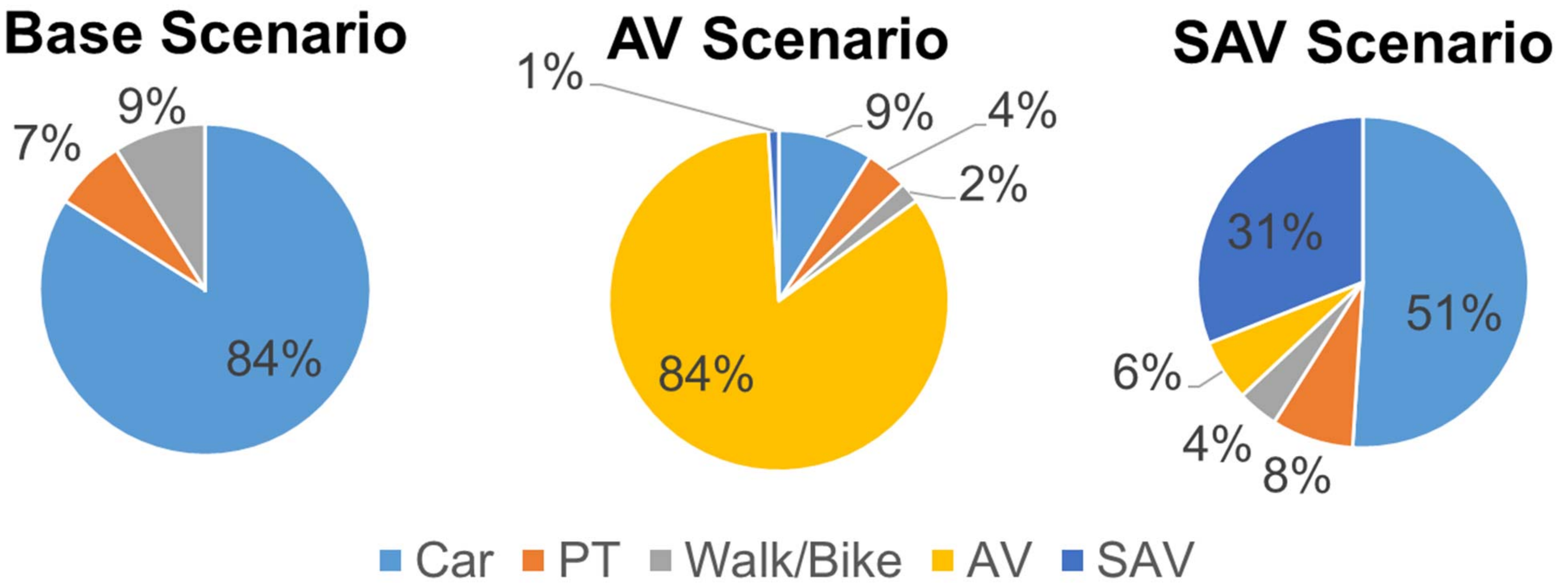
- 90% of travelers now own AVs (as an upgrade from HV in base case or a new AV)
- AVs travel similar to cars, but with **30% smaller headways** & lower cost.
- **1 SAV for every 50 agents**.

SAV-Access Scenario

- Low AV ownership (10% of travelers)
- Large fleet: **1 SAV for every 10 agents**
- 50% **lower SAV fares**

Note: At least 90% of travelers have access to personal vehicle in all scenarios

Mode Split & VMT Results



	Base Scenario	AV-oriented Scenario	SAV-oriented Scenario
Total Weekday VMT	2.8 M mi/day	**3.0 M mi/day**	**3.3 M mi/day**
VMT by Empty SAVs	0	< 0.1 M mi/day	0.3 M miles/day
Total Travel Delay (veh-hours per weekday)	437,887 hr/day	**459,781**	**523,594**

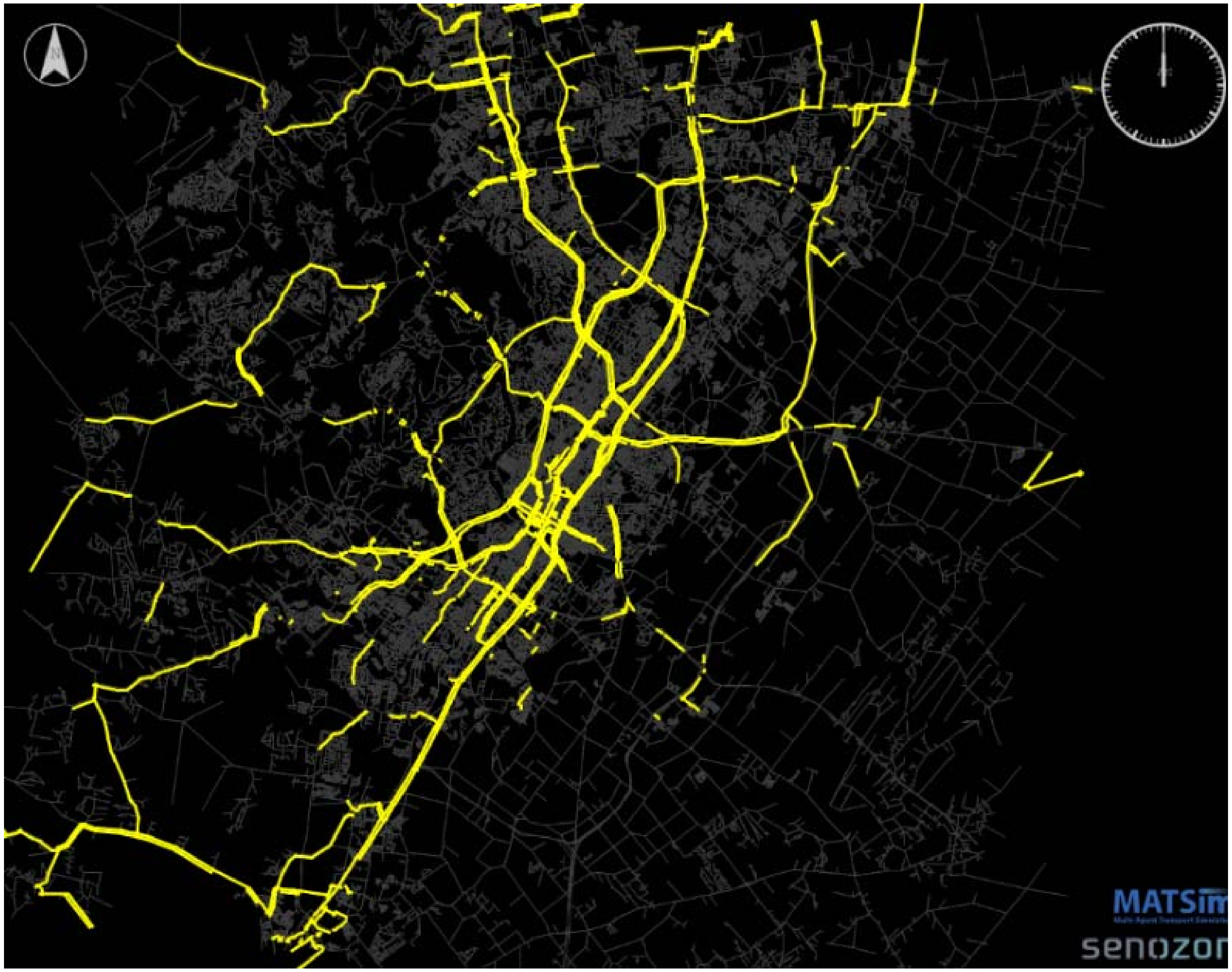
Simple Tolling Strategies

1. Congestion-based

- Toll **most congested links** (v/c > 0.9)
- Simply **$0.10 to $0.20** each, during **peak** periods
- **Just 4%** of Austin's **network**

2. Distance-based

- Simply **$0.10 per VMT**
- Over **entire day**



Advanced CP Strategies

3. Marginal Cost Pricing (MCP): Each link's toll varies dynamically based on fundamental diagram for traffic flow…

$$Delay, d_i = \left[\left(\frac{l_i}{v_i} - \frac{l_i}{FFS_i}\right) \cdot n_i\right] \quad \rightarrow \quad Toll = \tau_i = max\left\{0; \frac{d_i \cdot VOTT}{\Delta n_i}\right\}$$

where *v* = average speed, *n* = #vehicles at instant, Δn = # new vehicles in 5 min period, & *VOTT* = (average) value of travel time

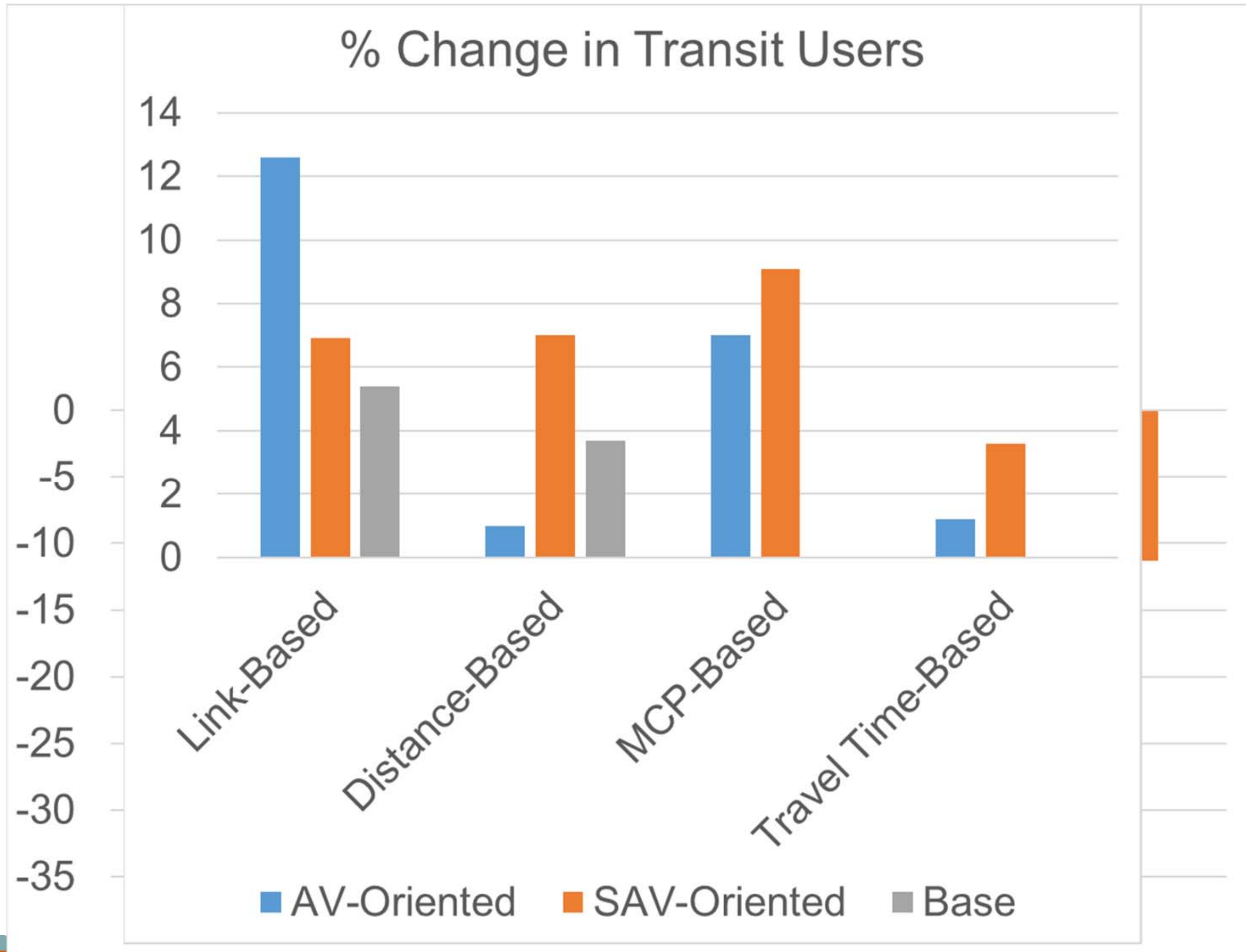
4. Travel Time-based Congestion Tolls: $\tau = \frac{\alpha\left(\sum_i^M d_i\right) \cdot VOTT}{\mathrm{D} \cdot r}$

where *D* = # departures; *r* = average trip duration; α = parameter; *M* = total # links

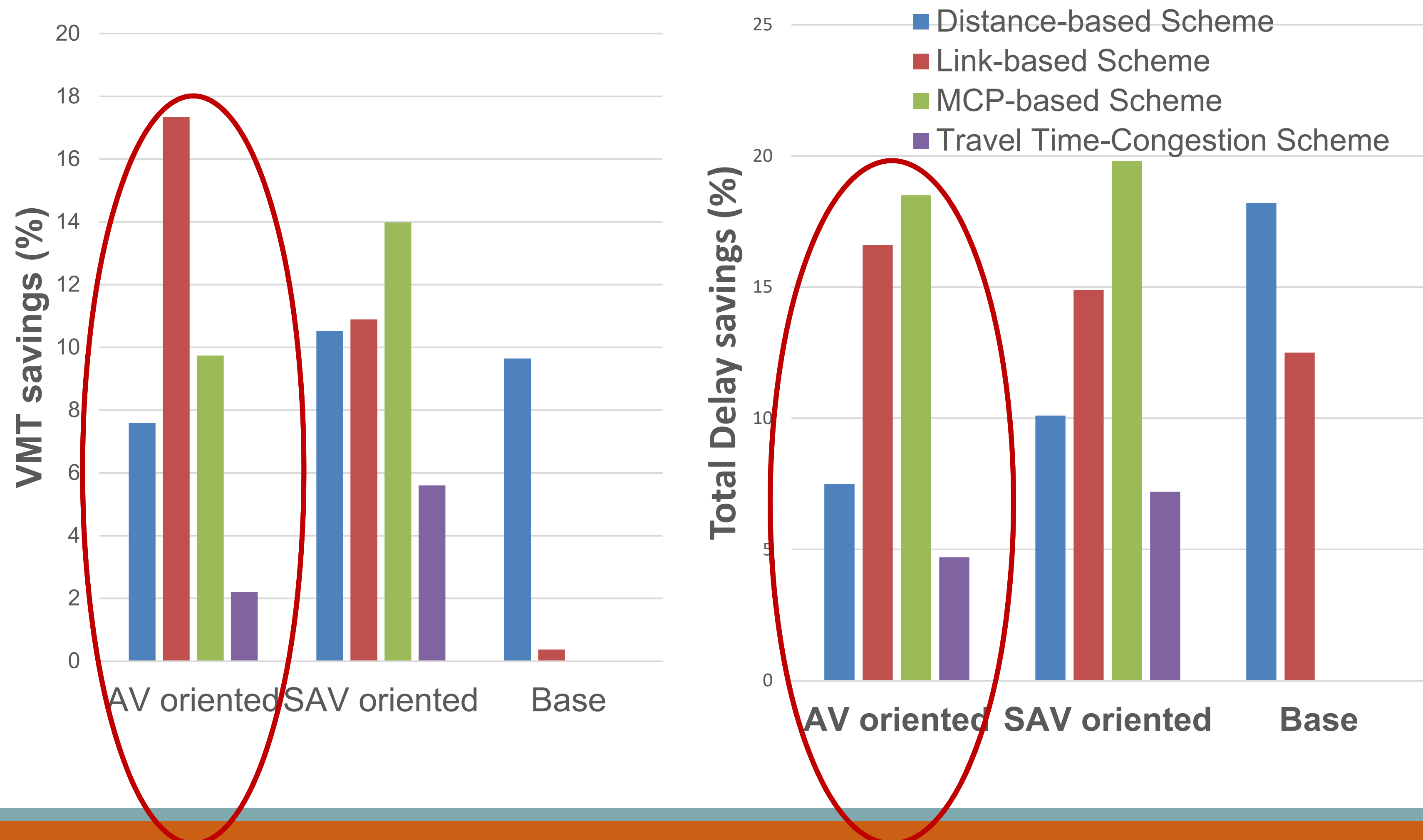
Results: Mode Shifts

All tolling scenarios lower AV & SAV use…

Transit use rises, **especially under simple link-based** (v/c > 0.9) **tolling…**



Results: Network Performance Changes



Results: Welfare Changes

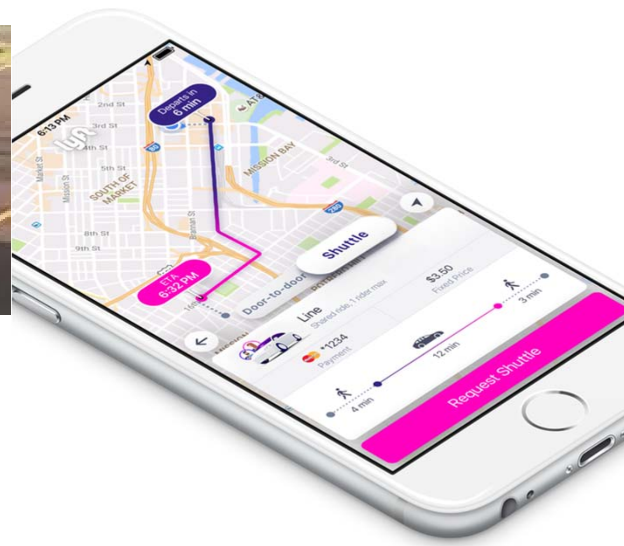
- **Link-Based Scheme**: Total traveler welfare rises just +**0.5%** & +**0.7%** across scenarios.
- **Distance-Based Scheme**: Welfare up +**1.2%** & +**1.4%** in SAV & *No*-AV Scenarios, but falls **-1.2%** in the AV-Oriented Scenario (!).
- **MCP Tolling**: +**2.0%** & +**3.2%** in AV & SAV Scenarios
- **Travel-Time Congestion-based Tolling**: +**2.6%** & +**4.4%** in AV & SAV Scenarios **= BEST result**

Conclusions

- **Smart system management** exploits benefits of smart cars & navigation apps.
- **All CBCP strategies improve traffic conditions.**
- But relatively **low welfare gains**, even after compensation $\rightarrow$ **Importance of thoughtful credit distribution.**
- **Dynamic CP schemes** are **best** (greatest improvements for lowest behavioral changes).
- Opportunities for **future research**: endogenous destination choice, explicit parking choice, & more advanced strategies.

More Slides

Evaluating Congestion Pricing + DRS



Fleet Size + Fare Assumptions

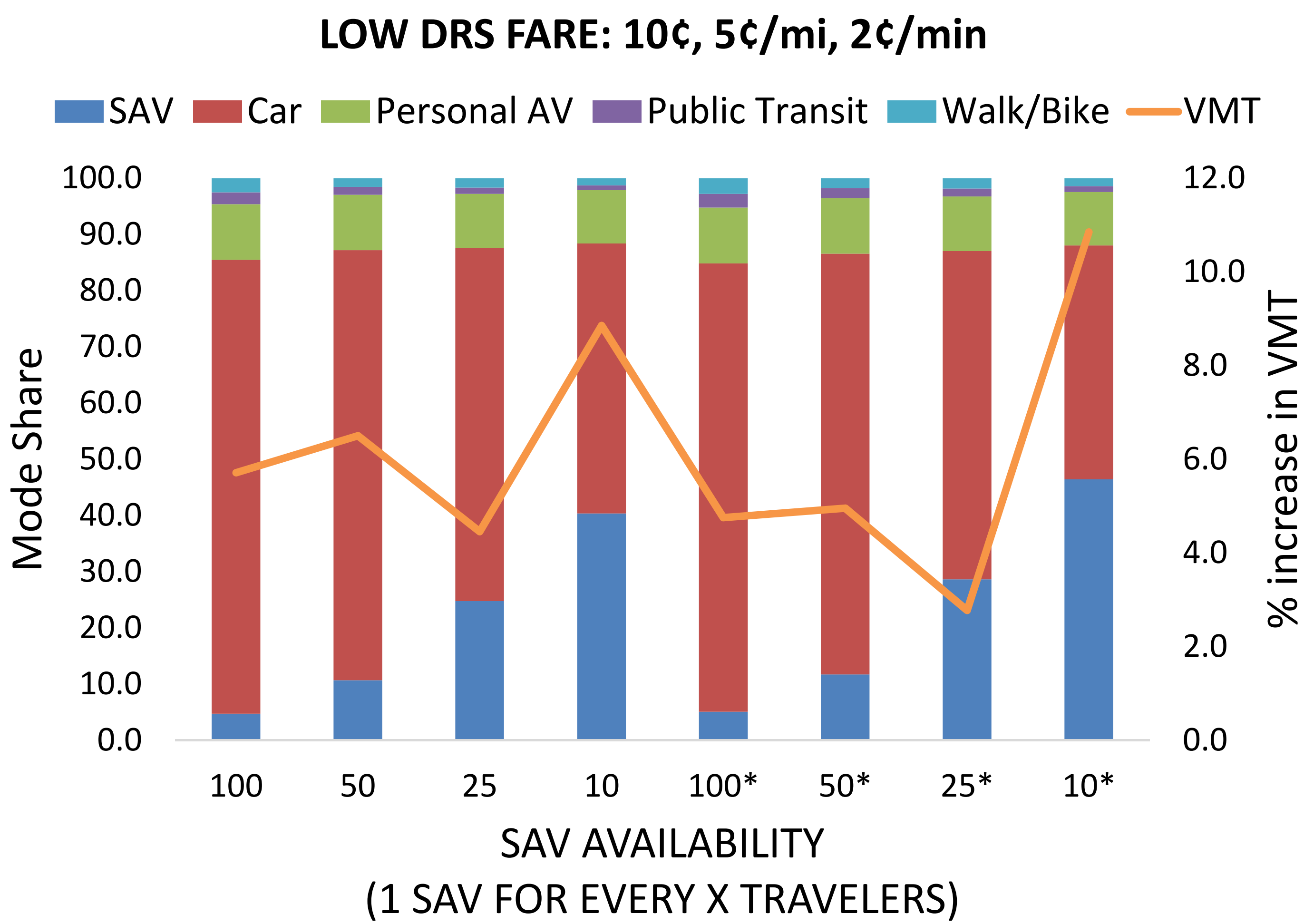
- **4** fleet sizes: **1 SAV** per **10**, **25**, **50** & **100** travelers
- DRS & SAV Pricing to **mimic ride-pooling apps**
- **Solo** travel in SAV costs **2x** a **shared ride.**

DRS Pricing	**Fixed Cost for Pickup**	**+ Distance-based Cost**	**+ Time-based Cost**
High Fare	25¢	20¢ per mi	5¢ per min
Medium Fare	15¢	10¢	3¢
Low Fare	10¢	5¢	2¢

Congestion Pricing (CP) Simulations

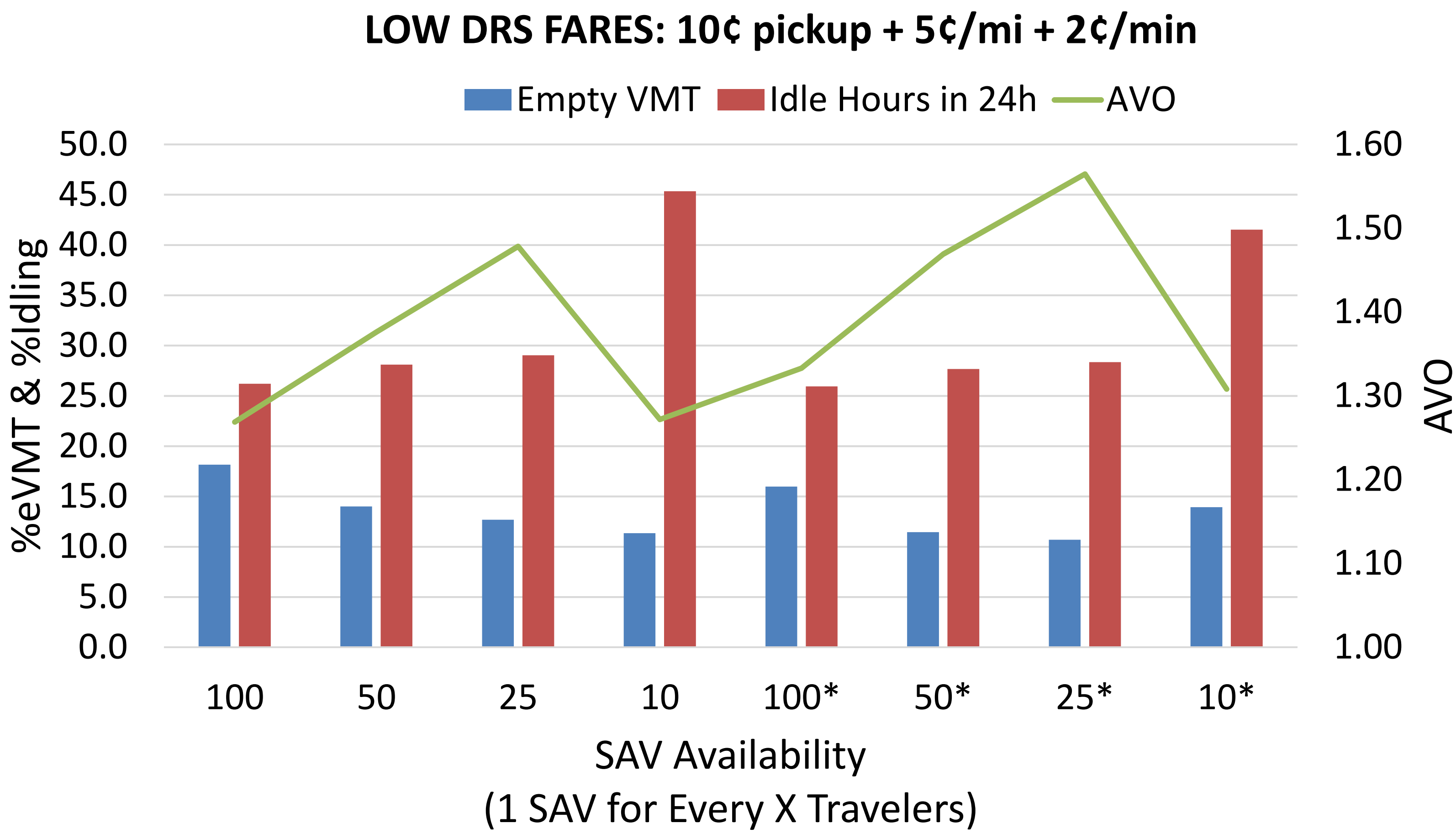
- **Austin's most congested corridors selected** for CP.
- **Peak-period tolling** peaks (**7-9 am** & **5-7 pm**).
- **CP Tolls based on travel times**: **5¢ per min.**
- **MATSim** DTA code modified for SAVs + DRS + CP.
- Horl's heuristic **DRS** code with 2 settings:
  - **SAV Under-supply**: **High** ratio of **# requests** to available SAVs (low-cost **DRS** paths calculated)
  - **SAV Over-supply**: **Low** ratio (requests matched **instantly** to nearest SAV)

Results: Mode Splits + VMT



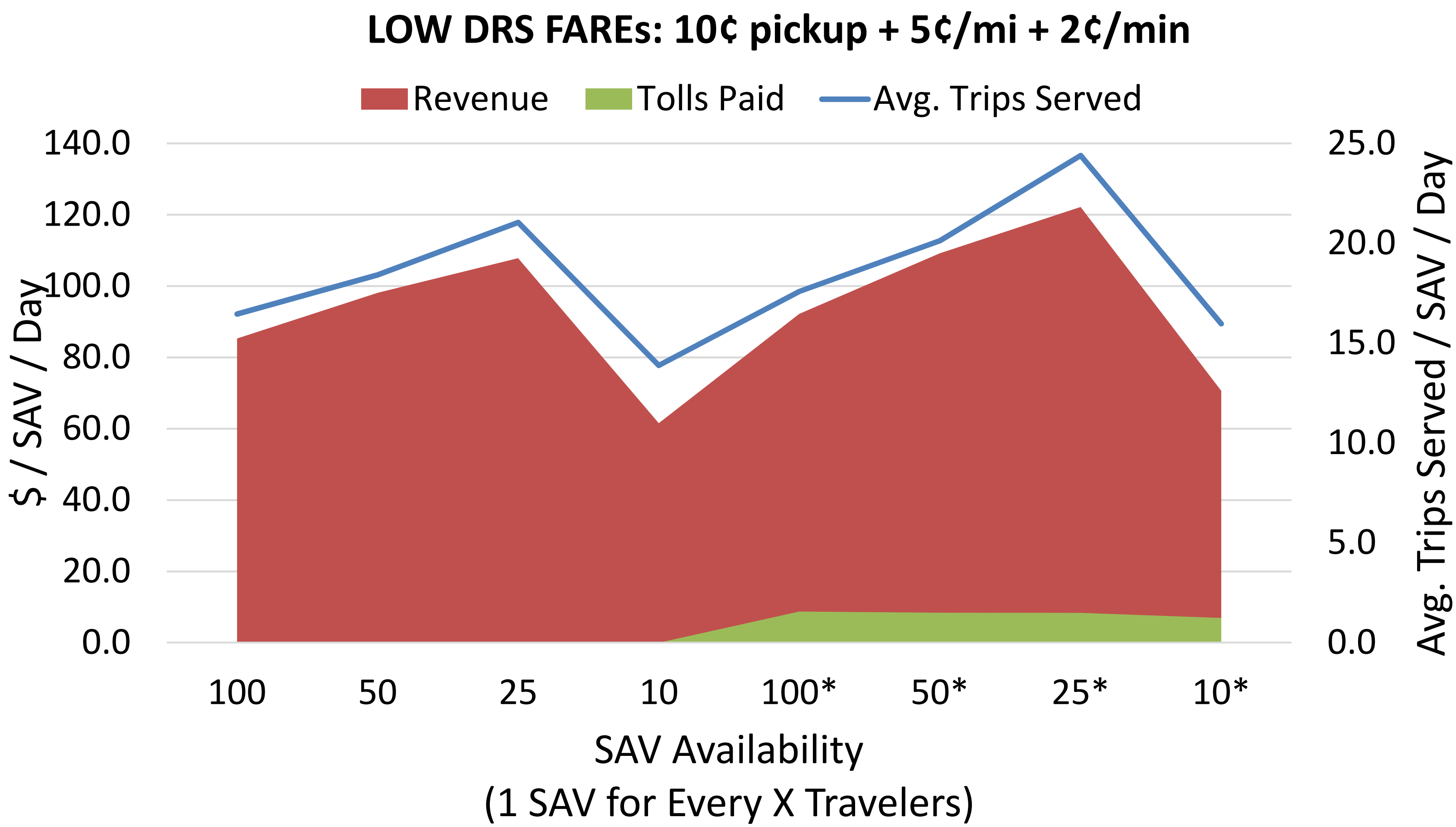
* with congestion pricing

%eVMT, %Idling, & AVO



* with congestion pricing

Revenue + Tolls + Trips/day/SAV



* with congestion pricing

Congestion Pricing Helps

- **AVs & SAVs** will bring benefits but also much **VMT**, especially with large fleet sizes or AV ownership levels.
- As expected, **CP moderates** VMT + congestion.
- But **truly dynamic pricing can be harmful** & needs much smoothing via demand anticipation.
- **DRS** is helpful, but may be popular in US only at **competitive fares.**
- Both large & small SAV fleet sizes (1:10 & 1:100 persons) deliver **low DRS use** (due to excess supply of vehicles & inadequate matching, respectively).
- **Fleet profits** ≈ **$113**/SAV/day, even with **low fares.**
- Targeted analysis needed if goal is to **maximize AVO.**

In Conclusion…

- **CAVs** offer **tremendous benefits** for mobility, safety & parking, ***but*** will **add VMT & congestion**.
- **SAVs** offer a **new & exciting** (transit?) mode, with each SAV **replacing ~8 personal vehicles**, for same level of motorized trip-making.
- SAVs add **7-15% extra VMT** (though DRS may reduce VMT).
- Yet SAVs may bring useful **travel-cost savings**, **emissions benefits + profits** for transit providers.
- **Smart system management** practices (like **credit-based congestion pricing**) are also needed, to avoid gridlock, sprawl, greater energy use, & other downsides.