How might automated vehicles affect energy use and emissions?

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Background:
Energy and emissions implications of AVs

Automation offers substantial energy & environmental benefits…

Travel Demand

Per-mile / per-minute pricing

Design

Right-sizing

Lower performance

Reduced crashworthiness

New vehicle concepts

Fuels

Lower infrastructure costs

Self-refueling

$$Emissions = Person\ Miles \cdot \frac{Vehicle\ Miles}{Person\ Mile} \cdot \frac{BTUs}{Vehicle\ Mile} \cdot \frac{Emissions}{BTU}$$

Mode Structure

On-demand mobility

Robo-taxis

Shared vehicles

Personal transit

Occupancy rates

Operations

Platooning

Congestion relief

Traffic smoothing

Eco-driving

Optimal speed/routing

Automation offers substantial energy & environmental benefits… and risks

Travel Demand

Per-mile / per-minute pricing

Underserved populations

Lower cost (VOTT)

Land use changes

Design

Right-sizing

Lower performance

Reduced crashworthiness

New vehicle concepts

"Mobile Barcalounger"

Fuels

Lower infrastructure costs

Self-refueling

$$Emissions = Person\ Miles \cdot \frac{Vehicle\ Miles}{Person\ Mile} \cdot \frac{BTUs}{Vehicle\ Mile} \cdot \frac{Emissions}{BTU}$$

Mode Structure

On-demand mobility

Robo-taxis

Shared vehicles

Personal transit

Occupancy rates

Deadheading

Operations

Platooning

Congestion relief

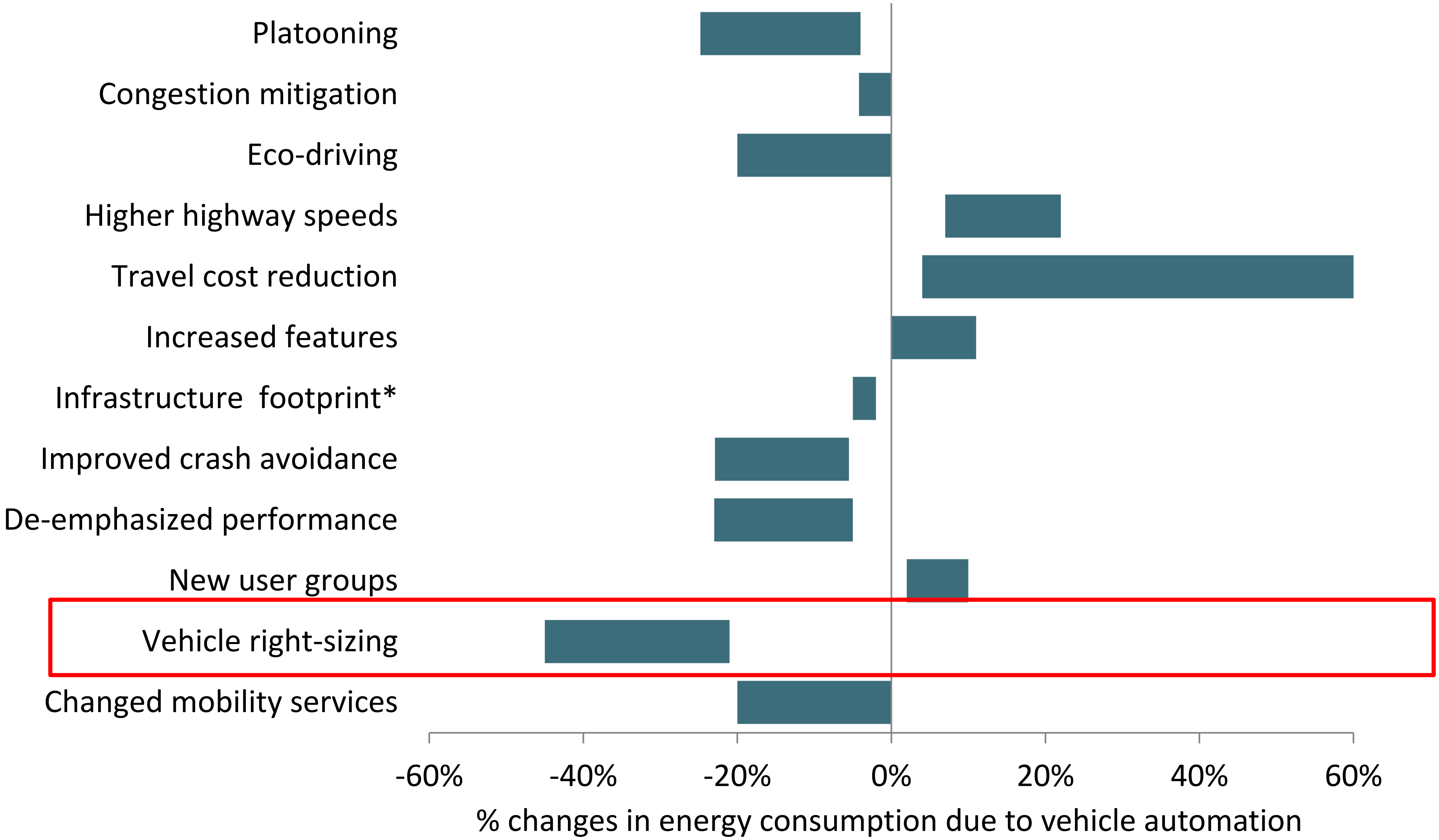
Traffic smoothing

Eco-driving

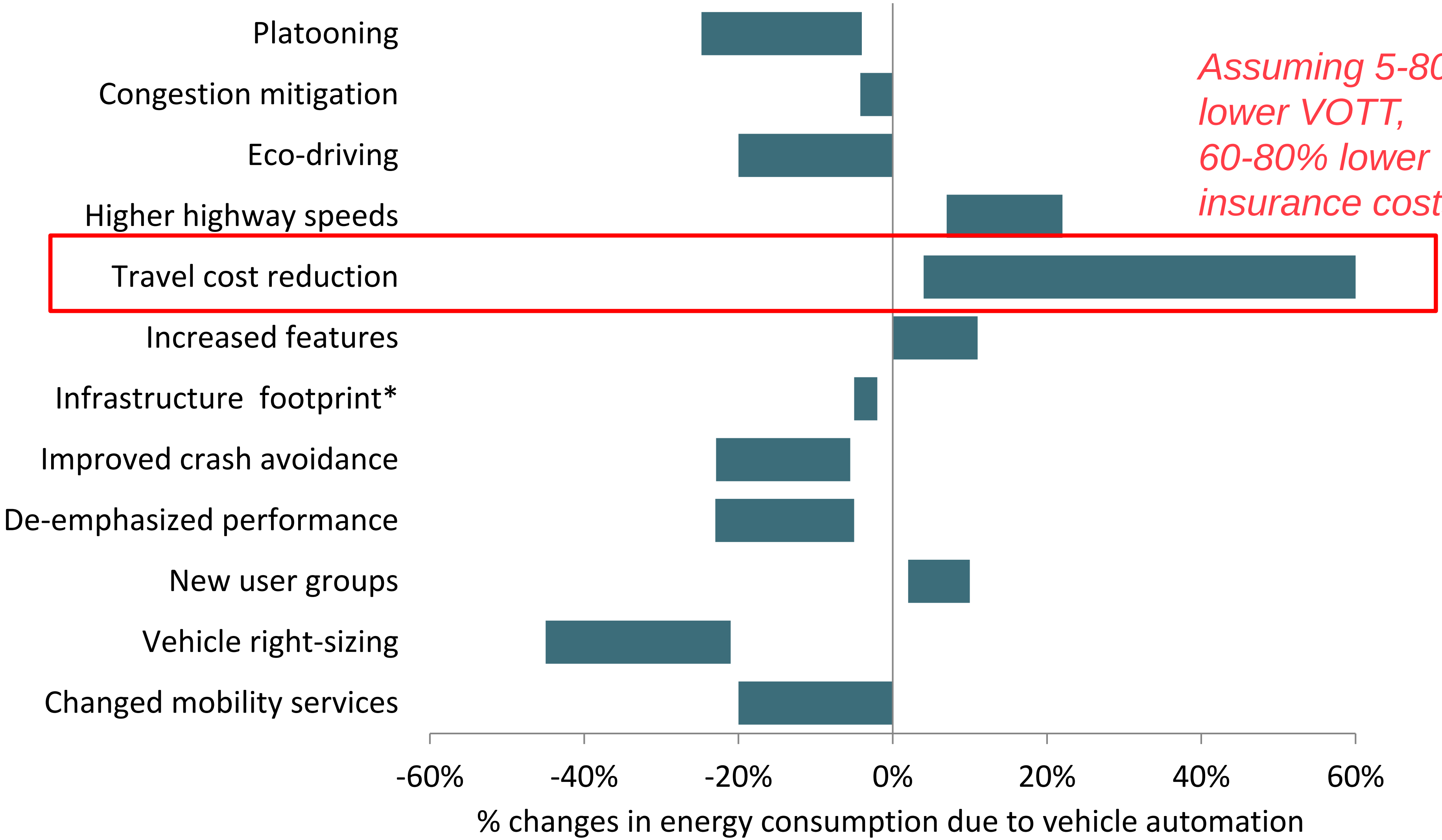
Optimal speed/routing

Highway speeds

Right-sizing is largest opportunity

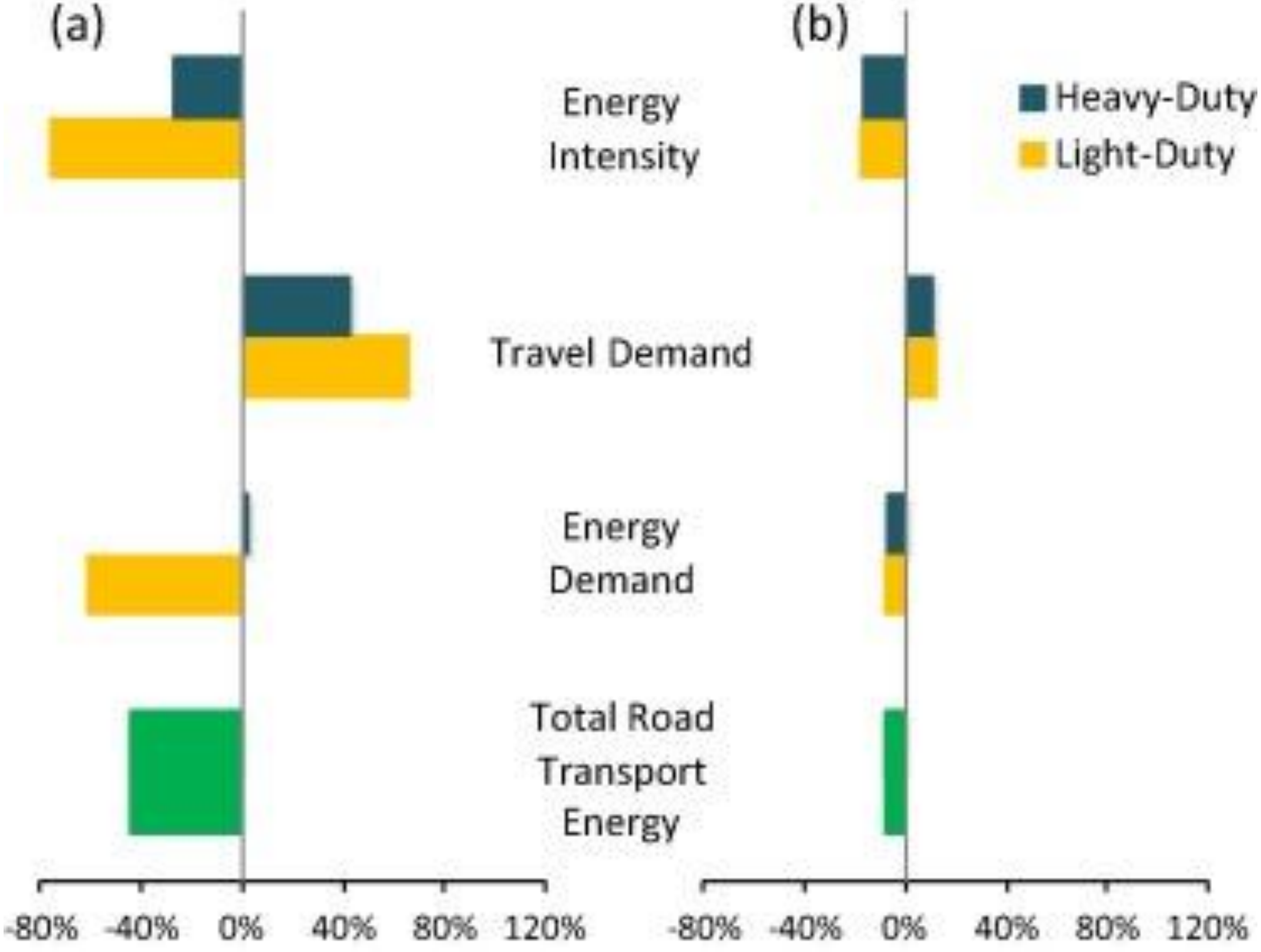


Lower cost of travel could swamp gains in efficiency

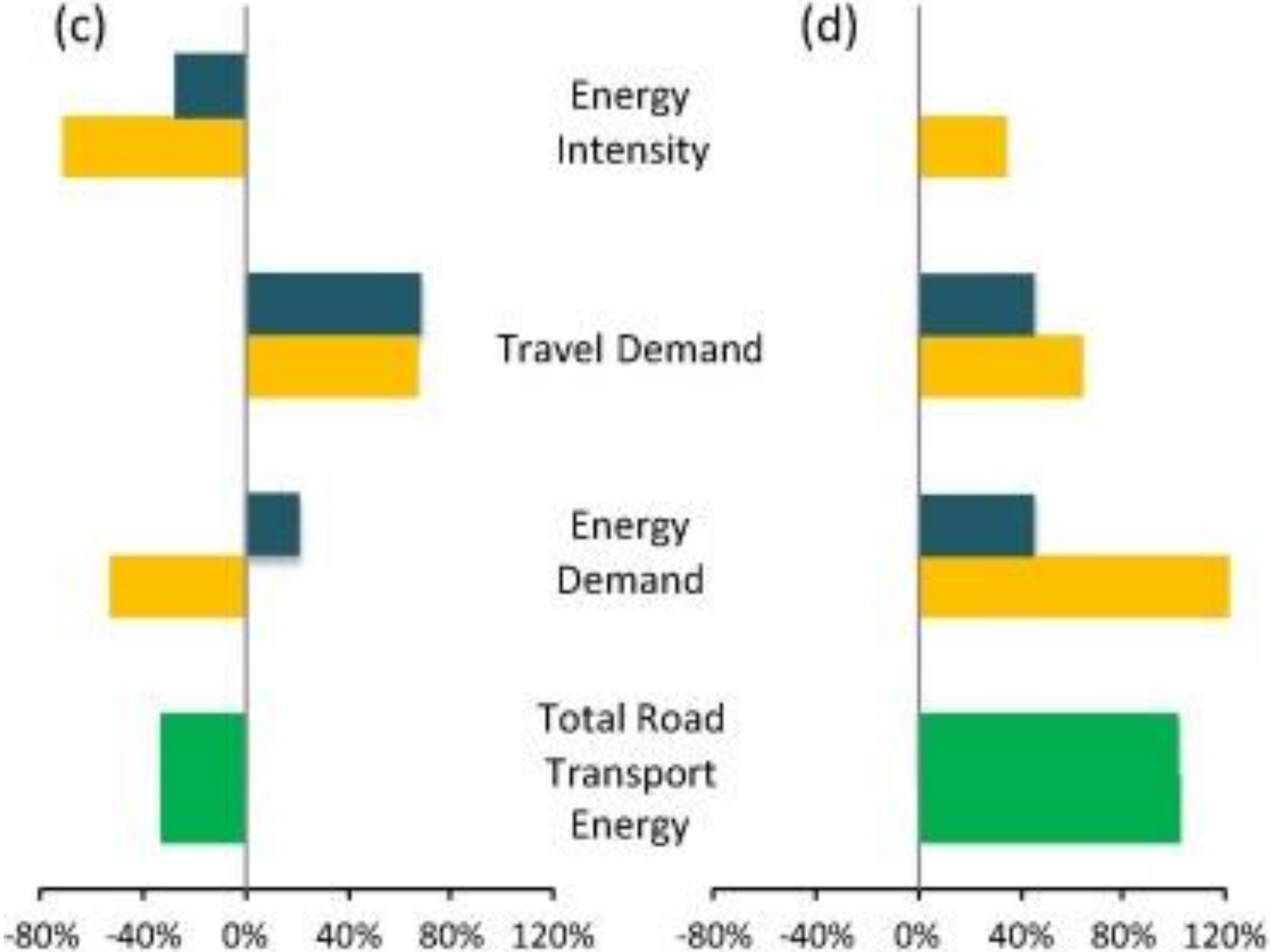


Assuming 5-80% lower VOTT, 60-80% lower insurance costs

Scenarios illustrate, but don't quantify, uncertainty



Scenarios illustrate, but don't quantify, uncertainty



Today's focus:
Trying to refine estimates of impacts

1. How does relieving traveler from driving affect value of travel time?

2. How does reduced value of travel time affect residential location choices?

3. How would a right-sized fleet affect fuel economy?

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Trying to refine estimates of impacts

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3. How would a right-sized fleet affect fuel economy?

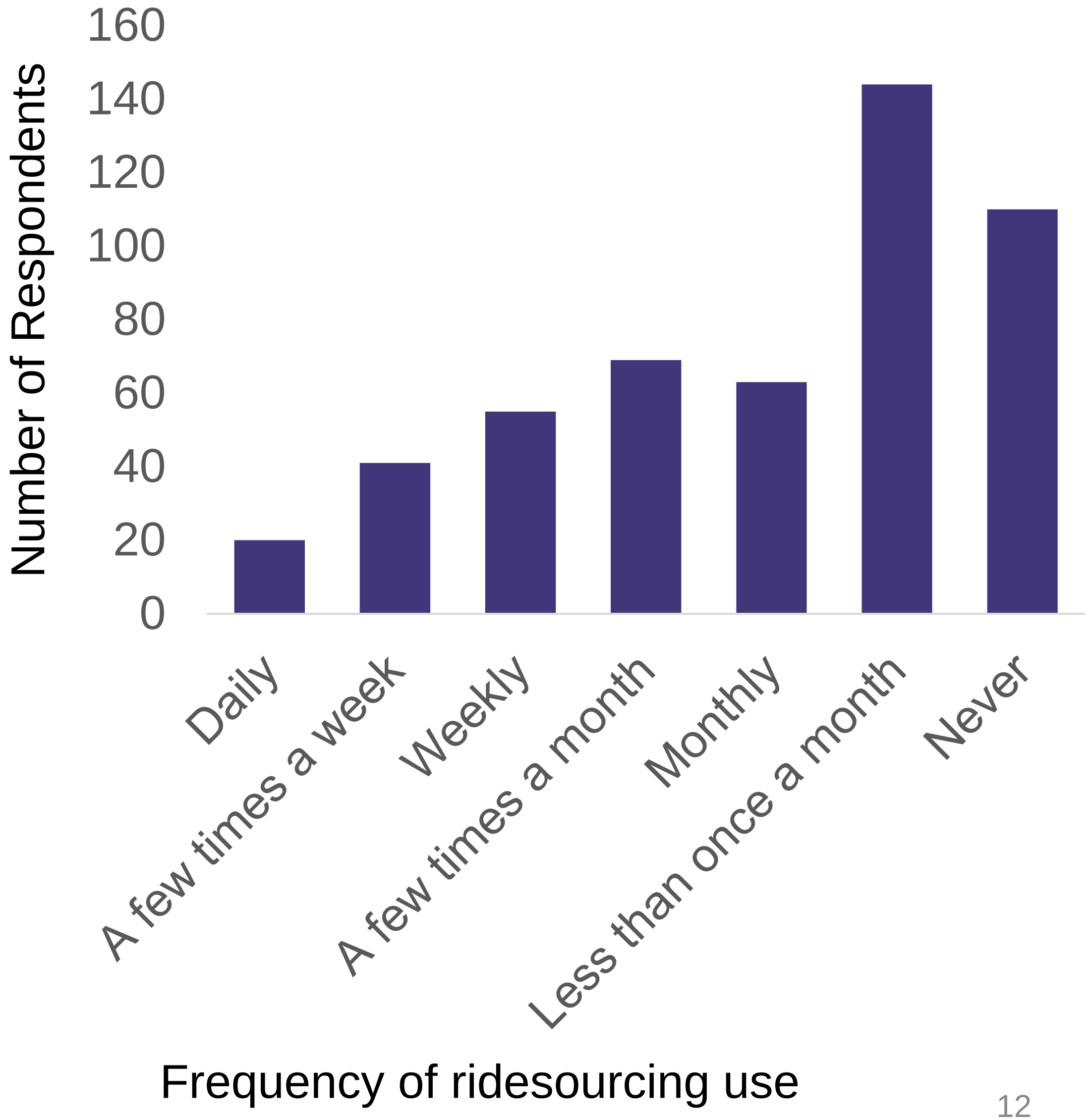
Automation can make vehicle travel cheaper, safer, and more convenient

"It was the same distance, but the commute felt like it took half the time"

https://www.teslamotors.com/customer-stories/how-autopilot-added-years-my-life

Premise: ridesourcing services provide analogous in-vehicle experience to Level 4-5 AVs

- No need to drive
- Productivity or relaxation
- **Ridesourcing is available today**



Stated choice experiment elicited marginal utility of time, money

If you had to make a **15-mile commute trip**, which of the following options would you choose?

Personal Car	Ride-hailing Service
Travel Time: 20 min	Travel Time: 15 min
Travel Cost: $5 (fuel, tolls, parking, etc.)	Travel Cost: $15 (fare)
Waiting Time: 0 min	Waiting Time: 2 min

- ◯ **Personal Car**
- ◯ **Ride-hailing Service**

Respondents were randomly assigned to one of four conditions

(a) Personal car

vs.

Human-driven ridesourcing

(b) Personal car

vs.

Driverless ridesourcing

(c) Personal car

vs.

Human-driven ridesourcing, multitasking explicitly mentioned

(d) Personal car

vs.

Driverless ridesourcing, multitasking explicitly mentioned

Conditions (c) and (d) included an activity attribute

If you had to make a **15-mile commute trip**, which of the following options would you choose?

Personal Car	**Ride-hailing Service**
Travel Time: 20 min	Travel Time: 15 min
Travel Cost: $5 (fuel, tolls, parking, etc.)	Travel Cost: $15 (fare)
Waiting Time: 0 min	Waiting Time: 2 min
Activity: Driving	Activity: Non-Driving(e.g. work, read, rest, using cellphone...)

- ◯ **Personal Car**
- ◯ **Ride-hailing Service**

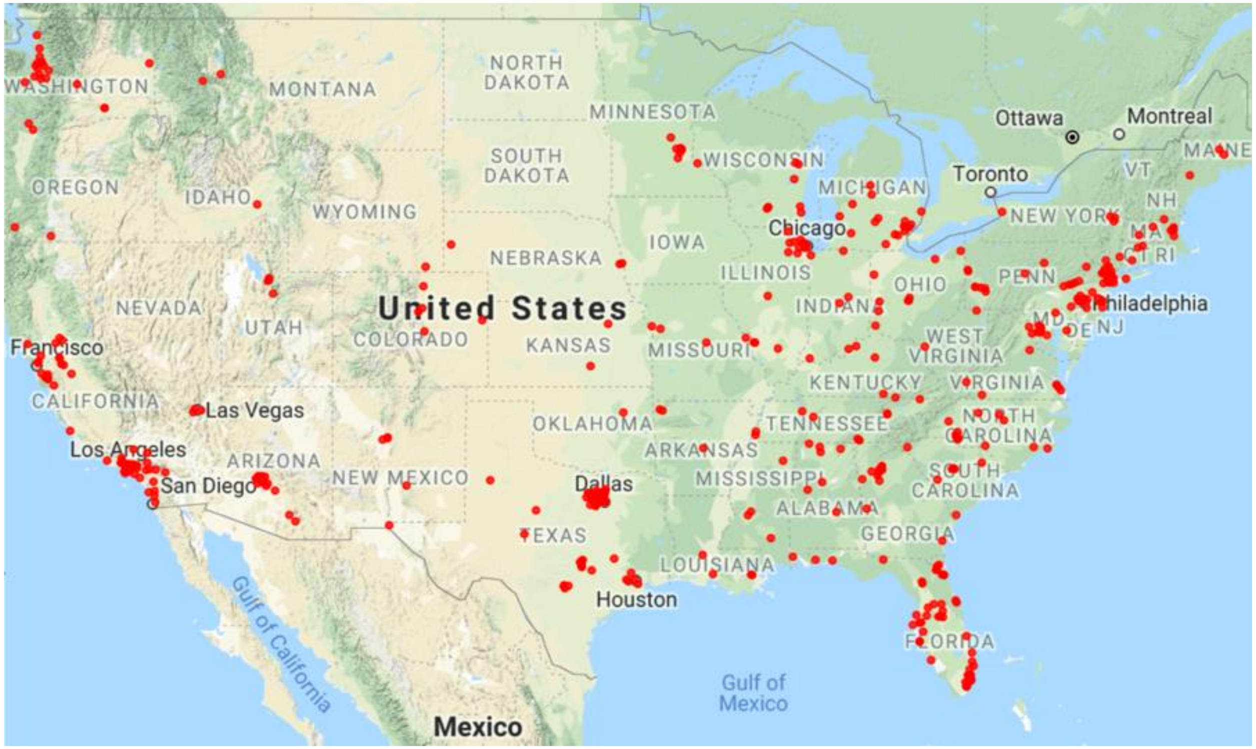
Within each condition, we used a full factorial experimental design

Attribute		Attribute level(s)	
Travel time car	15 min	20 min	25 min
Travel time ridesourcing	15 min	20 min	25 min
Travel cost car	$5	$10	$15
Travel cost ridesourcing	$10	$15	$20
Waiting time car	0 min		
Waiting time ridesourcing	2 min		

Survey was hosted on SurveyMonkey, respondents recruited through Amazon MTurk

- 535 respondents, 502 valid responses

- 6 choice situations each → 3012 observations



We used binary mixed logit to model utility of alternatives

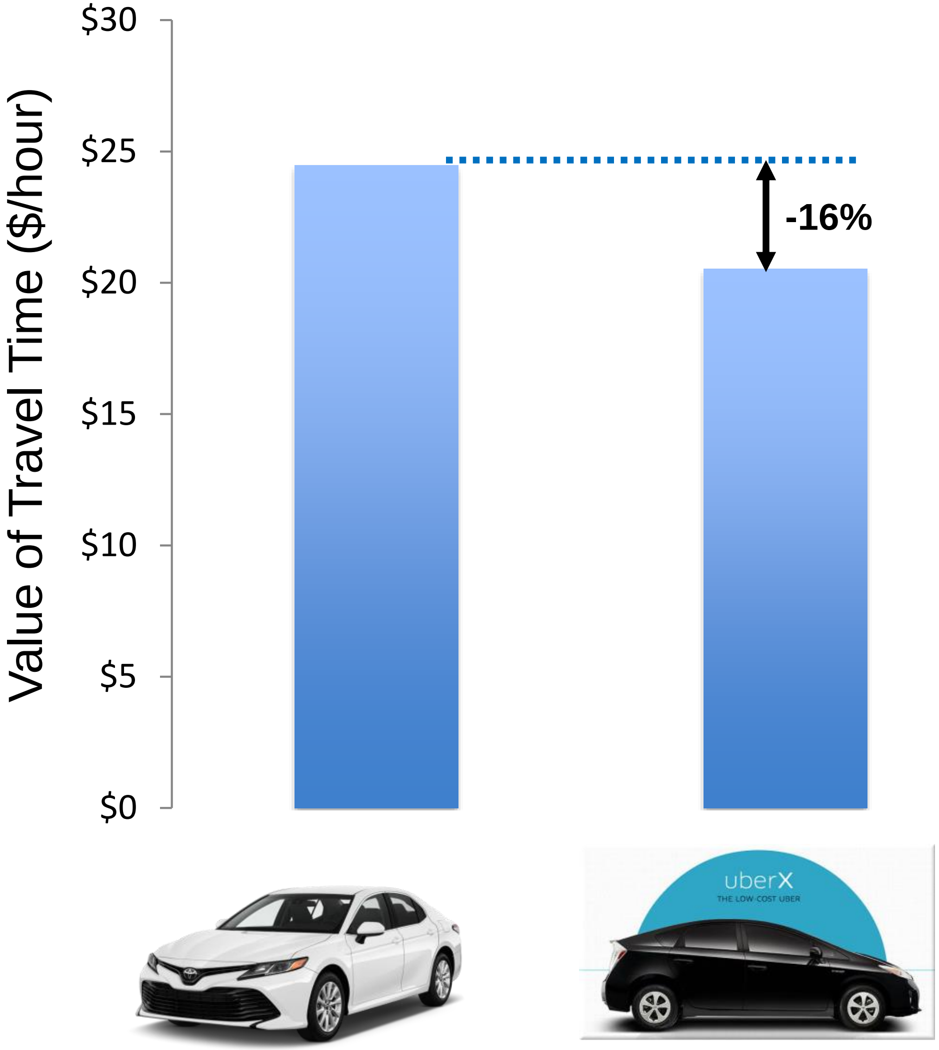
$$U_{ij,car} = \beta_1 cost_{j,car} + \beta_{2,car} time_{j,car} + \varepsilon_{ij,car}$$

$$U_{ij,RS} = \alpha_i + \beta_1 cost_{j,RS} + \beta_{2,RS} time_{j,RS} + \beta_3\, driverless_{j,RS} + \beta_4\, multitask_{j,RS}$$
$$+\beta_5\, driverless_{j,RS} time_{j,RS} + \beta_6\, multitask_{j,RS} time_{j,RS} + \varepsilon_{ij,RS}$$

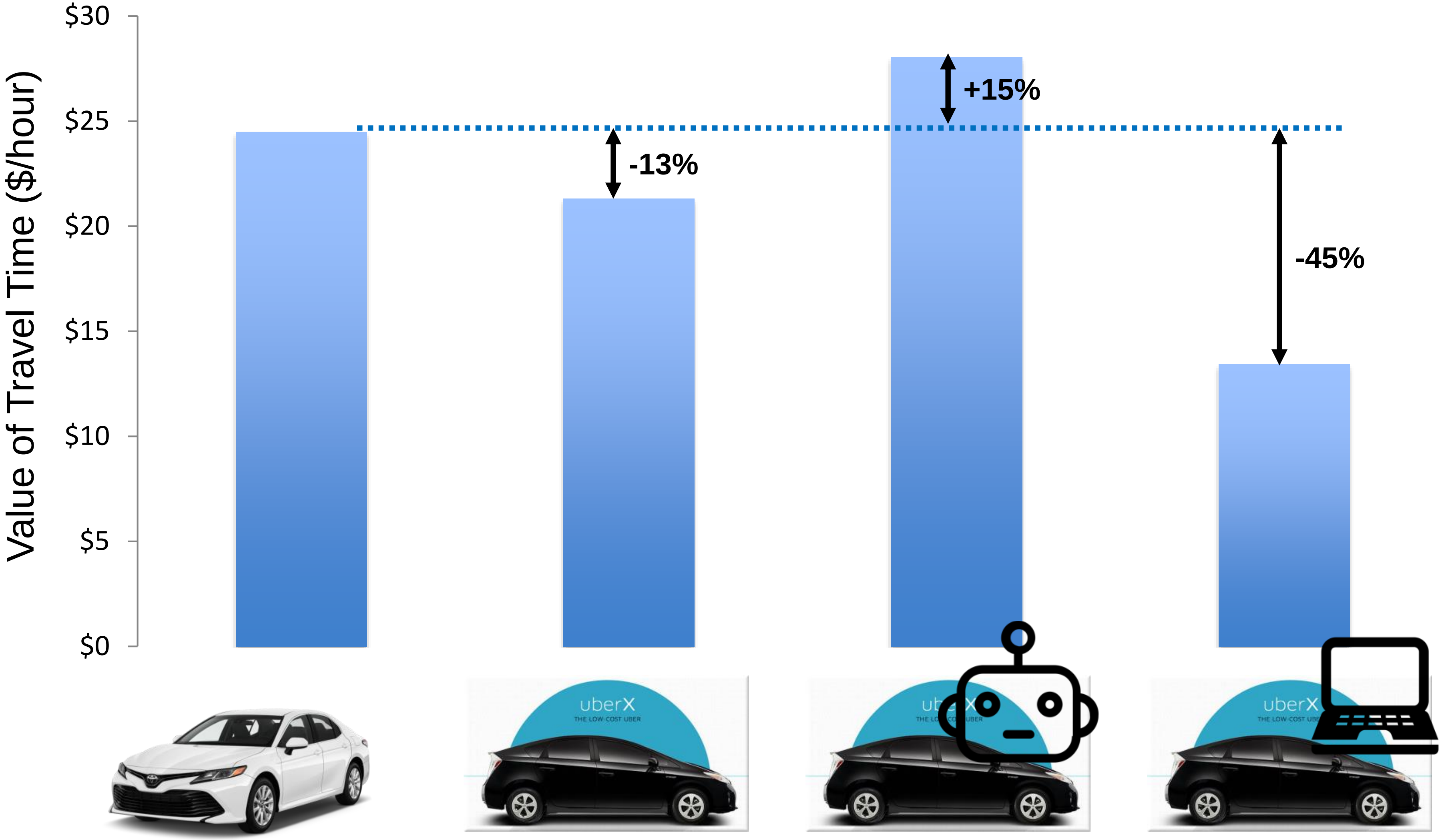
i: individuals

j: choice situations

Value of travel time is lower in ridesourcing services than when driving self



Value of time increases with automation; Decreases with multitasking



Conclusions

- Implied disutility to AV travel
- Value of time in ridesourcing 13-45% lower than driving

Gao, J., Ranjbari, A., & MacKenzie, D. Would being driven by others affect the value of travel time: taking ride-hailing service as an example. *TRB Paper No. 19-02360*, Transportation Research Board 98th Annual Meeting.

1. How does relieving traveler from driving affect value of travel time?

2. How does reduced value of travel time affect residential location choices?

3. How would a right-sized fleet affect fuel economy?

On-demand mobility services and **self-driving cars** → free the traveler from the effort of driving, which is expected to reduce the perceived cost of travel time.

Magic Carpet: an arbitrary technology that makes travel radically **more comfortable** and **convenient** and requires **little to no active control from the traveler.**

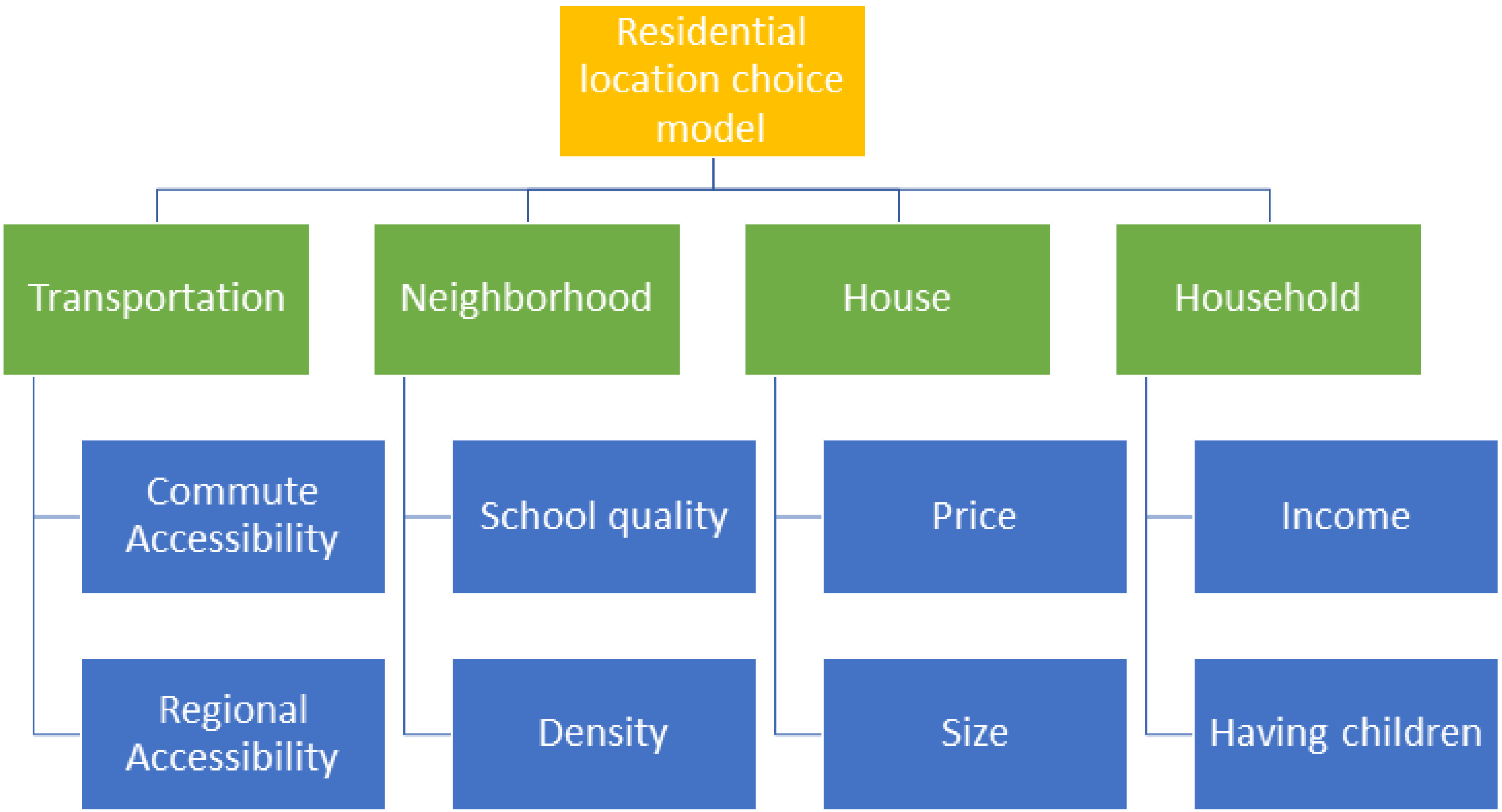
Goal: Explore how reductions in the perceived cost of travel time may affect the attractiveness of different neighborhoods in a region

- Puget Sound (Washington) region as a case study.

- Estimated a **multinomial logit residential location choice model** that incorporated travel time via two measures of accessibility

- Explored how changes in the cost of travel time might change land use patterns in that region.

Overview of the model



We used two measures of accessibility

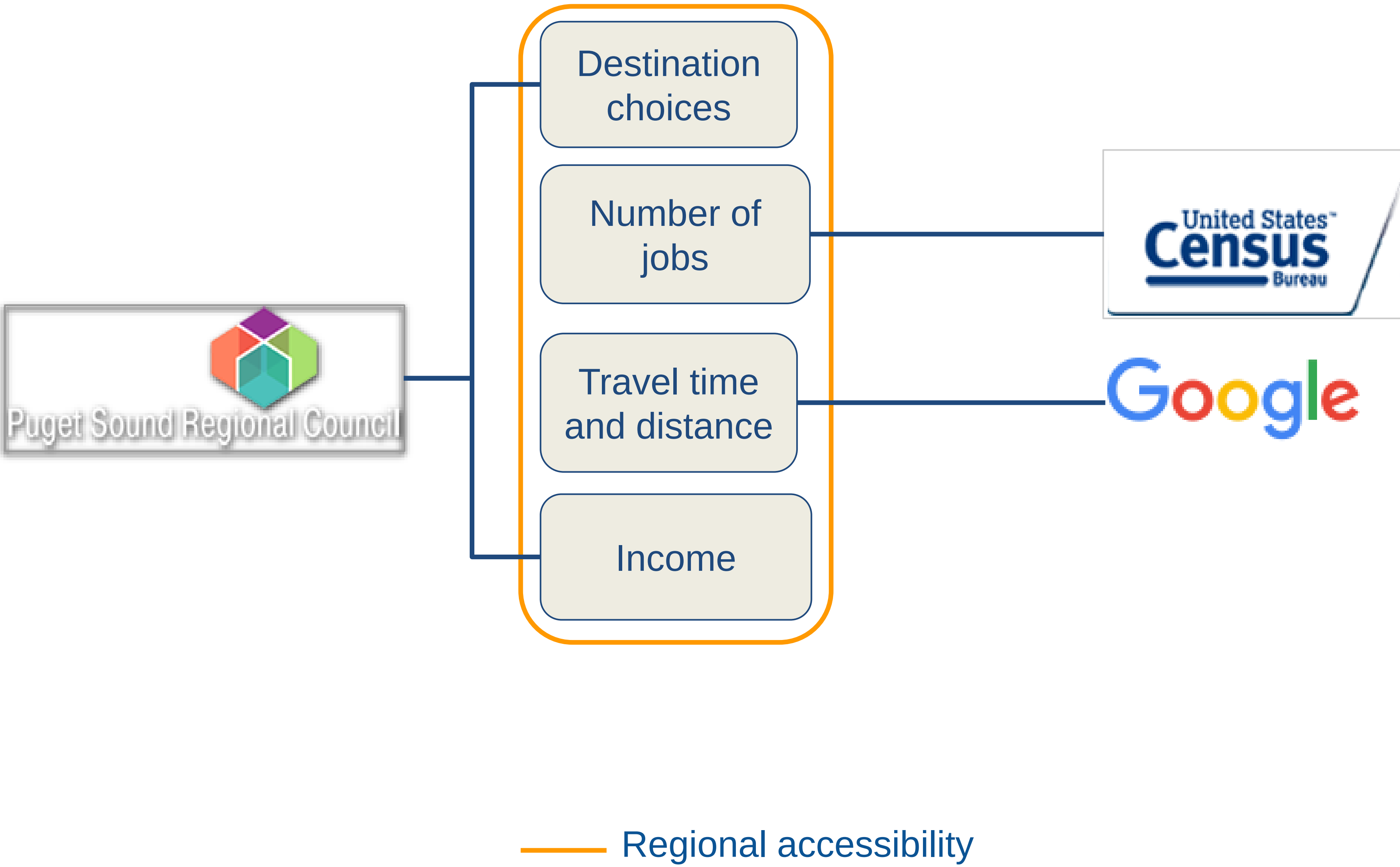
It depends on:

> **How long** it takes for residents to get to **work**,
> The **available** transportation options,
> Accessible opportunities in each zone (captured by number of retail jobs in each zone)

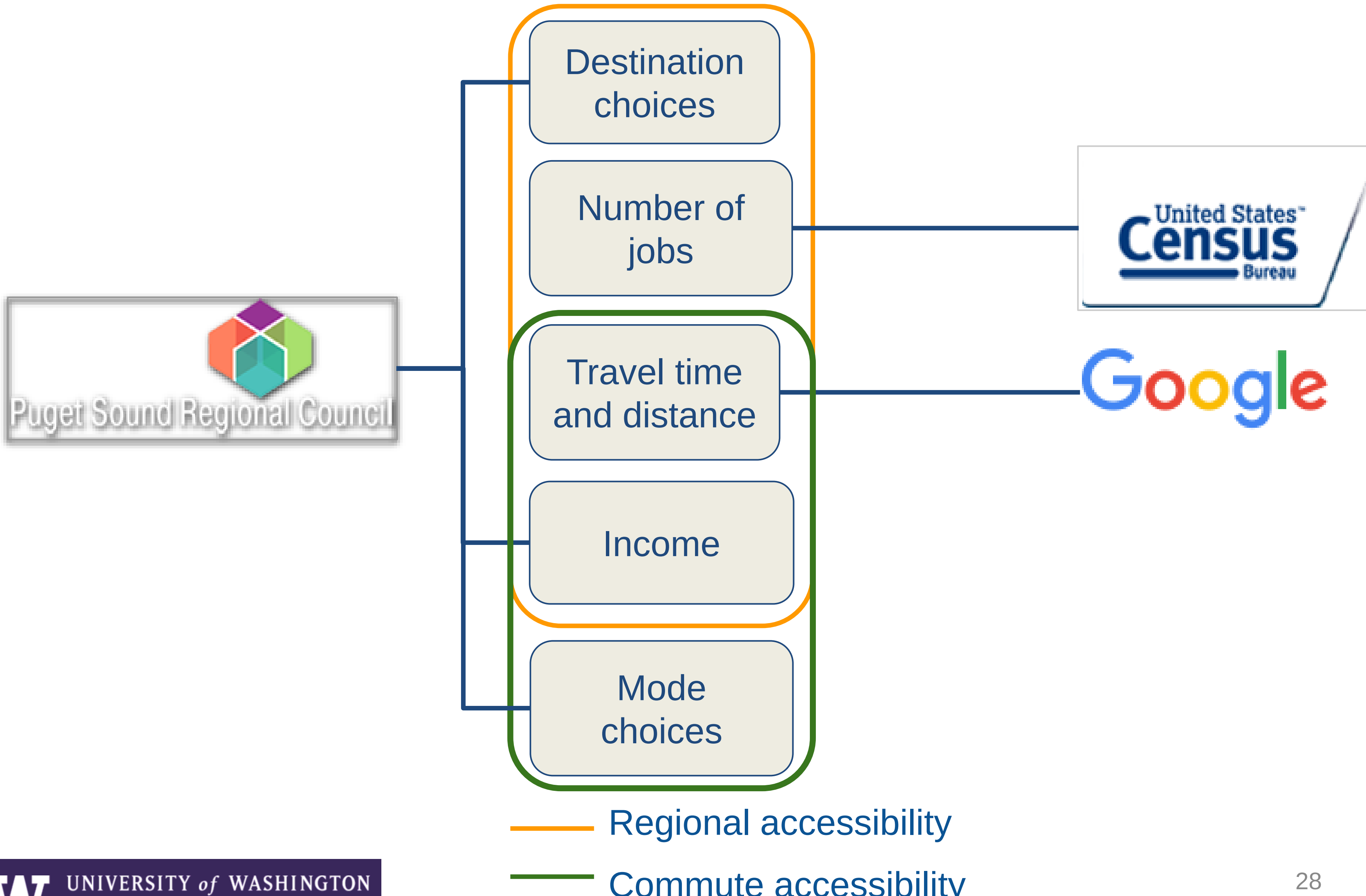
logsum measure for commute accessibility

gravity-based measure for regional accessibility

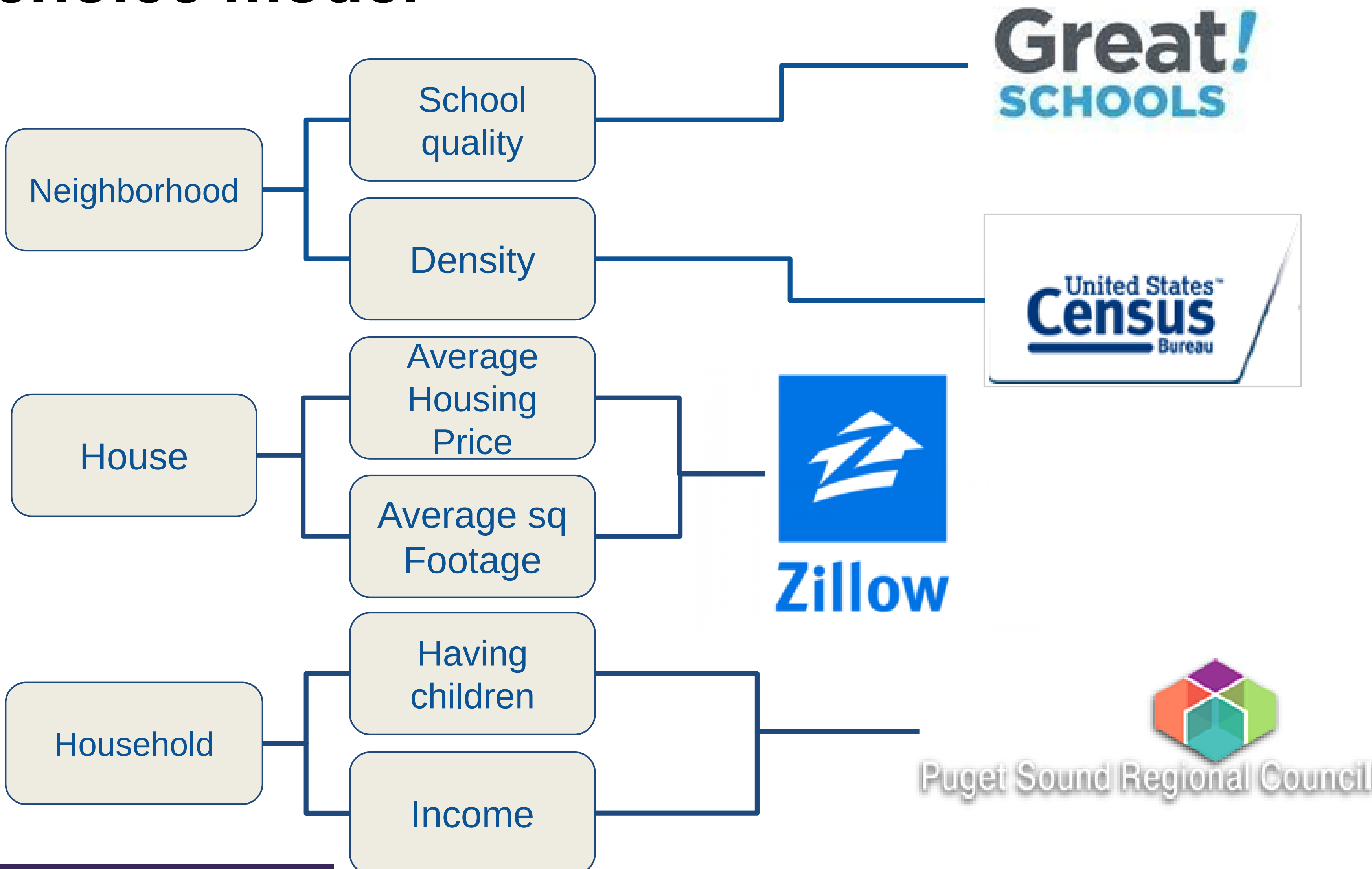
Data Sources for accessibility



Data Sources for accessibility



Data Sources for residential location choice model



We investigated effects of changing time cost of travel

- Cut cost of travel time by half.
  - **Reduction in value of travel time**
  - **Magic carpets being a faster mode** compared with cars
  - Combination of both

The choice of 50% is arbitrary and is for the purpose of exploring the methodology and observing the impact of the hypothetical magic carpet.

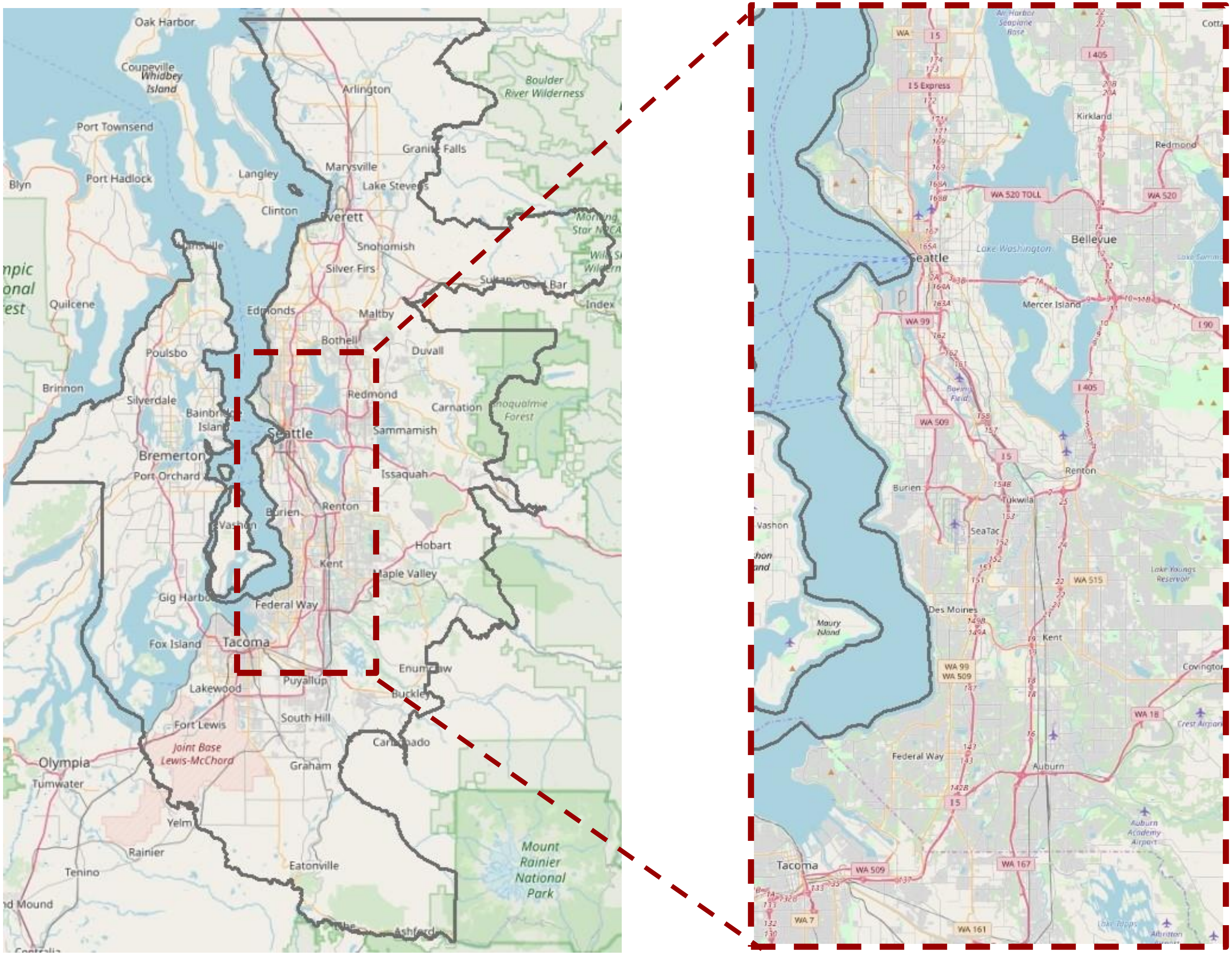
We tested two scenarios

1) Magic carpets replace cars

   – **The time cost of travel is reduced by half**
   – short run **financial cost** of magic carpet travel is same as for cars ($0.10/mile)

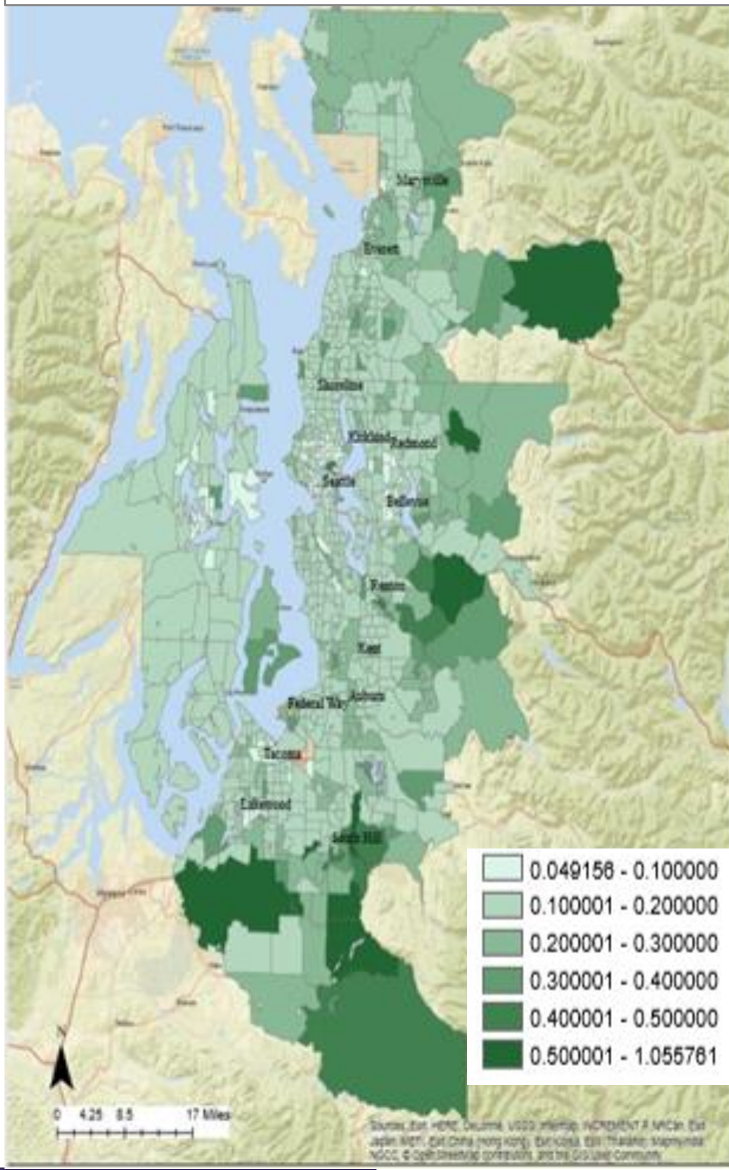
2) Magic carpets are introduced as an additional mode available to all people as an on-demand service

   – **The time cost of travel is reduced by half**
   – **price** of the magic carpet service is **$0.50 / mile**,

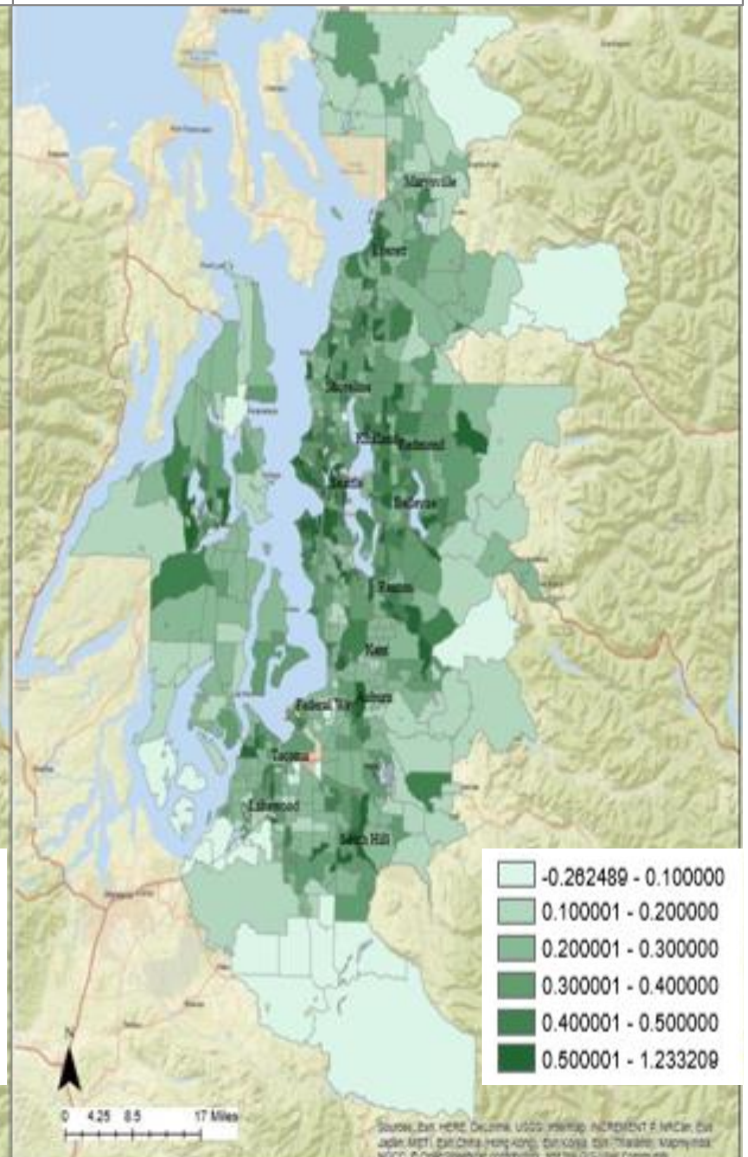

Oak Harbor
Coupeville
Whidbey Island
Port Townsend
Arlington
Boulder River Wilderness
Granite Falls
Marysville
Lake Stevens
Blyn
Port Hadlock
Langley
Clinton
Everett
Snohomish
Silver Firs
Quilcene
Edmonds
Maltby
Index
Bothell
Poulsbo
Duvall
Redmond
Brinnon
Silverdale
Carnation
Seattle
Sammamish
Bremerton
Port Orchard
Issaquah
Burien
Renton
Vashon
Hobart
Kent
Maple Valley
Gig Harbor
Federal Way
Fox Island
Tacoma
Puyallup
Lakewood
Buckley
South Hill
Fort Lewis
Joint Base Lewis-McChord
Olympia
Tumwater
Graham
Yelm
Rainier
Tenino
Eatonville
Mount Rainier National Park
Kirkland
Bellevue
Lake Washington
Mercer Island
SeaTac
Tukwila
Des Moines
Maury Island
Auburn
Covington
Lake Youngs Reservoir
Auburn Academy Airport
WA 520 TOLL
WA 520
I 405
I 5 Express
WA 99
WA 509
WA 515
WA 18
WA 167
WA 7
WA 161
I 90
I 5

Changes in commute accessibility with respect to base accessibility

Magic carpets replace private cars

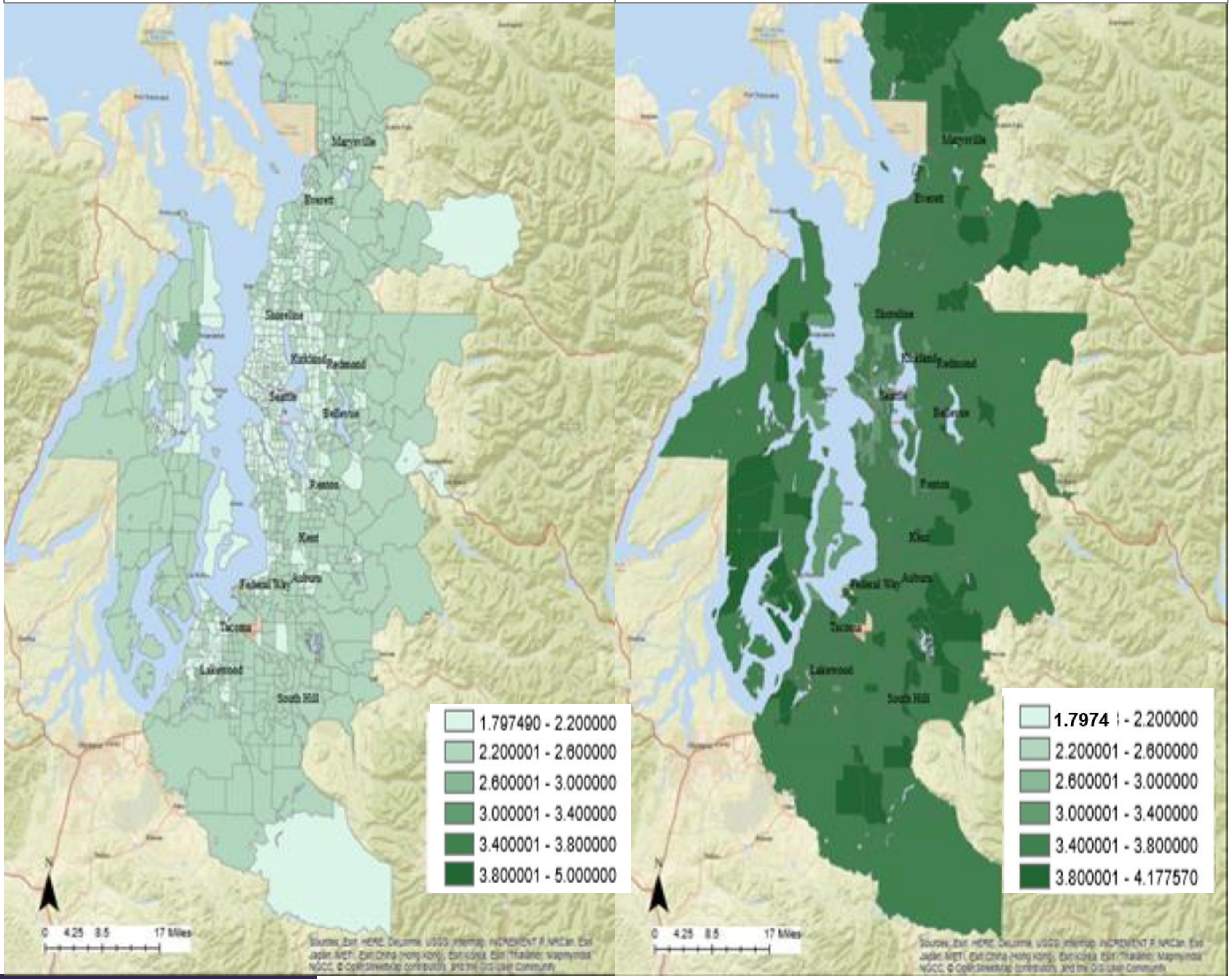


Magic carpets as an additional service

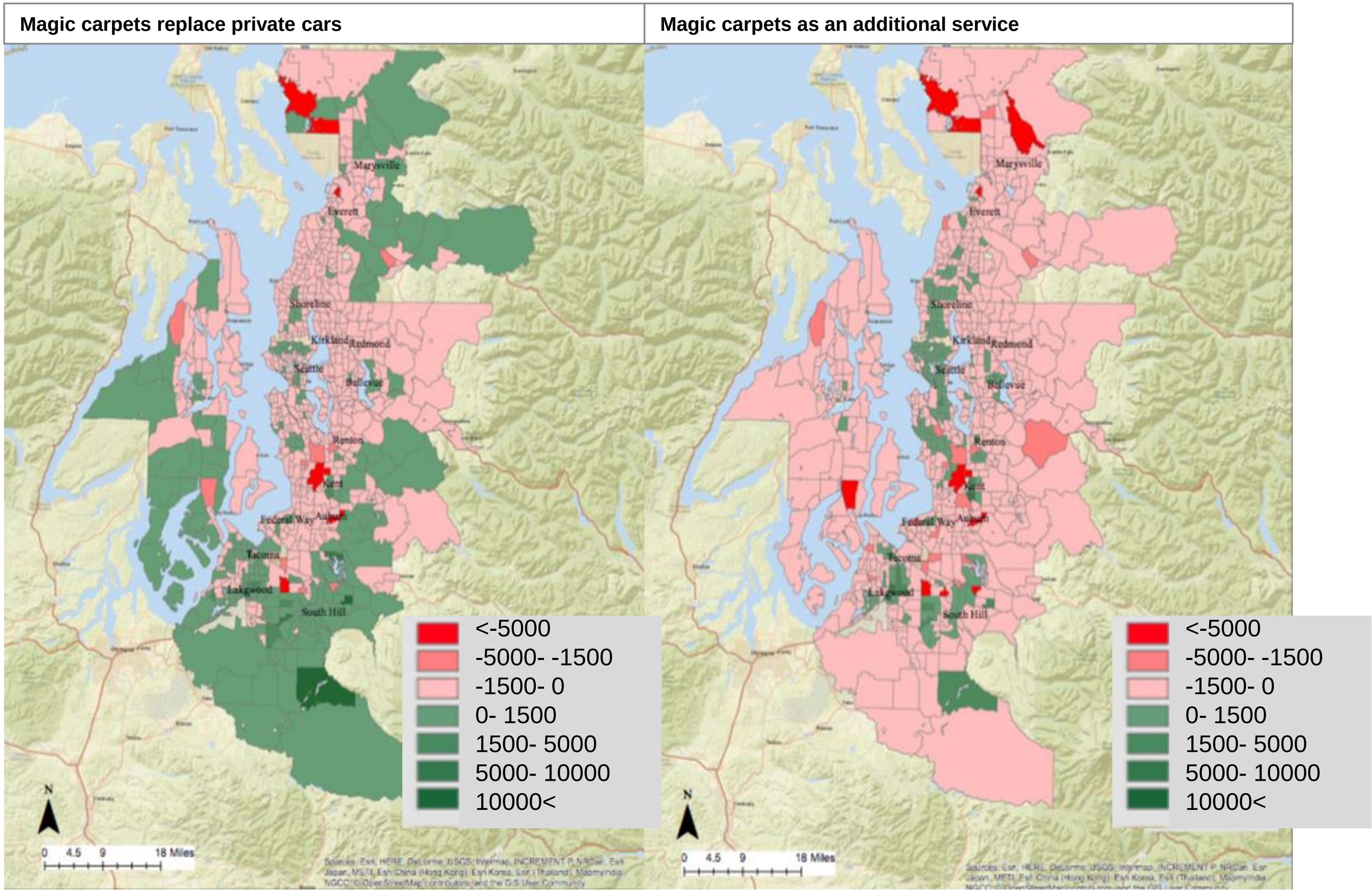


Changes in log of regional accessibility with respect to base accessibility

Magic carpets replace private cars	Magic carpets as an additional service



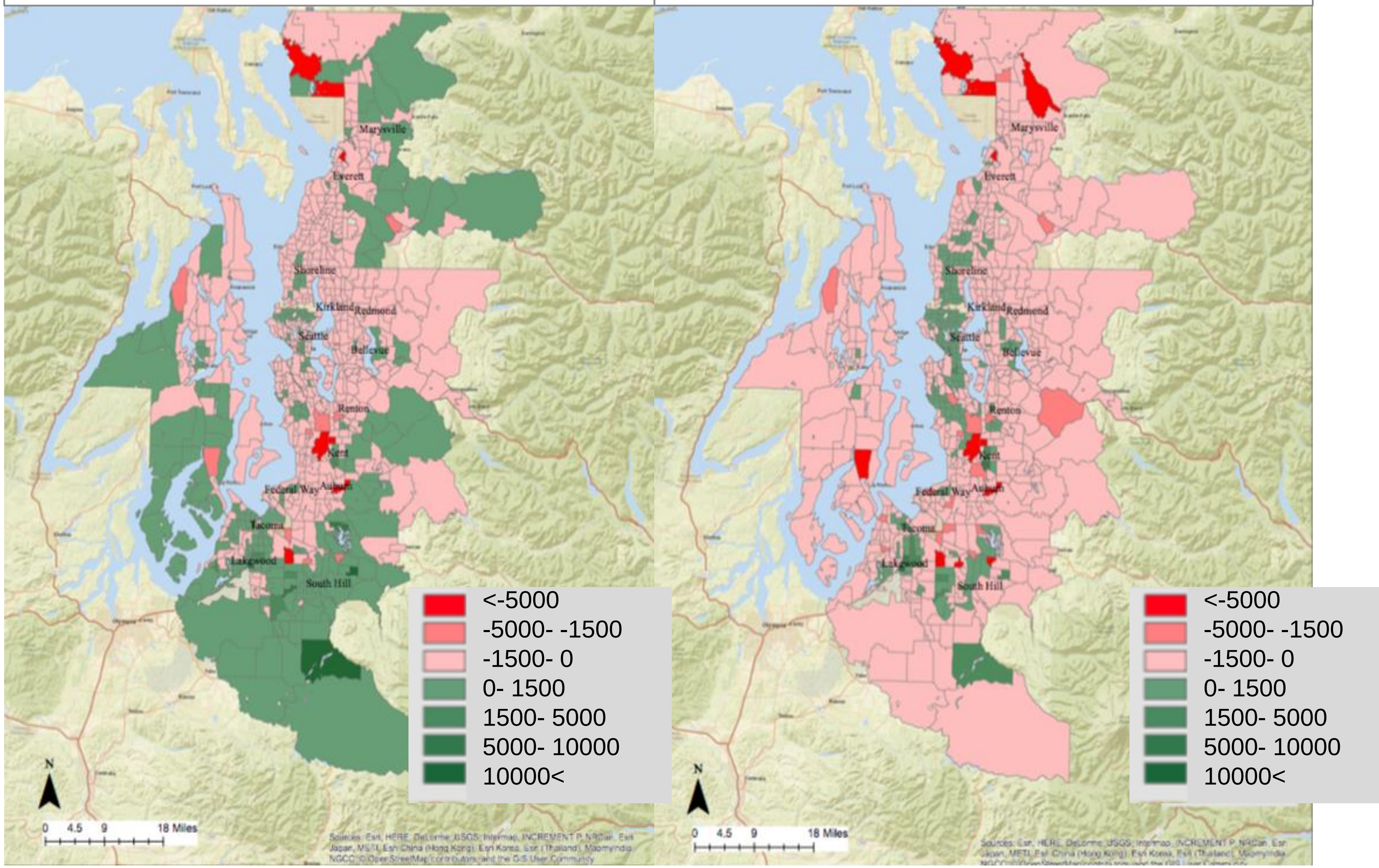
Changes in residential location demand, holding prices constant



Magic carpets replace private cars → shift population to the urban fringes,

Magic carpets as an additional on-demand service → increase the attractiveness of living in central cities

Magic carpets replace private cars	Magic carpets as an additional service



Reflections and Limitations

- Many uncertainty sources
- The results of this analysis are strongly dependent on multiple layers of models
- Many model specifications returned nonsensical results

Jabbari, P., Barber, E., Laberteaux, K., & MacKenzie, D. Where will your magic carpet take you? Analyzing accessibility effects of automated vehicles and mobility services. *TRB Paper No. 19-05259*, Transportation Research Board 98th Annual Meeting.

1. How does relieving traveler from driving affect value of travel time?

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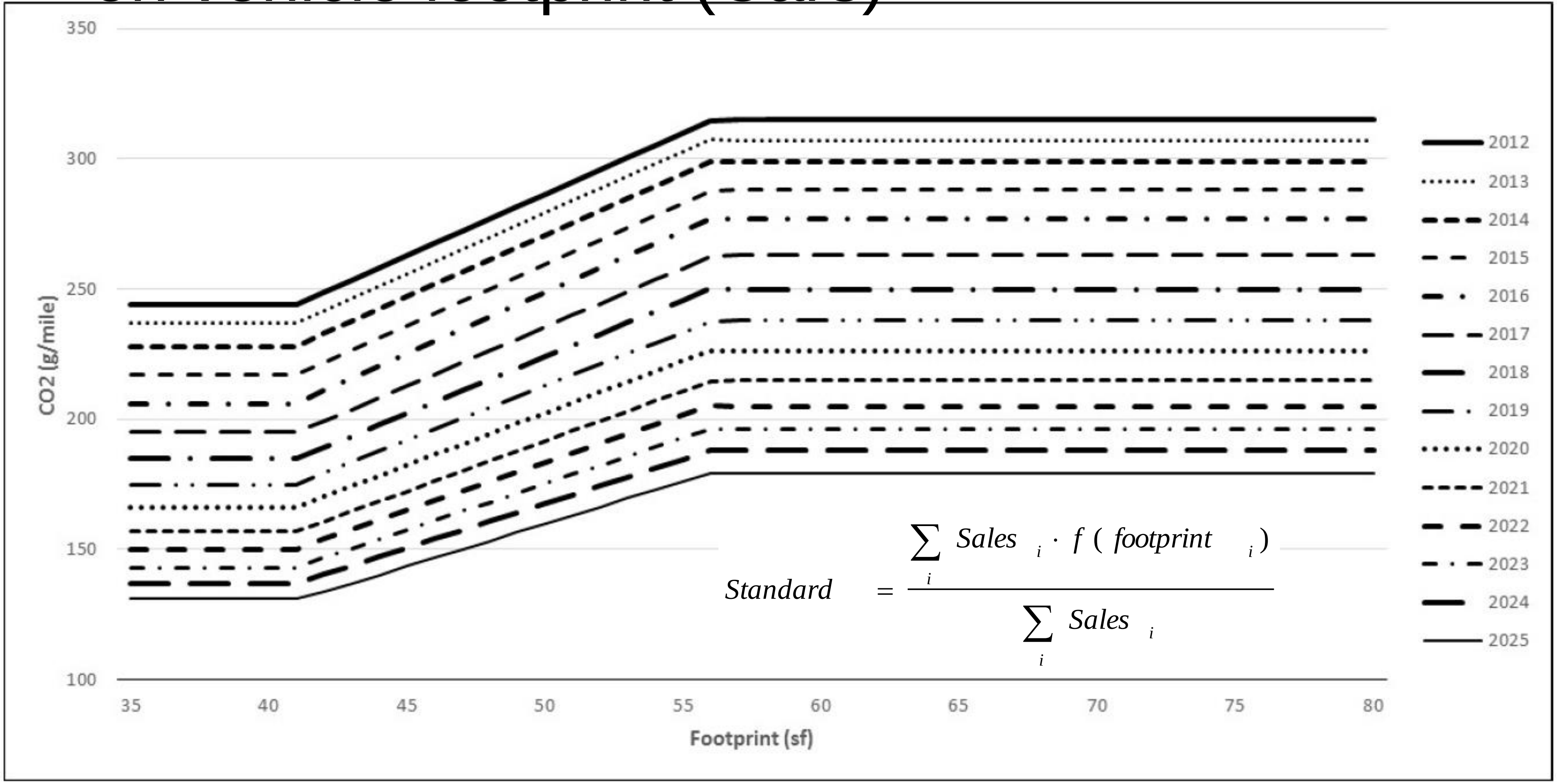
3. How would a right-sized fleet affect fuel economy?

Fuel economy & GHG standards are based on vehicle footprint (Cars)

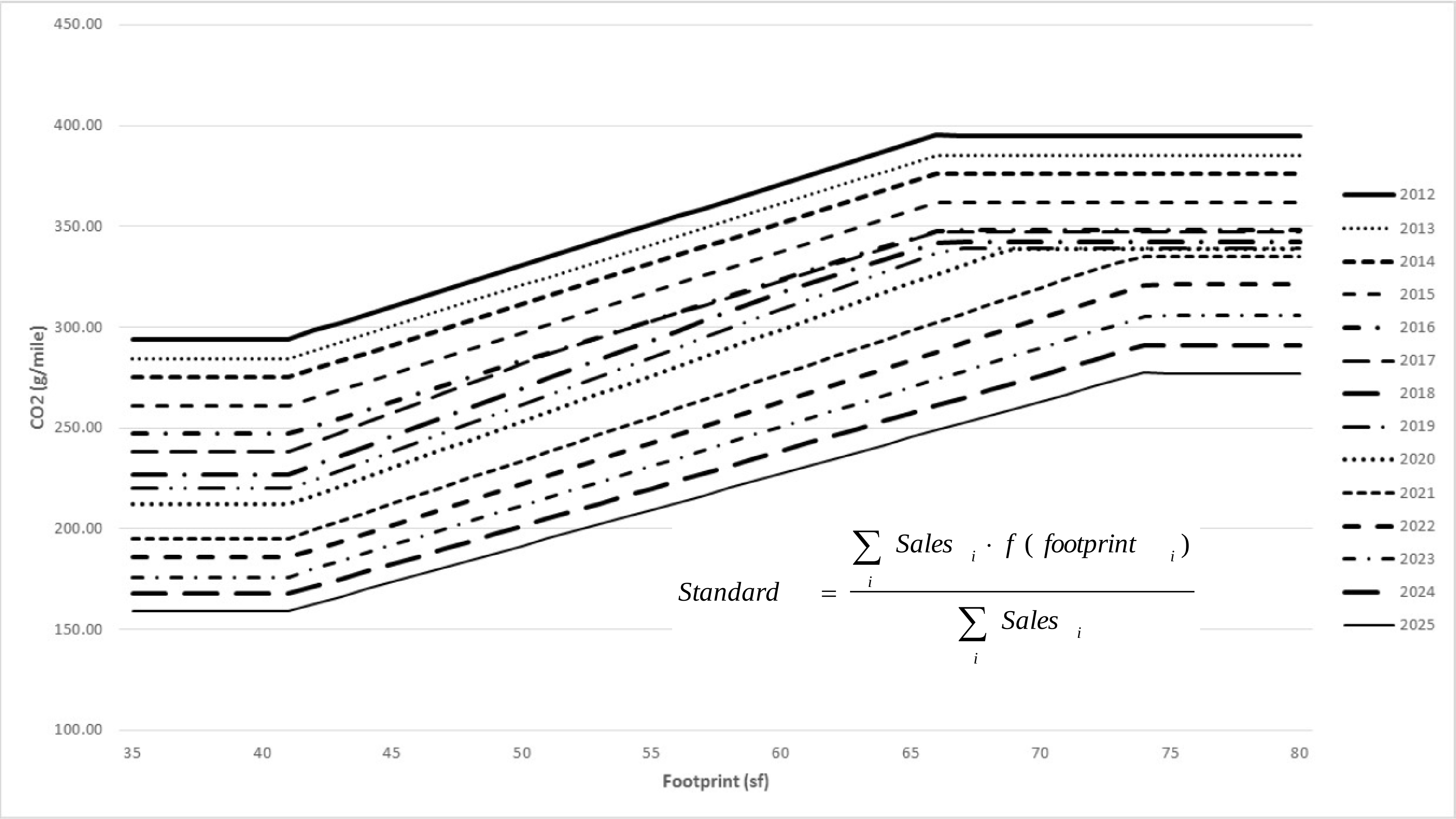


$$Standard = \frac{\sum_i Sales_i \cdot f(footprint_i)}{\sum_i Sales_i}$$

Figure I.1 CO_2 (g/mile) Passenger Car Standards Curves

Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation. EPA-420-R-17-001 **January 2017.**

Light-duty trucks

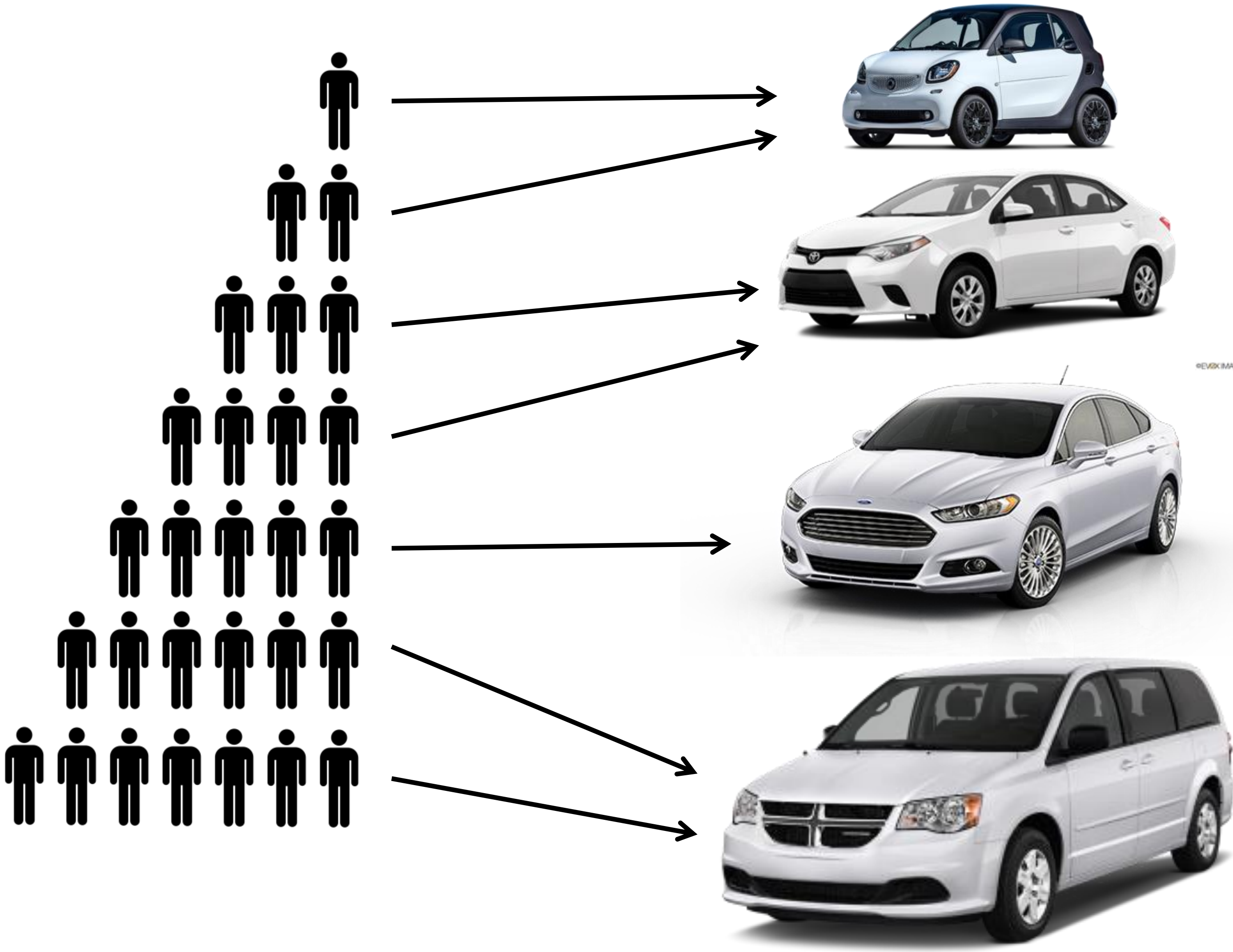


$$Standard = \frac{\sum_i Sales_i \cdot f(footprint_i)}{\sum_i Sales_i}$$

Figure I.2 CO_2 (g/mile) Light Truck Standards Curves

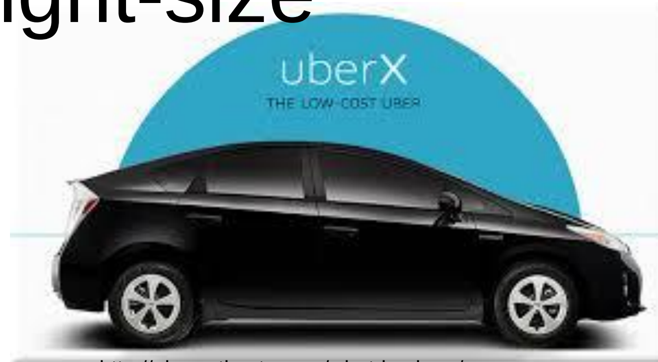
Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation. EPA-420-R-17-001 **January 2017.**

We assume that vehicle size matches travel party size, for mobility services



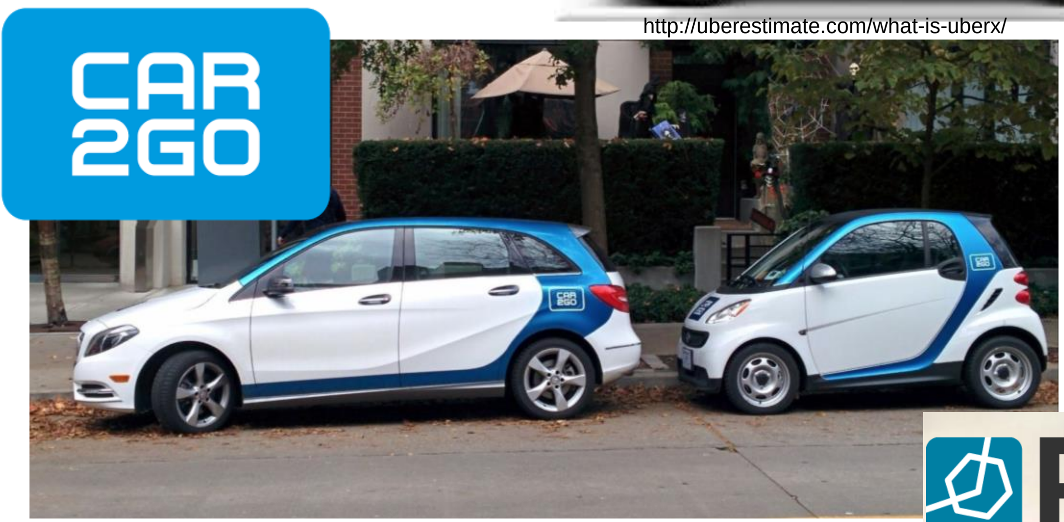
	Avg Footprint	2016 Standard
	$30\ ft^2$	41 mpg
	$43\ ft^2$	39 mpg
	$48\ ft^2$	36 mpg
	$56\ ft^2$	28 mpg

Mobility services providers are already starting to right-size



http://uberestimate.com/what-is-uberx/

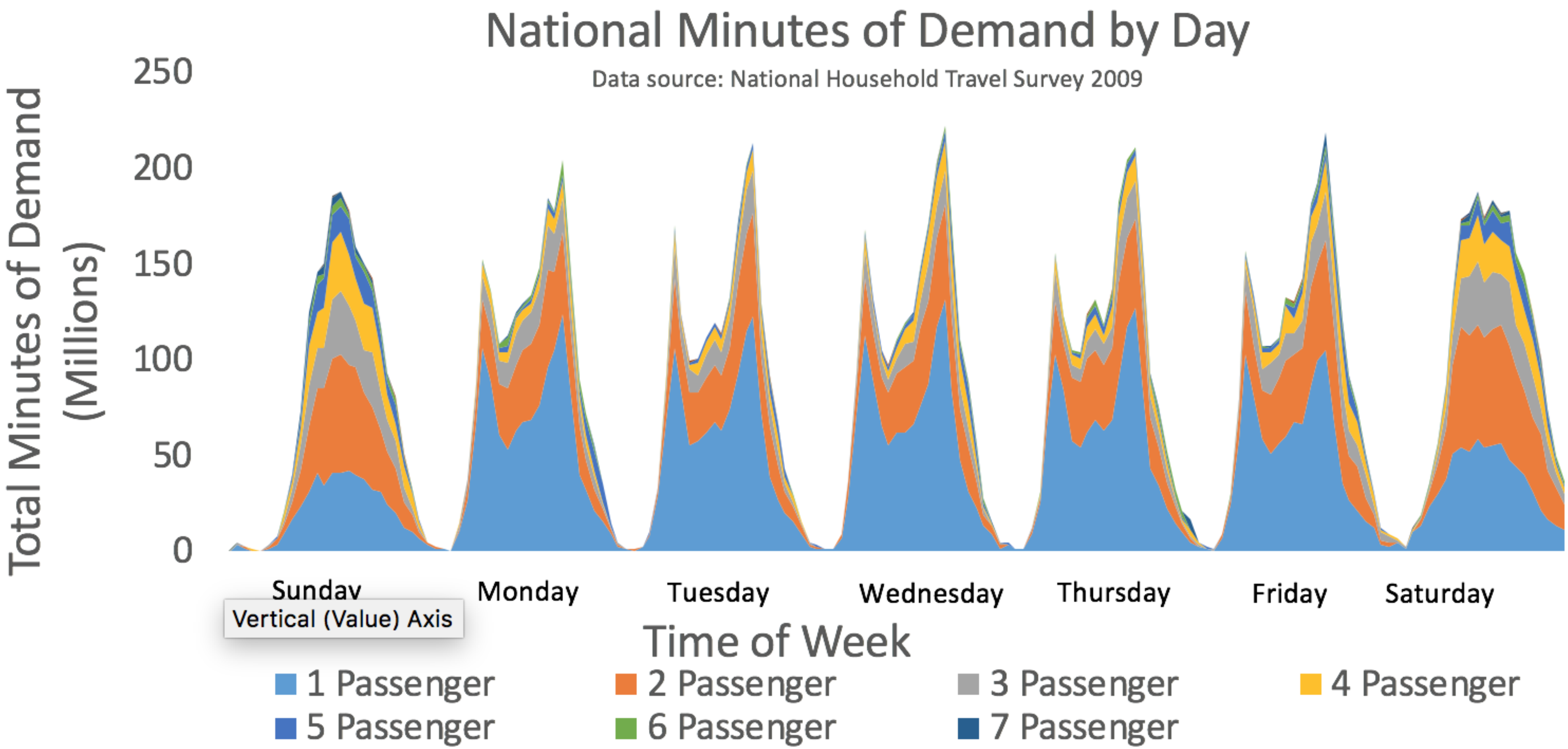
http://uberestimate.com/what-is-uberxl/



By Wakasui - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=

http://www.techtimes.com/articles/148876/20160409/bmw-reachnow-vs-daimler-car2go-how-these-car-sharing-services-work-and-price-comparison.htm

Mix of travel party sizes depends on day, time, location



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We considered two approaches to right-sizing fleet

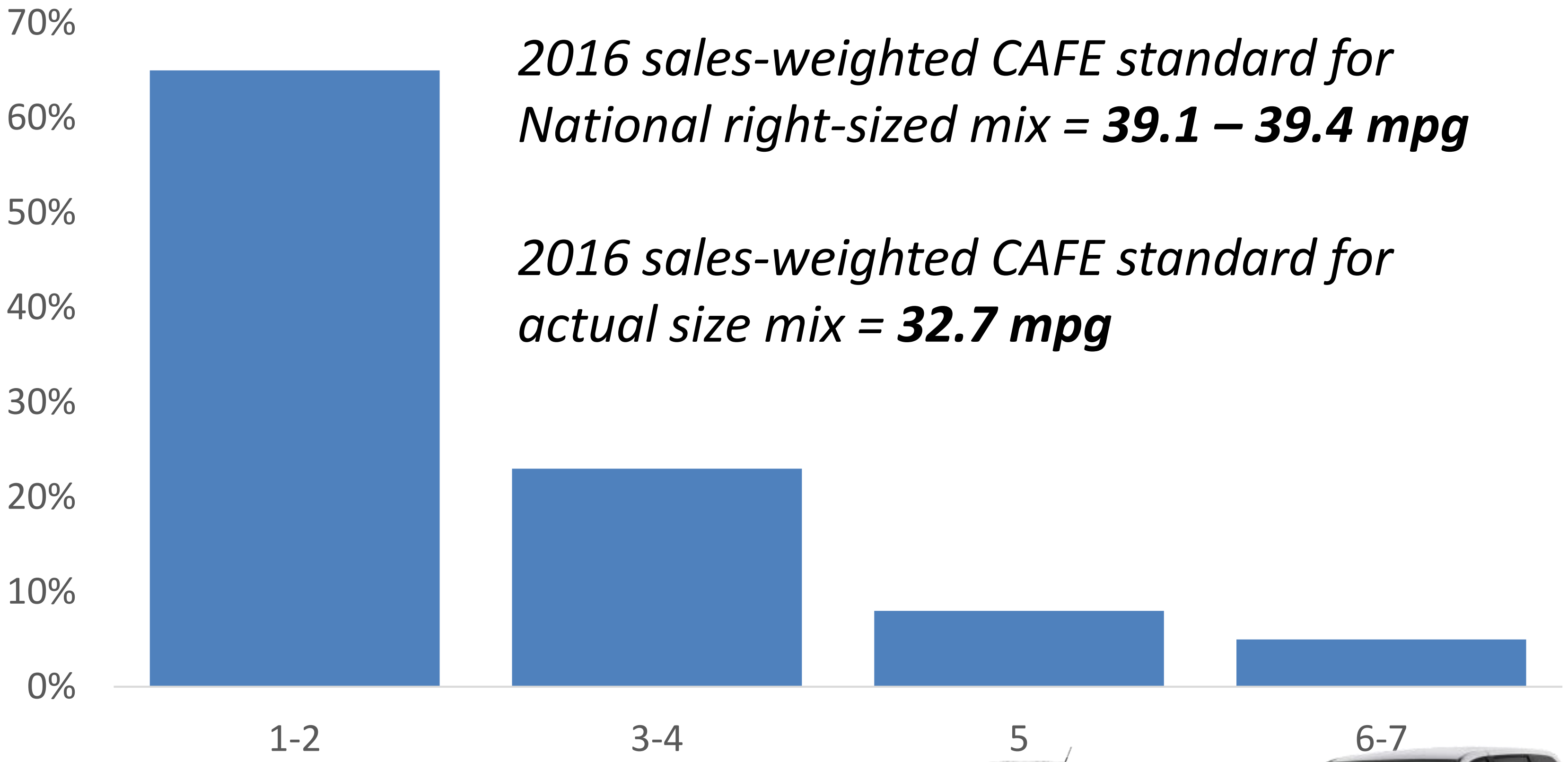
1. Minimize number of vehicles
(larger vehicles sometimes move smaller parties)

$$Number\ of\ n - seat\ Vehicles\ = Max\left(\sum_{i=n}^{7} X_{it}\right) - Max\left(\sum_{i=n+1}^{7} X_{it}\right)$$

2. Minimize number of seats
(vehicle size matches party size for each trip)

$$Number\ of\ n - seat\ Vehicles\ = Max(X_{nt})$$

Right-sizing fleet would increase MPG standard 20% above actual 2016 sales mix



Many unanswered questions about right-sizing

- Market potential for micromobility?

- Social optimum vs market equilibrium?

- Asymmetry between costs of providing larger vehicles and opportunity costs of unfulfilled requests?

- Willingness of travelers to split parties?

Barber, E., Chernicoff, W., & MacKenzie, D. Fleet Right-sizing: The Corporate Average Fuel Economy Effect of a Transition to a Shared Autonomous Fleet. *TRB Paper No. 19-03931*, Transportation Research Board 98th Annual Meeting.

Thank you!

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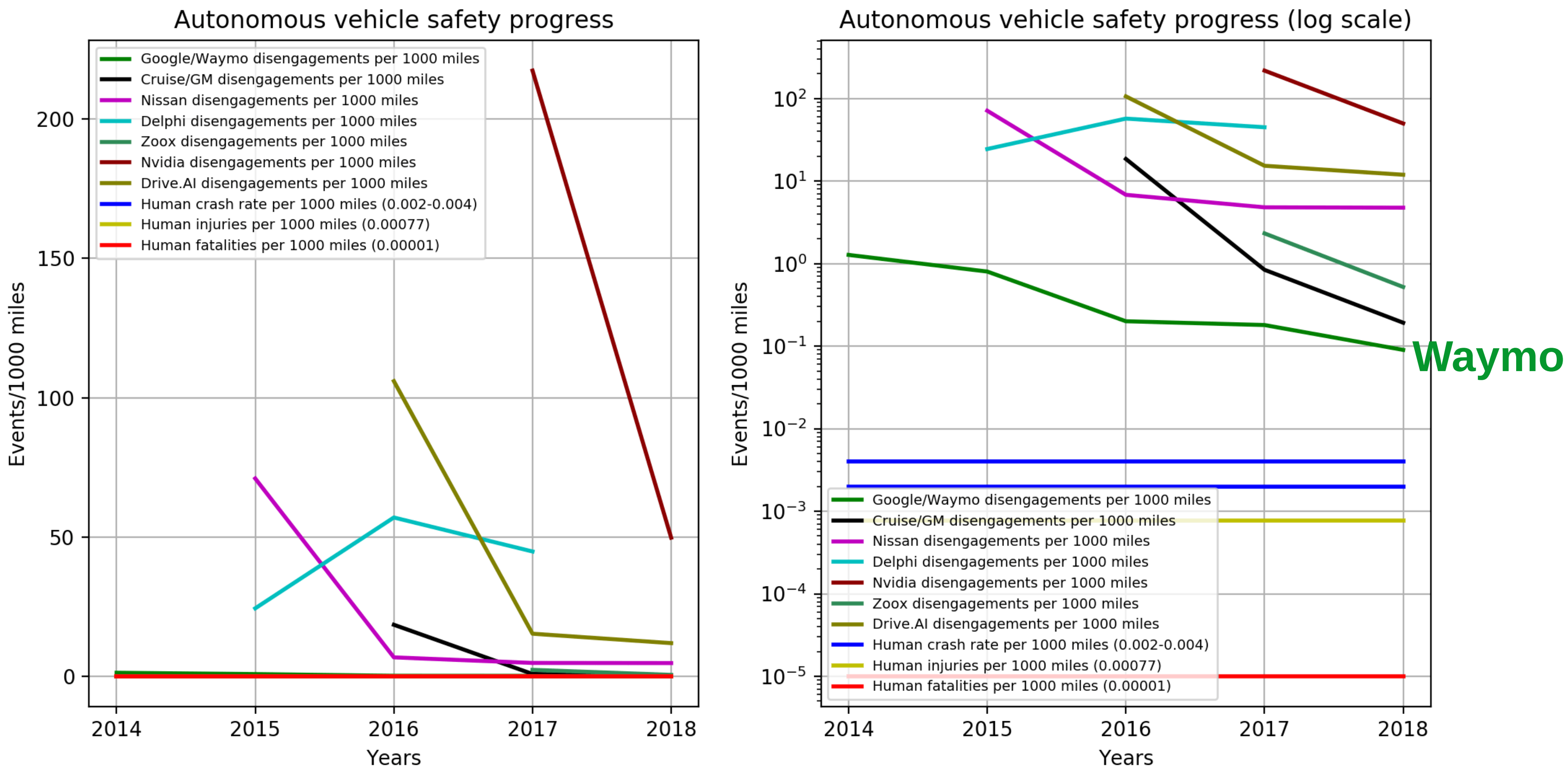
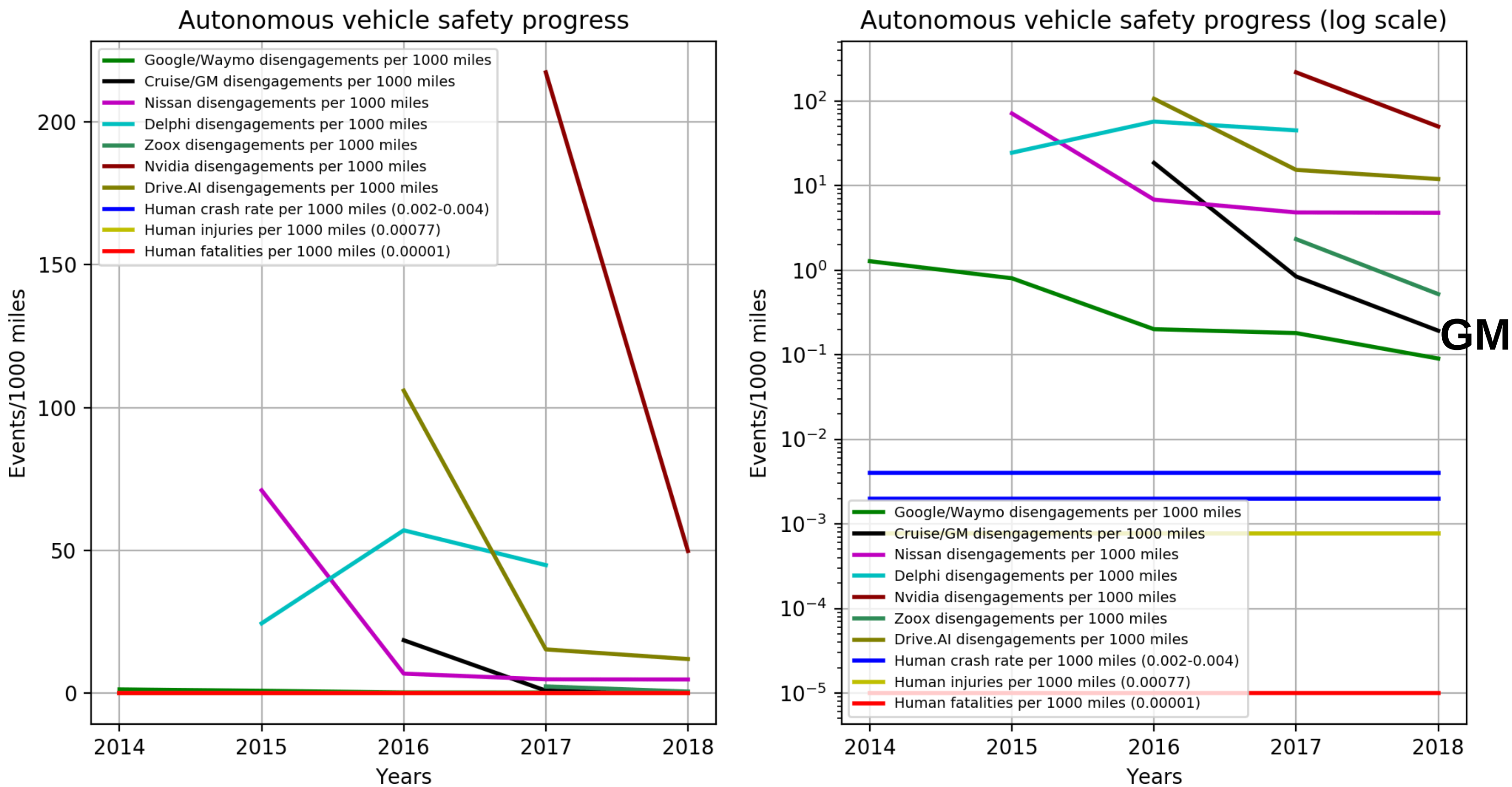
Appendix slides follow

Waymo has reduced disengagement rate 90% in 3-4 years



https://blog.piekniewski.info/2019/02/16/a-v-safety-2018-update-2/

GM has reduced disengagement rate 99% in 2 years, now 1-2 years behind Waymo



https://blog.piekniewski.info/2019/02/16/a-v-safety-2018-update-2/

Waymo's estimated crash rate is ~ 10X human crash rate

About 20% of disengagements in 2015 would have resulted in a crash.
http://fortune.com/2016/01/13/google-self-driving-car-accidents/

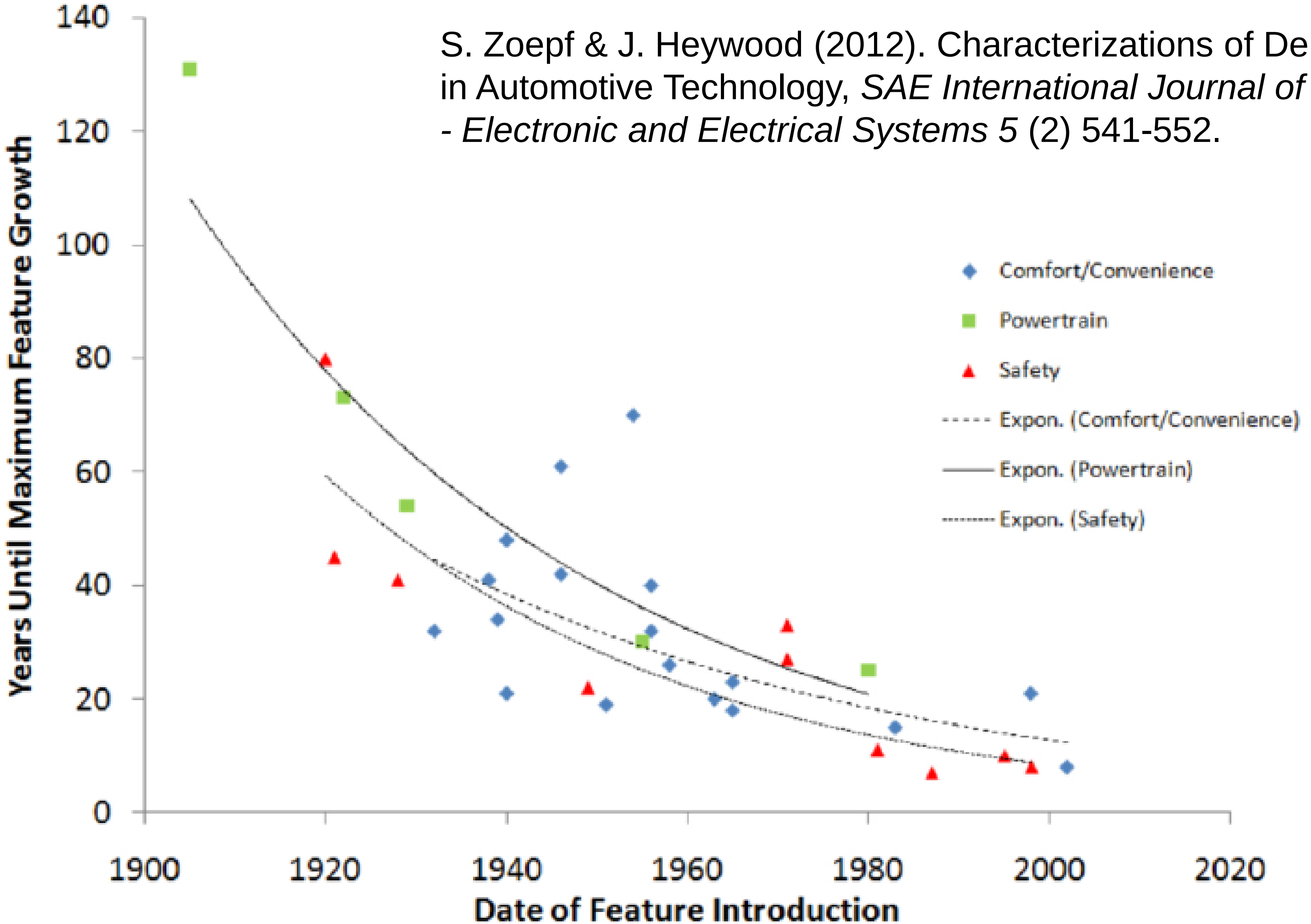
	Miles between incidents
Uber, all disengagements (March 2018)	13
GM Cruise, safety disengagements (2018)	5,000
Waymo, safety disengagements (2018)	10,000
Waymo, crashes (estimated, 2018)	50,000
Human drivers, crashes (2015)	490,000

Extrapolating…
Crash rate might be competitive with human drivers in 4-10 years

https://blog.piekniewski.info/2019/02/16/a-v-safety-2018-update-2/
https://arstechnica.com/cars/2018/03/leaked-data-suggests-uber-self-driving-car-program-years-behind-waymo/
http://fortune.com/2016/01/13/google-self-driving-car-accidents/
https://www.fhwa.dot.gov/policyinformation/statistics/2015/xls/vmt421c.xls
https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318
http://www.thedrive.com/tech/18150/waymo-self-driving-cars-are-the-most-competent-ca-reports-say

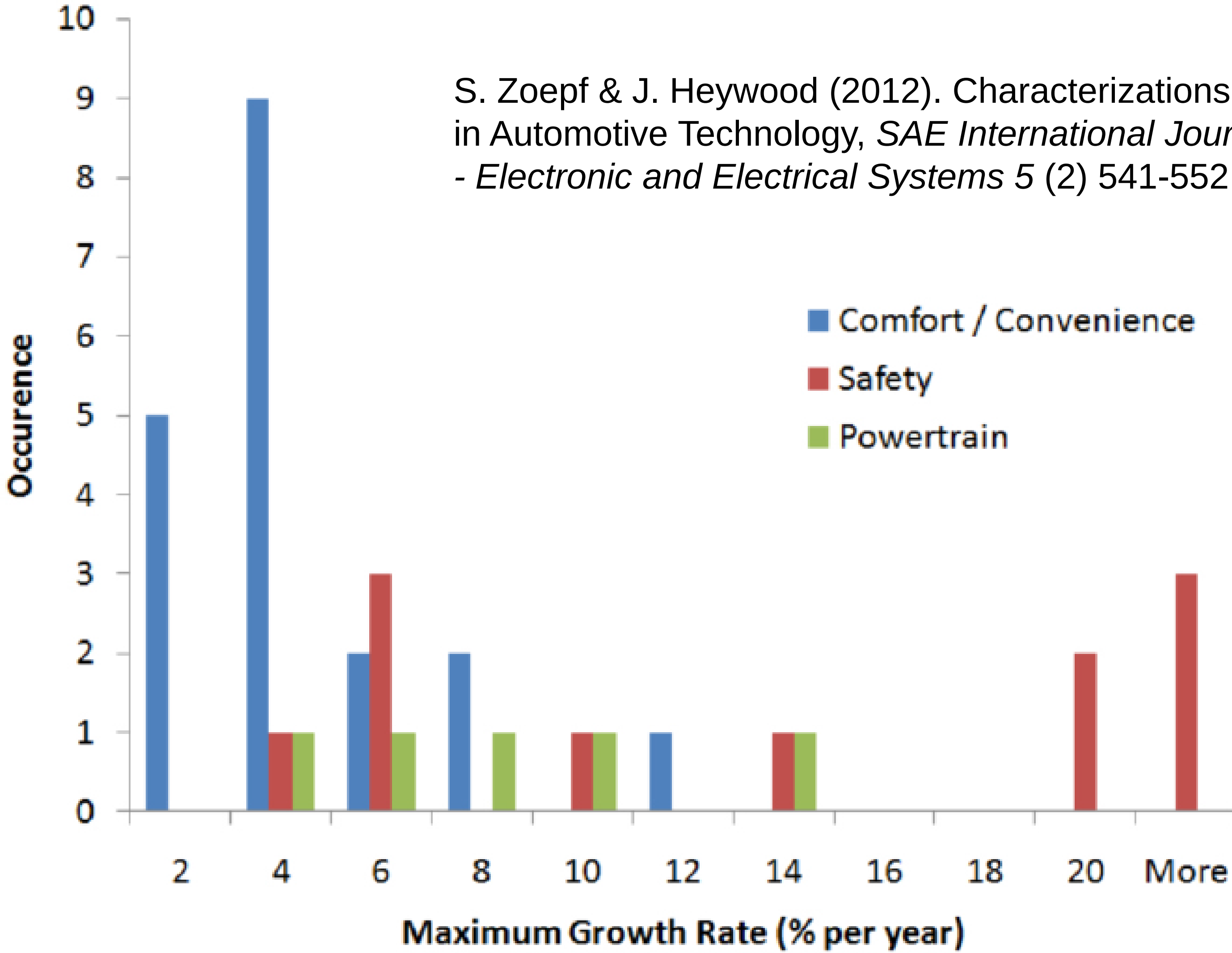
Market intro. to peak growth is ~10 years, could be ~5 years by 2030

S. Zoepf & J. Heywood (2012). Characterizations of Deployment Rates in Automotive Technology, *SAE International Journal of Passenger Cars - Electronic and Electrical Systems 5* (2) 541-552.

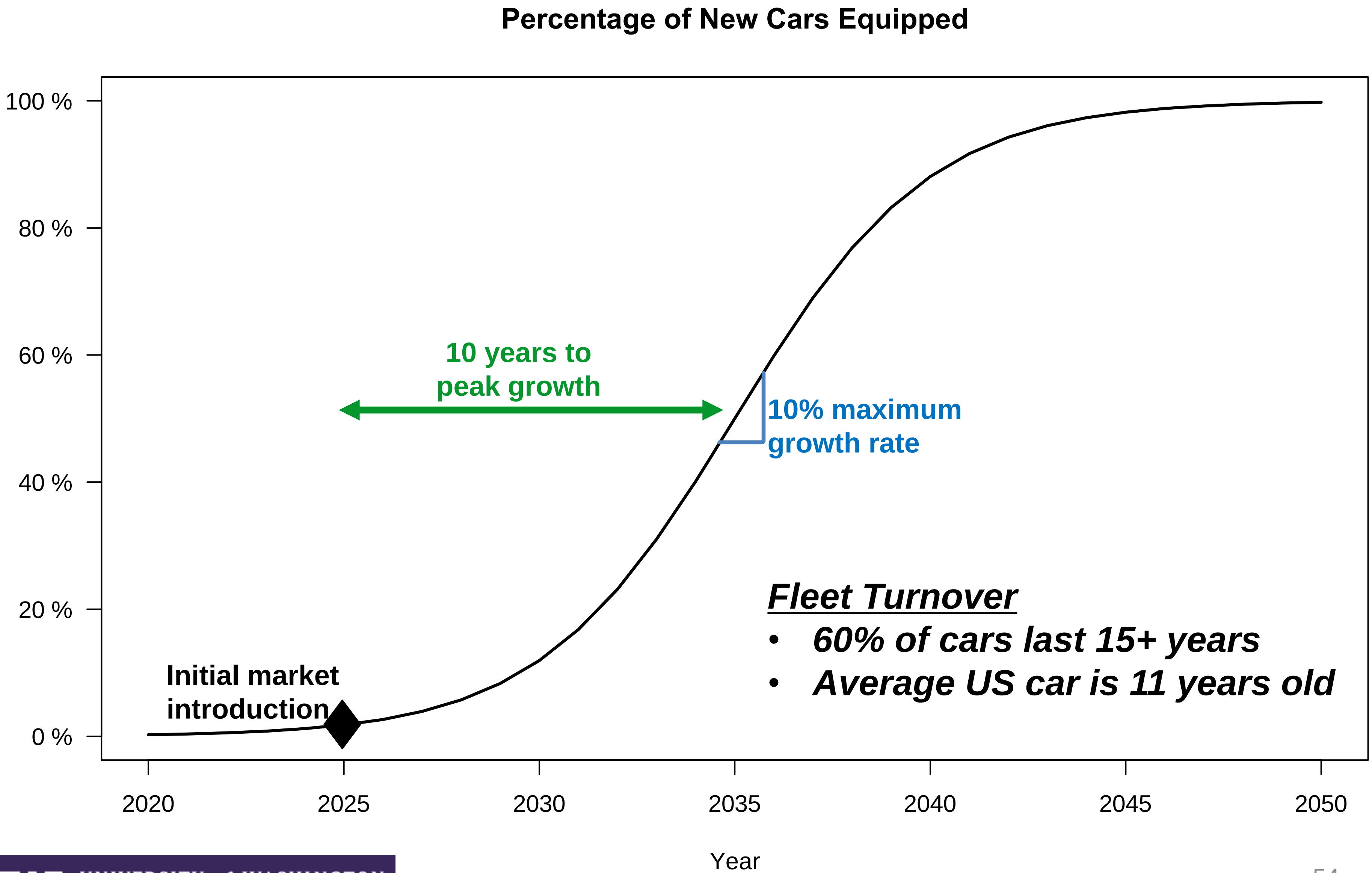


New automotive features rarely grow by more than 10% per year

S. Zoepf & J. Heywood (2012). Characterizations of Deployment Rates in Automotive Technology, *SAE International Journal of Passenger Cars - Electronic and Electrical Systems 5* (2) 541-552.



It will be decades before all vehicles can drive themselves.



Driver's time is single largest cost, for both light and heavy duty vehicles.

	Cars	Light Duty Trucks	Heavy Duty Truck
Driver's time	$0.50	$0.50	$0.61
Wear & Ownership	$0.30	$0.43	$0.19
Fuel	$0.15	$0.20	$0.59
Insurance & Accidents	$0.08	$0.08	$0.07
Maintenance	$0.05	$0.06	$0.19
Registration & Fees	$0.05	$0.07	$0.06
Parking	$0.02	$0.02	$0.00
Generalized Cost per Mile	**$1.16**	**$1.37**	**$1.71**

Travel demand impacts were estimated using a generalized cost approach.

- Elasticity of travel demand w.r.t. generalized cost: -1.0
  - For both LDV and HDV

- Assumed cost reductions through automation:

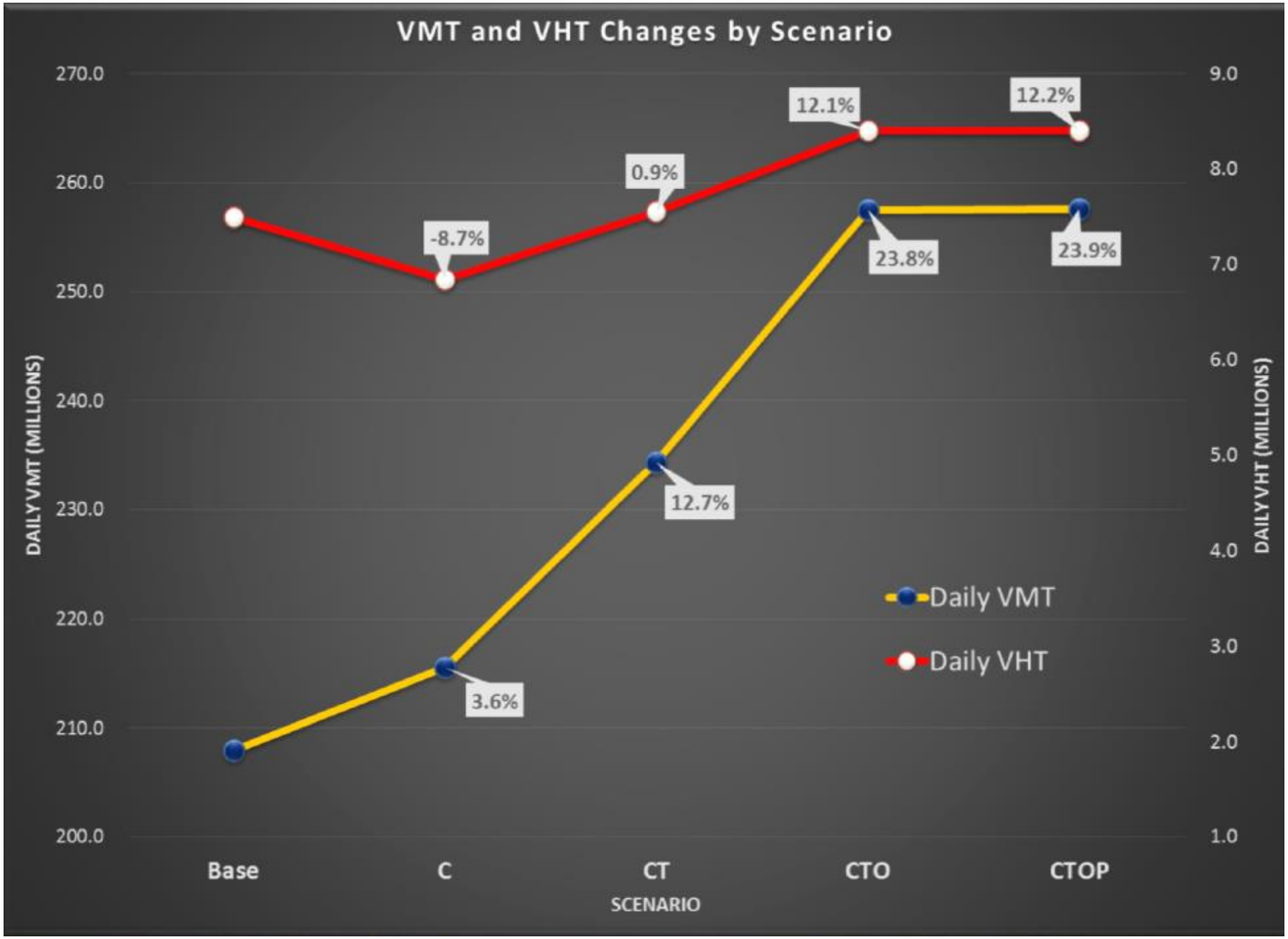
	Insurance Costs	Driver's Time
Driver assist	60%	0-5%
Full automation	80%	50-80%

$$VKT_{auto} = VKT_{pre-auto}\left(\frac{generalized\ cost_{auto}}{generalized\ cost_{pre-auto}}\right)^{elasticity}$$

PSRC has simulated travel demand impacts for Seattle region

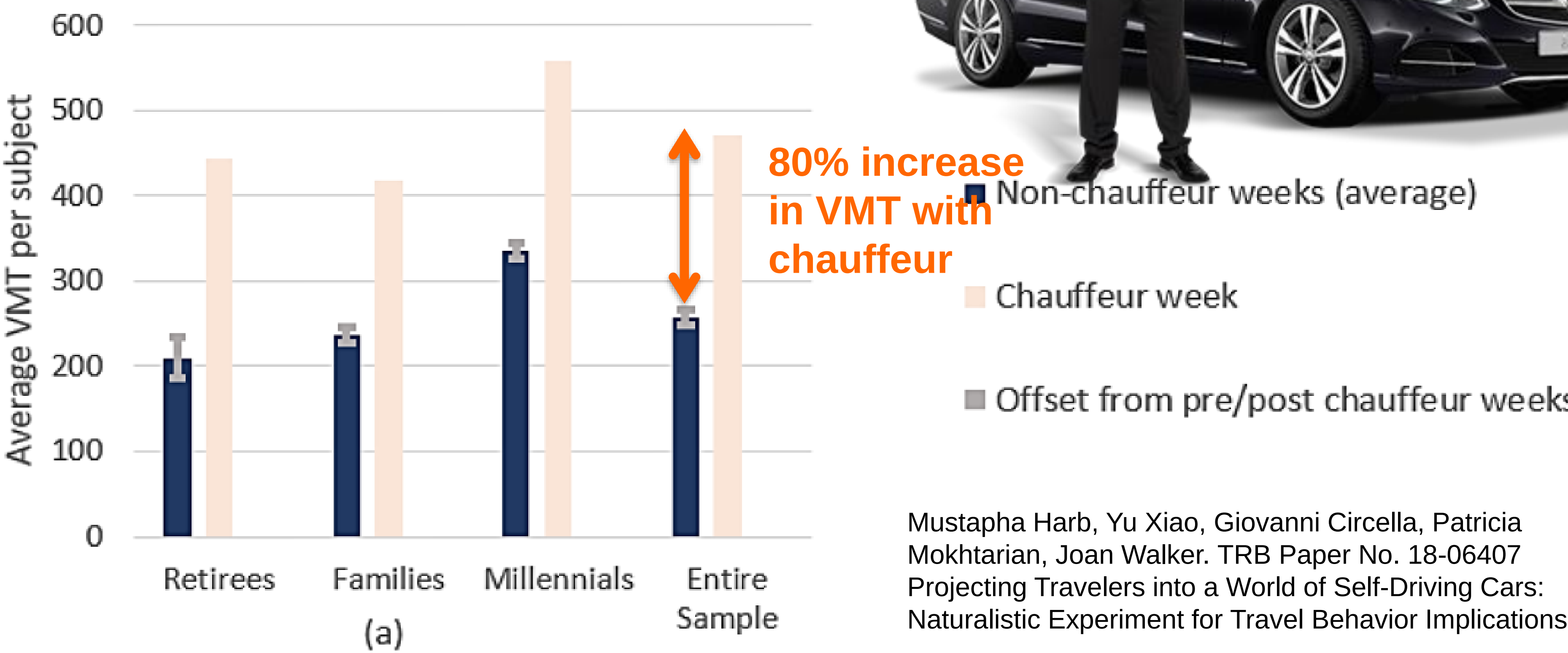
Scenario 1	Scenario 2	Scenario 3	Scenario 4
"AVs increase network capacity."	*"Important trips are in AVs"*	*"Everyone who owns a car owns an AV."*	*""All autos are automated, with all costs of auto use passed onto the user."*
30% capacity increase on freeways, major arterials	30% capacity increase on freeways, major arterials Travel time is perceived at 65% of actual travel time for high value of time household trips (>$24/hr.)	30% capacity increase on freeways, major arterials Travel time is perceived at 65% of actual travel time for ***all*** trips 50% parking cost reduction	Cost per mile is $1.65
+3.6%	**+5.0%**	**+19.6%**	**-35.4%**

ARC has simulated impacts for Atlanta region



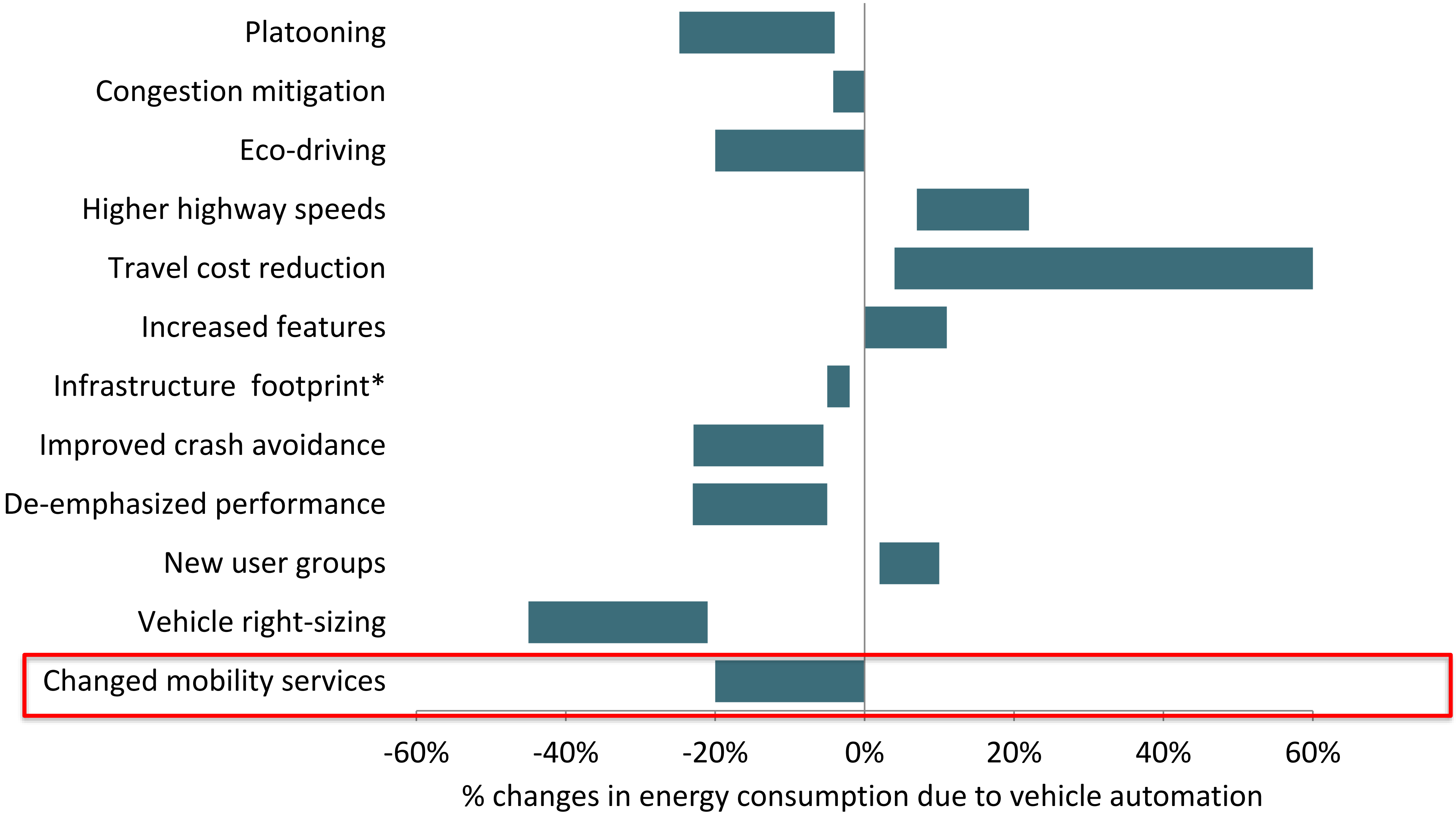
Capacity +50%	Value of Time -50%	Operating Cost -71%	Parking Cost -100%

Harb et al. gave people chauffeurs to simulate owning a driverless car

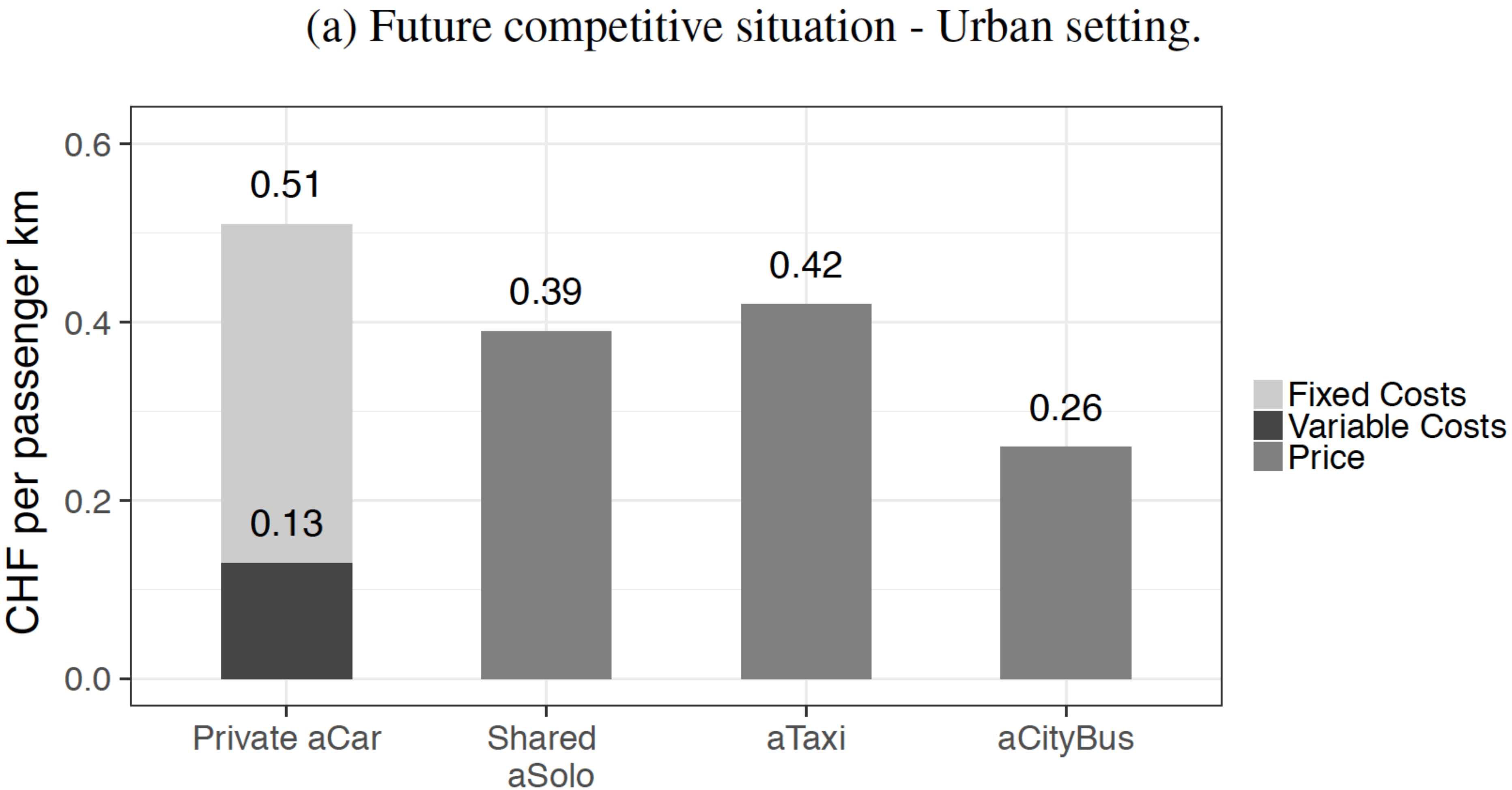


Mustapha Harb, Yu Xiao, Giovanni Circella, Patricia Mokhtarian, Joan Walker. TRB Paper No. 18-06407 Projecting Travelers into a World of Self-Driving Cars: Naturalistic Experiment for Travel Behavior Implications

(Full) Automation makes mobility services more feasible, and more essential



The hope is that lower total costs will induce shift to mobility services and fewer trips, but…



Bösch, P. M., Becker, F., Becker, H., & Axhausen, K. W. (2018). Cost-based analysis of autonomous mobility services. *Transport Policy*, *64*, 76-91. https://doi.org/10.1016/j.tranpol.2017.09.005

Questions for you

- How many of you have a phone plan?
  - X minutes, Y GB per month
- How many of you are on a pay-as-you-go plan?
  - \$X / minute, \$Y / MB?
- Why?

… subscription based models are popular, and reduce marginal incentive to forego trips

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TRANSPORTATION LYFT RIDE-SHARING

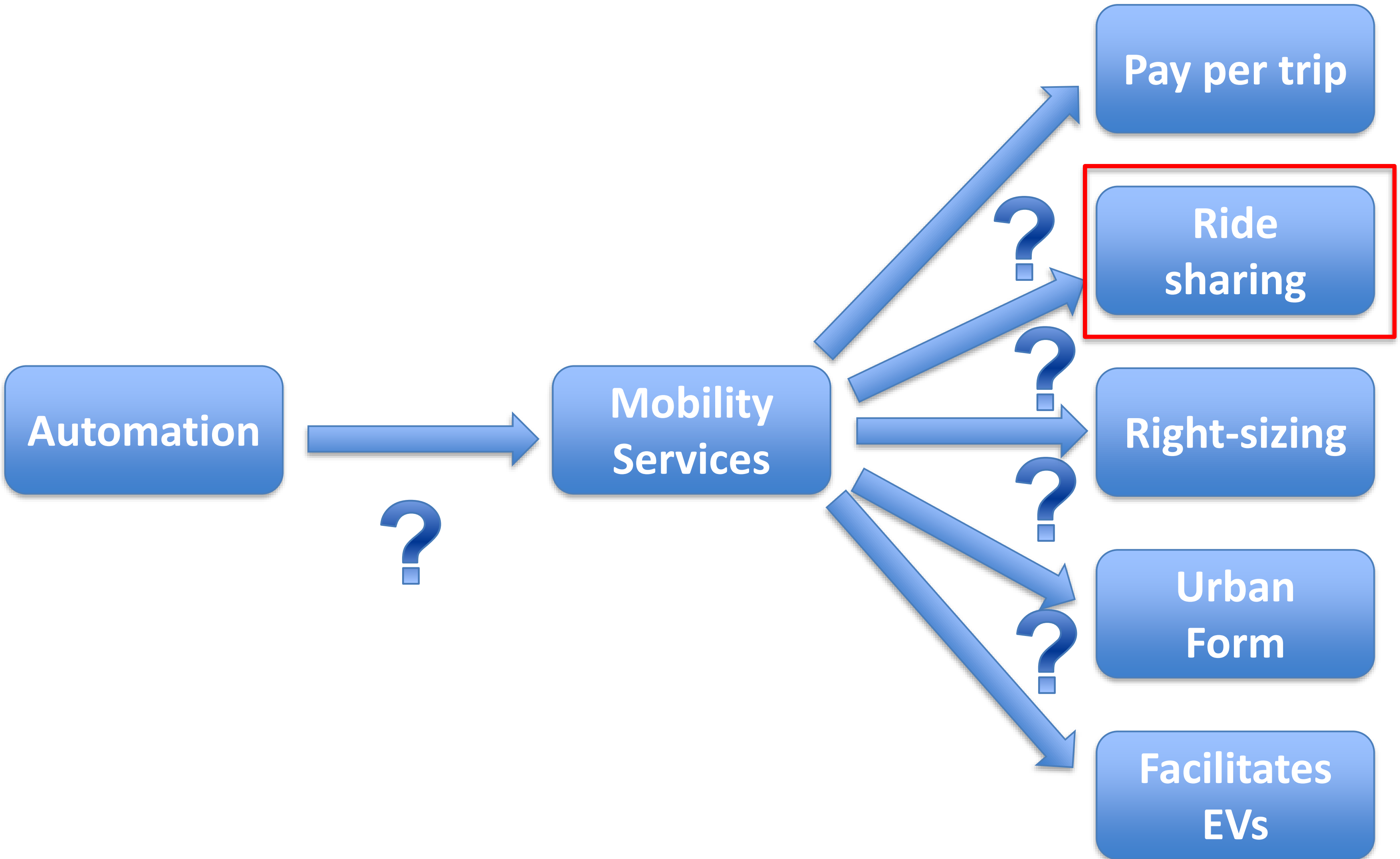
Lyft's monthly subscription plan is expanding — and now has a waitlist

$200 a month for $15 off 30 rides

By Andrew J. Hawkins | @andyjayhawk | May 9, 2018, 2:06pm EDT

spend up to $450 on ride-hailing a month. One all-access pass offered up to 30 standard Lyft rides for $199 a month, another was priced at $300, and another at $399 for 60 rides.

Mobility services appear to be the key to unlocking many benefits of automation.



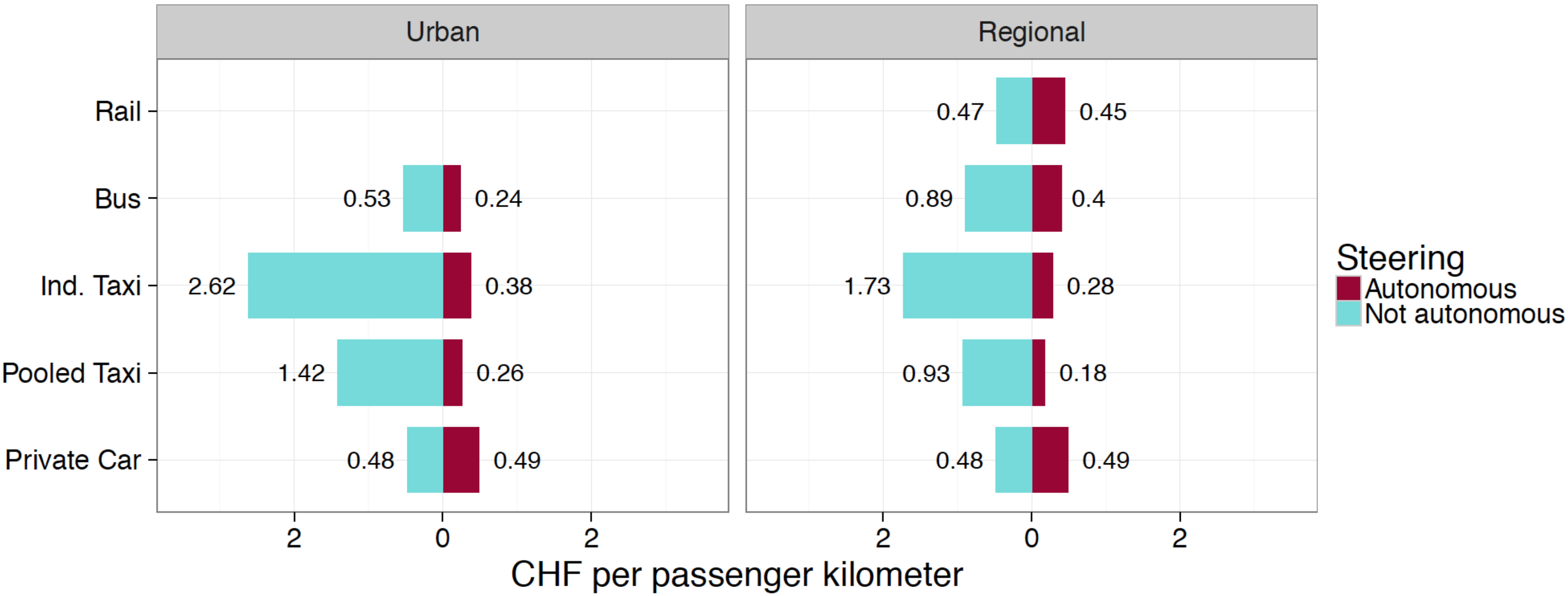
Questions for you

- How many of you have used Uber, Lyft, or a similar service?

- How many of you have used UberPool, Lyft Line, or a similar service?

- Why?

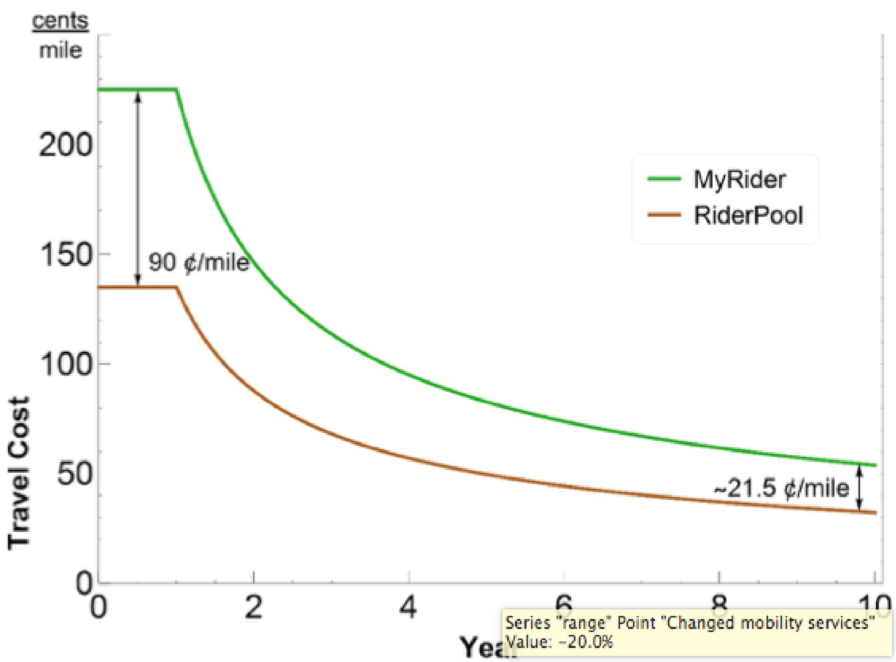
By reducing total cost of mobility services, automation reduces incentive to share rides

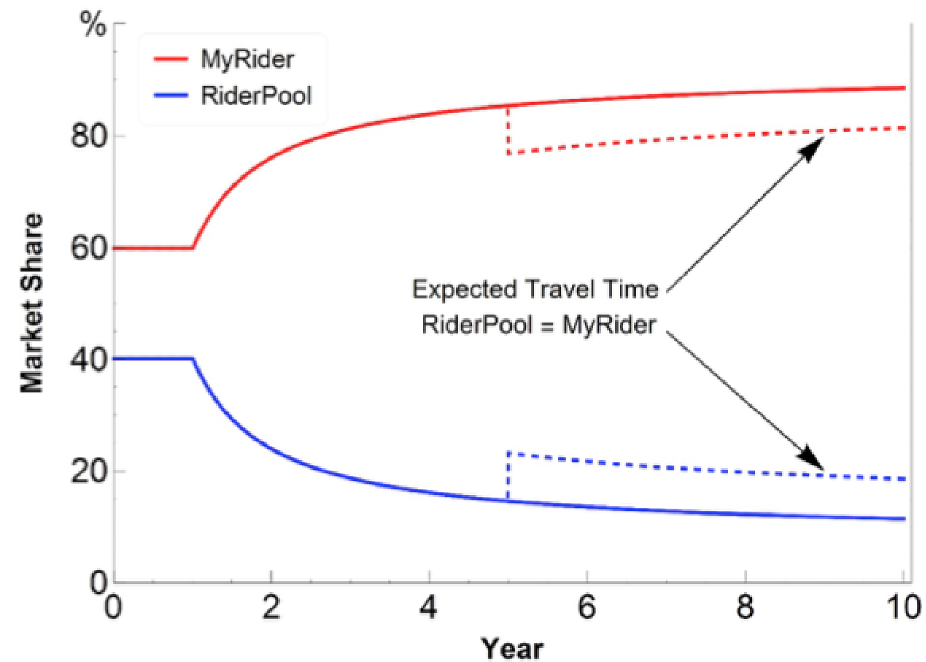


Bösch, P. M., Becker, F., Becker, H., & Axhausen, K. W. (2018). Cost-based analysis of autonomous mobility services. *Transport Policy*, *64*, 76-91. https://doi.org/10.1016/j.tranpol.2017.09.005

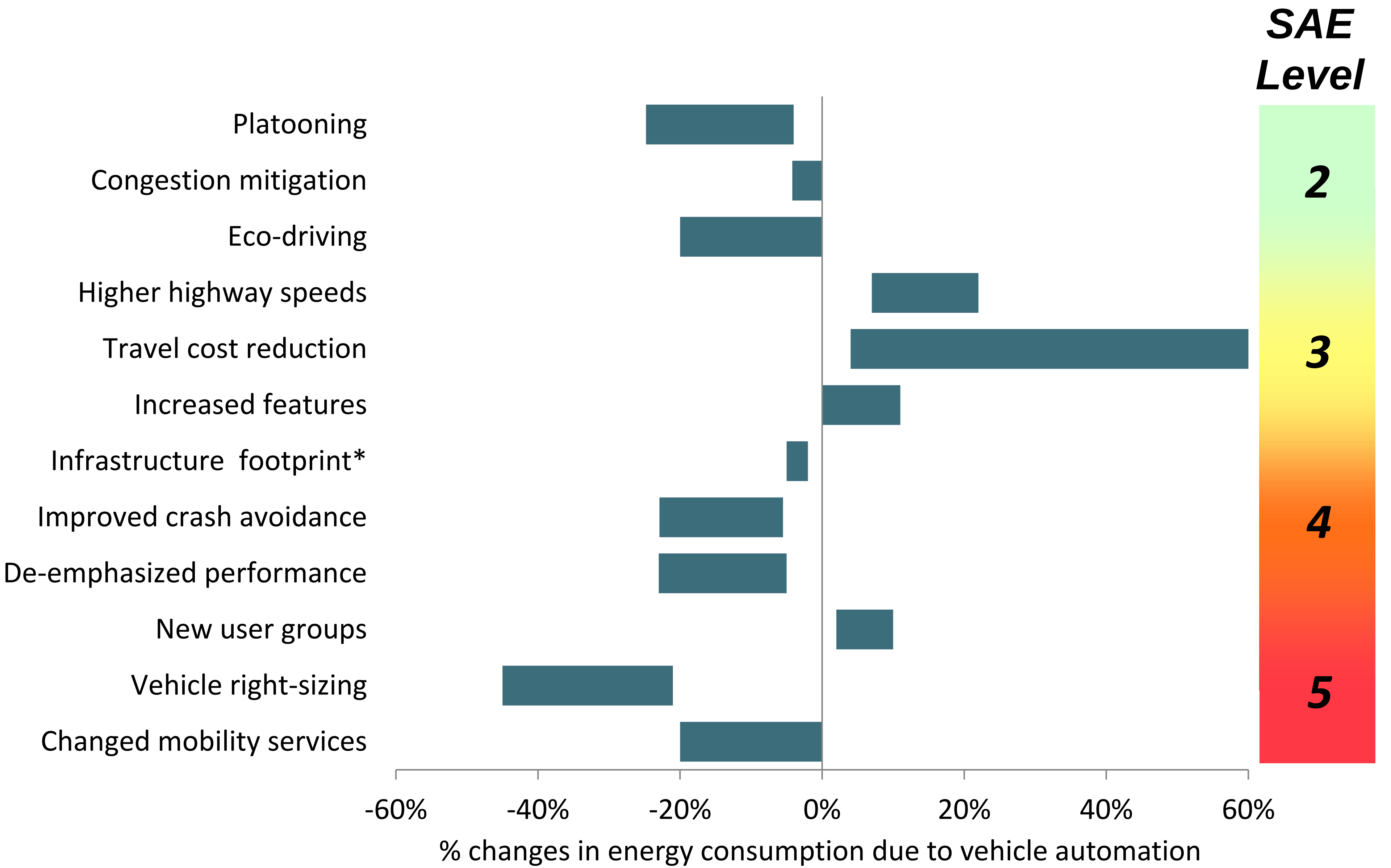
Emerging work by David R. Keith & Sergey Naumov (MIT) suggests lower market share for pooling

Utility Attribute	MyRider	RiderPool
Initial Trip Price	$11.25	$6.75
Pick Up Time	3 min	7 min
Travel Time	16 min	16-24 min





Mobility services require L4-5 automation



Shared mobility fleets should have fewer emission-intensive cold starts

- Rule of thumb:
  - "80% in first 30 seconds, 90 % in first 5 minutes"

TABLE 5 Comparison of Emissions from Initial Engine Start and Restart

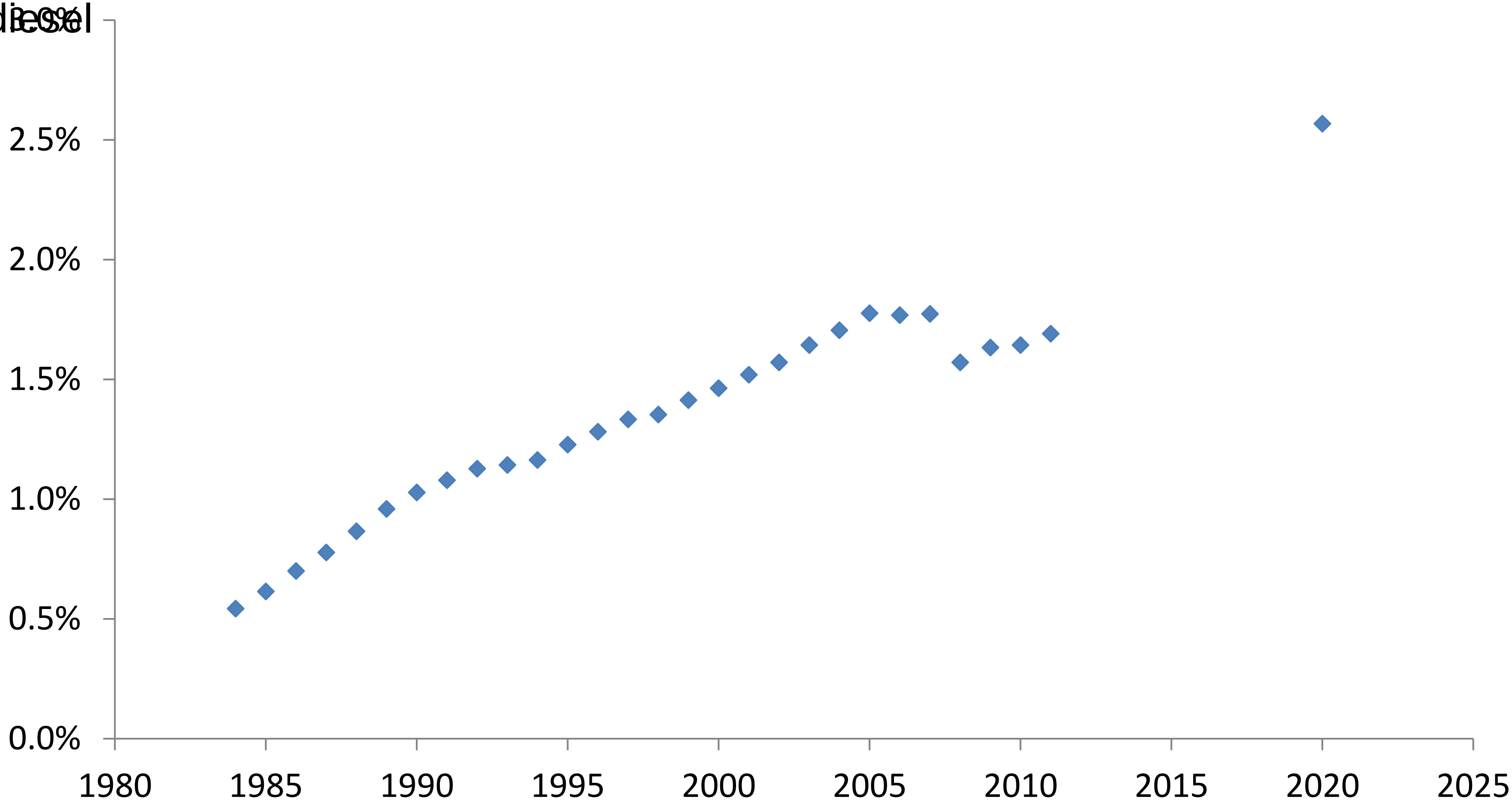
	Tier 2-Bin 5 (*15*)[a]	Initial Engine Start	Engine Restart
THC (mg)	878	191	44
NO_x (mg)	552	228	6
CO (mg)	31290	2970	1253

[a] Tier 2-Bin 5 g/mi converted to FTP-75 mg

L. Gaines, E. Rask, and G. Keller. Which Is Greener: Idle, or Stop and Restart? Comparing Fuel Use and Emissions for Short Passenger-Car Stops. TRB Paper No. 13-4606.

We spend a lot of **time** in traffic, but don't travel a lot of **miles** in traffic

Estimates of wasted fuel from TTI Urban Mobility Report, as % of on-highway gasoline & diesel



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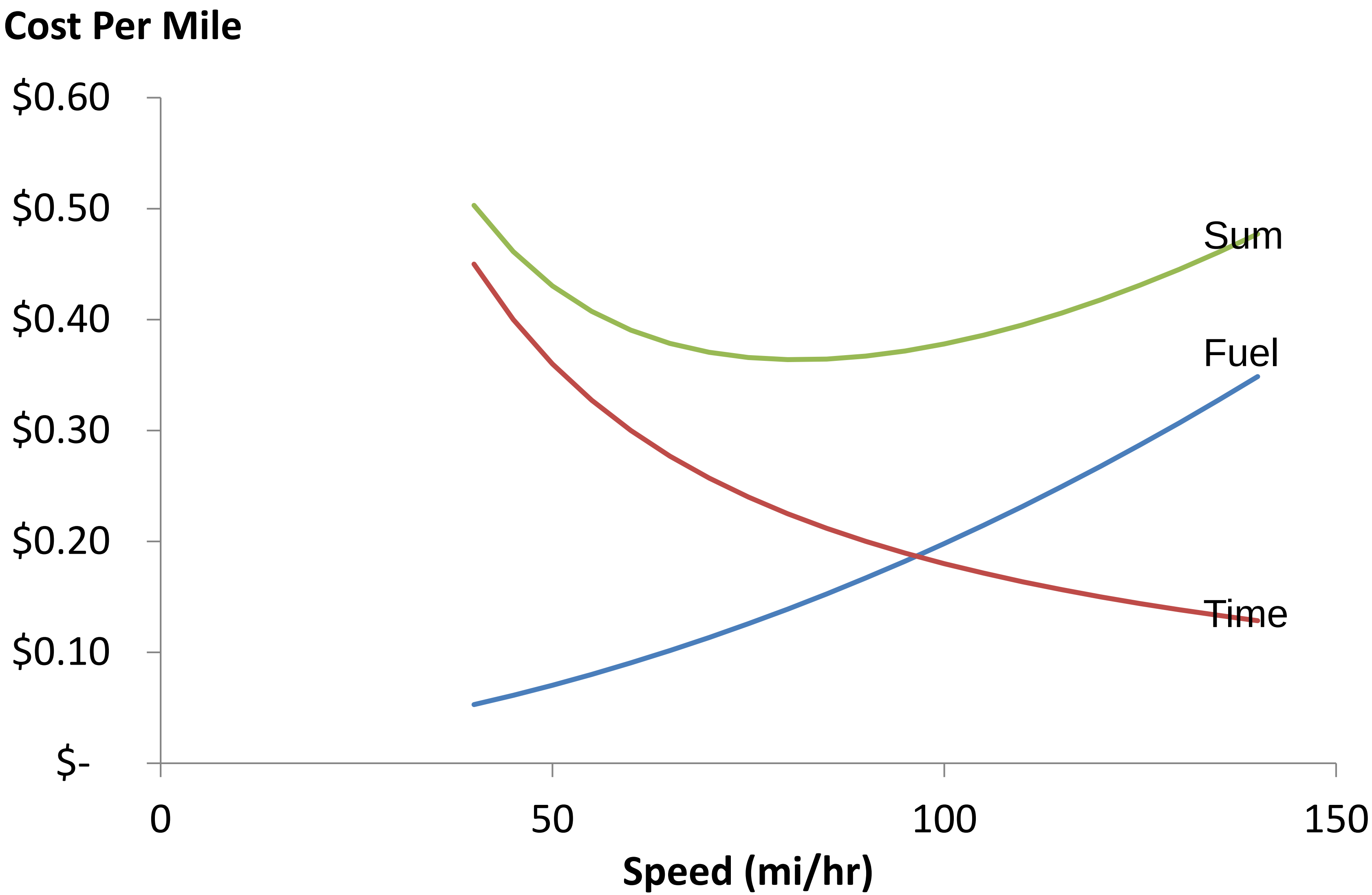
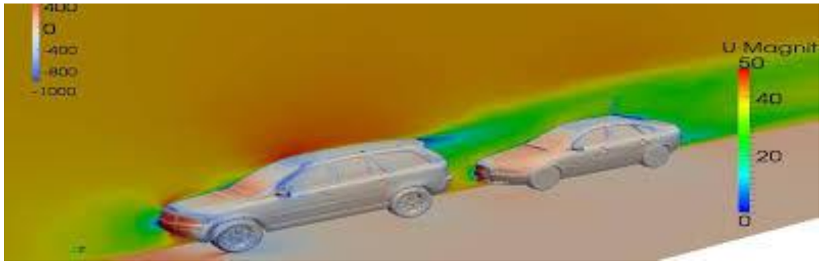
CIVIL & ENVIRONMENTAL ENGINEERING

Unconstrained by driver reaction times, highway speeds could increase



Platooning could reduce energy intensity in near term



http://www.sartre-project.eu/en/publications/Documents/SARTRE_4_003_PU.pdf

Zabat, M., Stabile, N., Farascaroli, S., Browand, F. (1995)

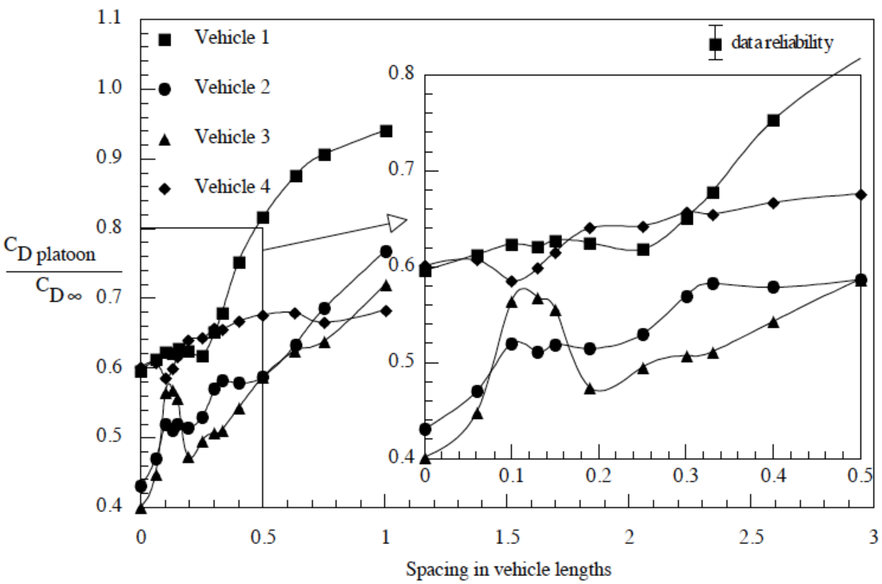
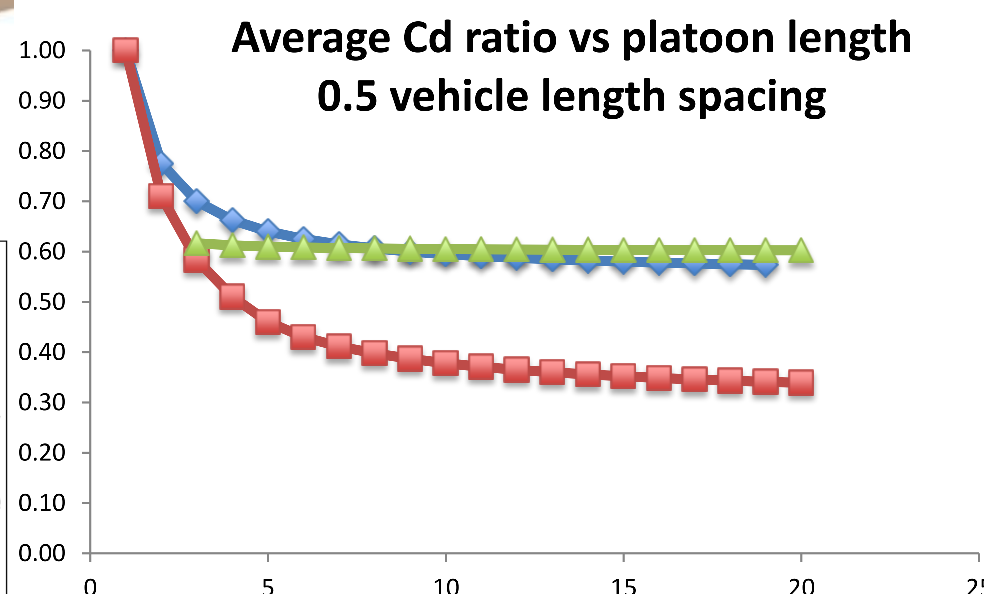
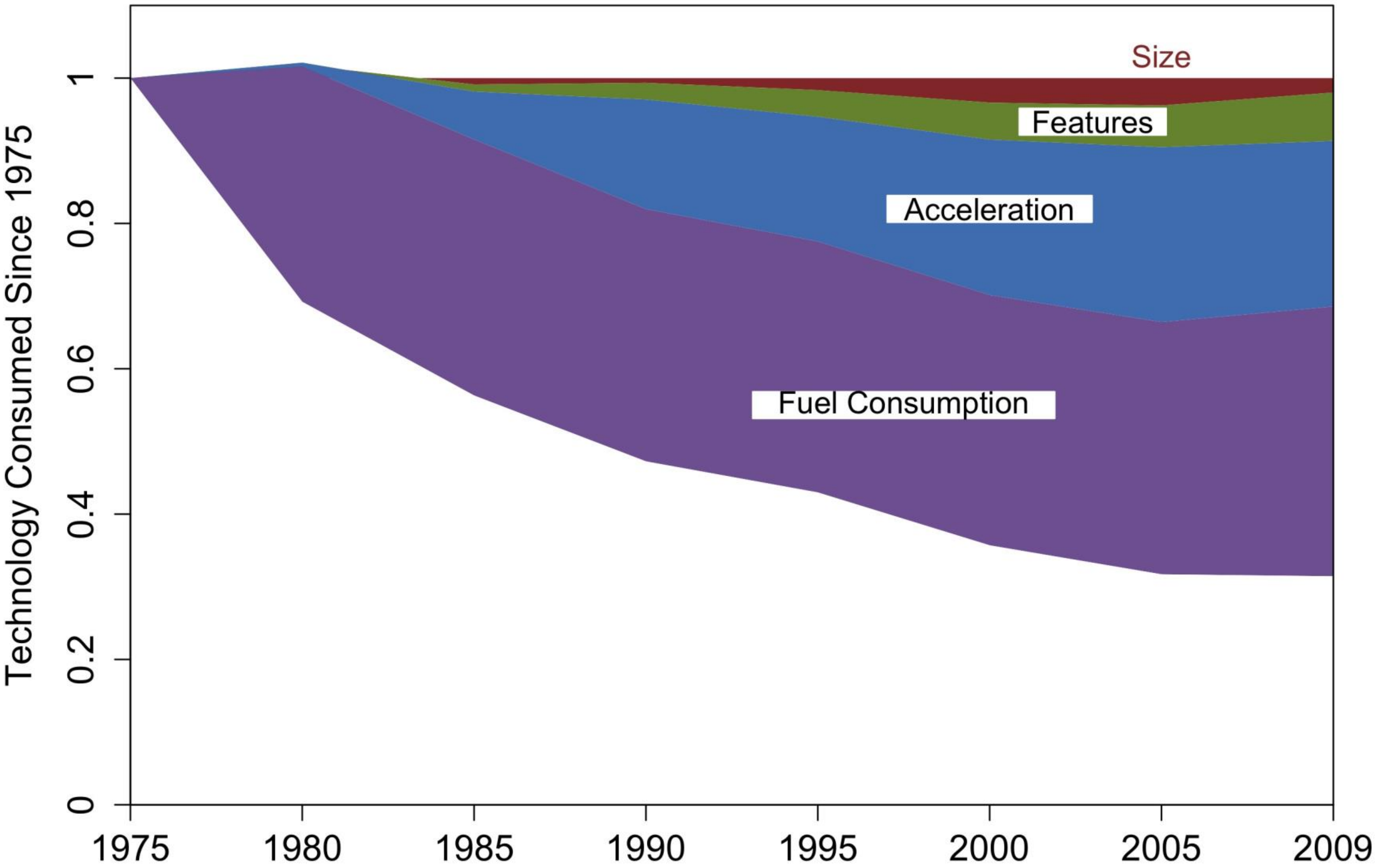


Figure 11: Results for 4-vehicle platoon

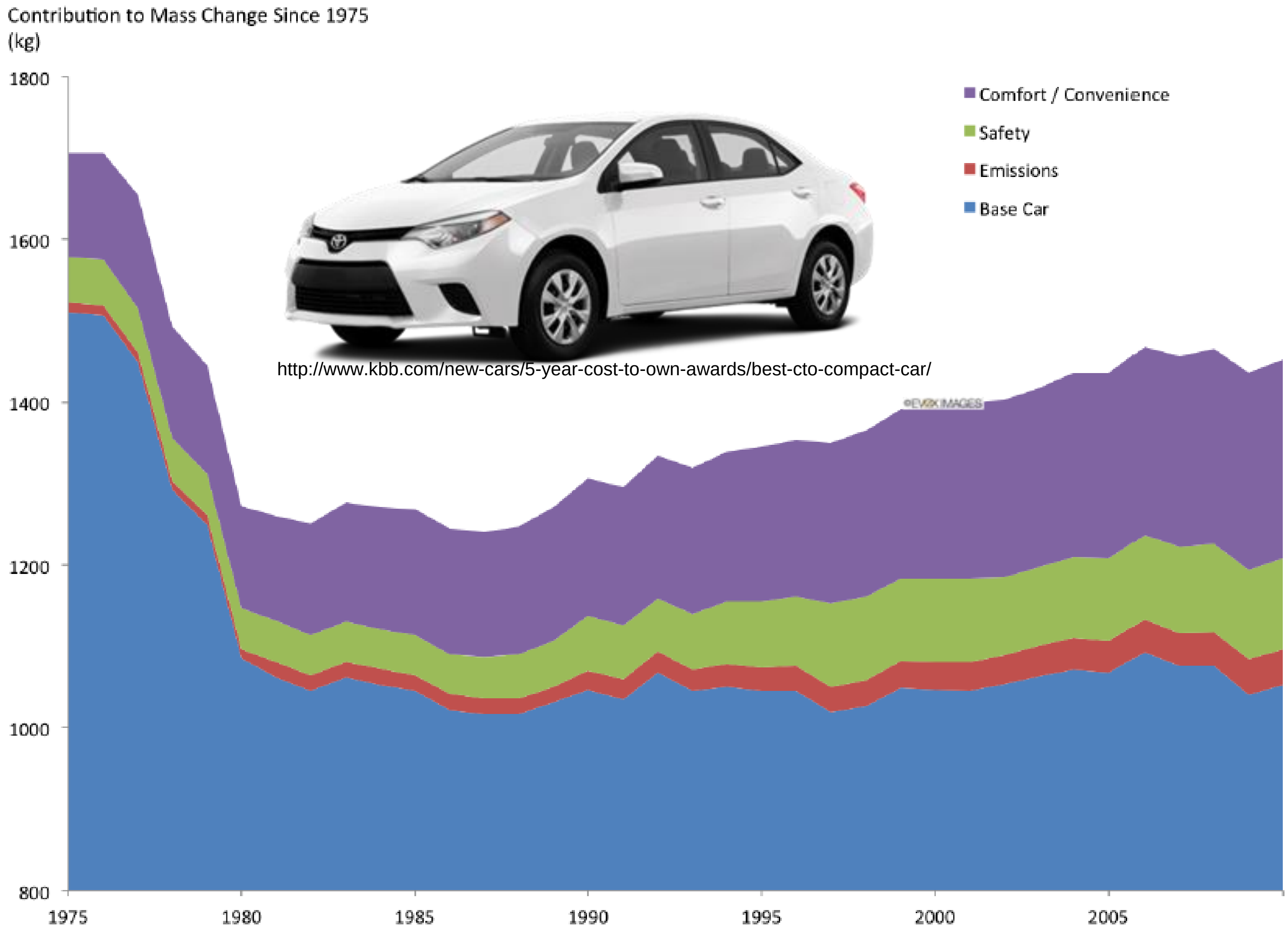


Could automation mean a ceasefire in the horsepower wars?



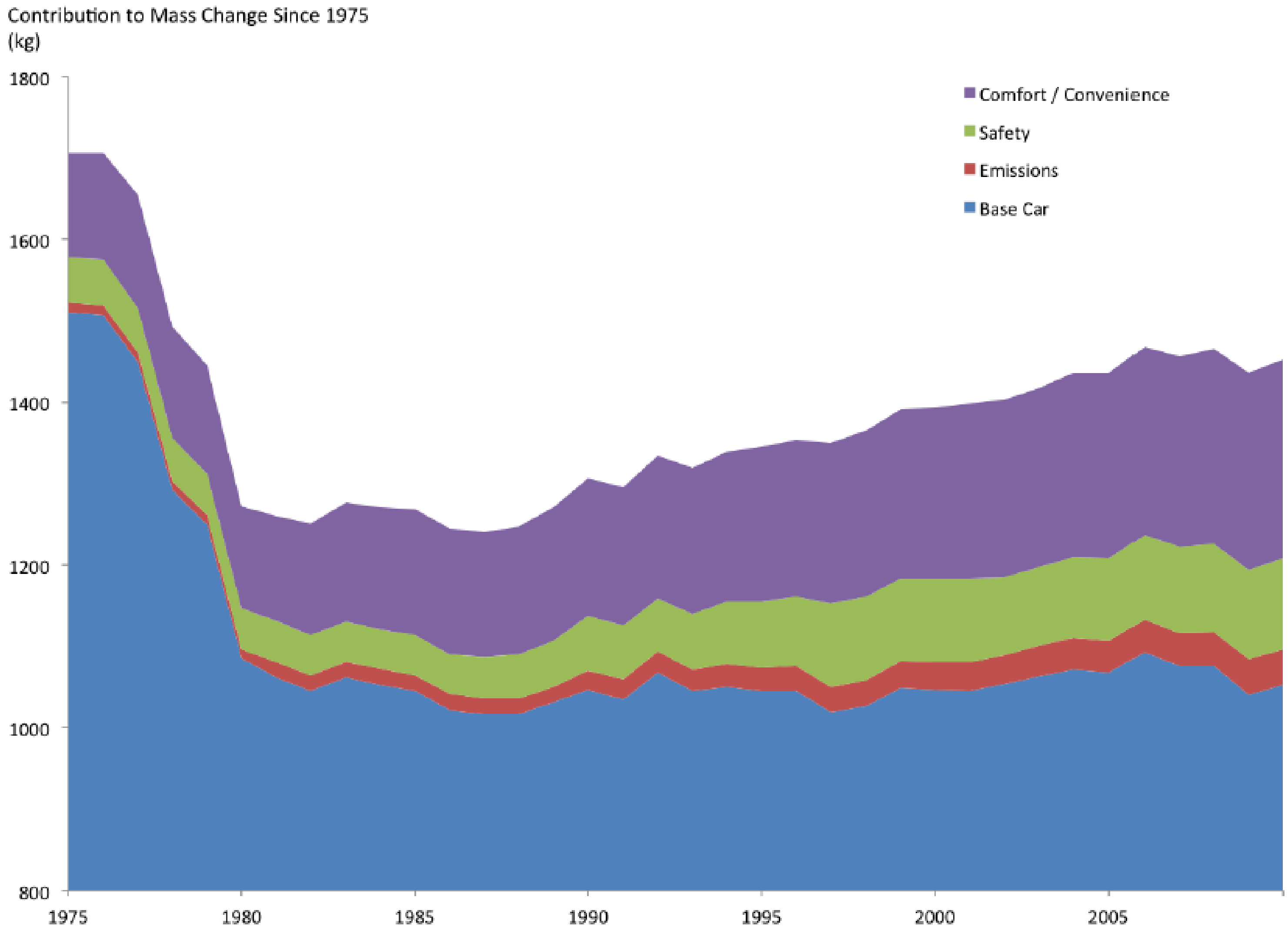
MacKenzie, D., & Heywood, J. *Quantifying efficiency technology improvements in U.S. cars from 1975-2009.* Applied Energy 157, pp. 918-928. (2015)

Without crash risk, could we remove safety equipment? Get everyone into a compact car?



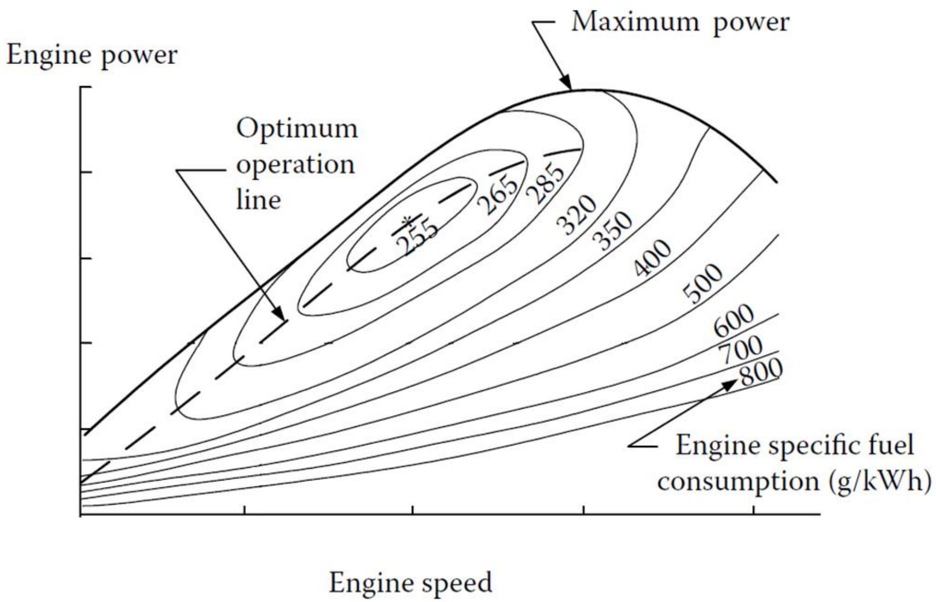
MacKenzie, D., Zoepf, S., & Heywood, J. *Determinants of U.S. Passenger Car Weight*. International Journal of Vehicle Design 65(1), pp. 73-93. (2014)

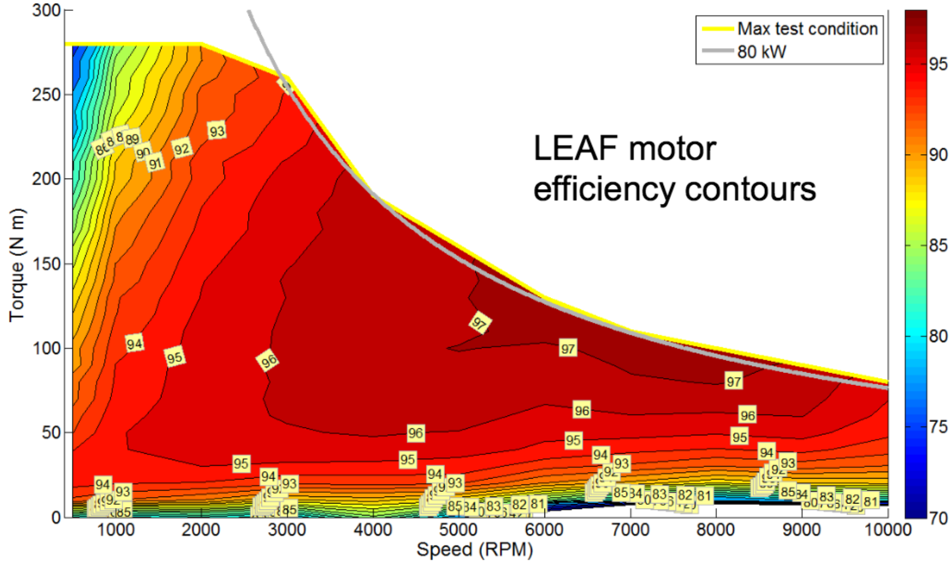
With more free time, travelers may demand more comfort & convenience features



MacKenzie, D., Zoepf, S., & Heywood, J. *Determinants of U.S. Passenger Car Weight*. International Journal of Vehicle Design 65(1), pp. 73-93. (2014)

Some of our impacts may be different for EVs than for conventional vehicles





EV efficiency is less sensitive than ICEs to engine speed and load. So…

EVs likely to be ***more sensitive*** *to highway* ***speeds*** *and* ***platooning*** *effects.*

EVs likely to be ***less sensitive*** *to* ***congestion*** *relief and* ***eco-driving****.*

Sensitivity to changes in acceleration performance…???

Read More: http://faculty.washington.edu/dwhm/2016/02/29/will-automation-benefit-electric-vehicle-efficiency/

Conditions (c) and (d) included additional text in description of mode alternatives

- “You will have the option of doing other tasks (e.g. working, reading, watching videos, texting, etc.) or just relaxing during the trip, because you don’t need to pay attention to driving”.

- “A driverless ride-hailing service is similar to services offered by Uber and Lyft, where you can request a ride using an application on your smartphone, but the car will be driven by the computer rather than a human driver”

Regression results: car vs ridesourcing

Variable	Description	Model 1		Model 2	
		coefficient	significance level	coefficient	significance level
InterceptRHS		-0.8973	*	-0.8604	*
SdIntercept		-0.1169		-0.1124	
Cost		-0.1517	***	-0.1516	***
TimeDrive	Travel time of personal car	-0.0619	***	-0.0620	***
TimeRHS	Travel time of RHS	-0.0516	***	-0.0536	**
DriverlessRHS	(Binary, Associated with RHS) 1: Driverless; 0: Regular	-0.2282	*	0.1060	
MultitaskingRHS	(Binary, Associated with RHS) 1: Explicit mention of multitasking; 0: otherwise	0.263	**	0.1289	**
TimeDriverlessRHS	Travel time for driverless RHS	-		-0.0171	*
TimeMultitaskingRHS	Travel time of RHS in cases where multitasking is mentioned explicitly	-		0.0200	*
Log-likelihood		-1427.6		-1427.0	
Null Model Log-likelihood		-1623.4		-1623.4	
Rho-Squared		0.1206		0.1210	
Adjusted Rho-Squared		0.1191		0.1190	
No. of Observations		3012		3012	

0 ‘***’ 0.001 ‘**’ 0.01 ‘*’

Multinomial logit model results:

Variable	**Coefficient Estimate**	**Standard Error**	**t-value**	**p-value**
Zestimate / Income / AvgSqFt	-4.71	2.48	-1.90	0.06
SchoolQuality*Child	0.0582	0.0221	2.63	0.01
ln(Gaccess)	1.27	0.118	10.74	0.00
Logsum	2.70	0.0511	52.86	0.00
WorkplaceDummy	2.06	0.111	18.49	0.00
Density	15.8	7.27	2.18	0.00
$\ln(Gaccess)^2$	0.0736	0.00613	12.01	0.00
$Logsum^2$	0.0819	0.00238	34.38	0.00
SchoolQuality	0.0475	0.0109	4.37	0.00
Null Log Likelihood: -13621.4 Final Log Likelihood: -10126.808 AIC: 20271.616 BIC: 20327.483				

Mode choice model

$$A_{ij} = \ln\left[\sum_{c \in C_{ij}} \exp(V_{cij})\right]$$

$$V_{cij} = \beta_{0c} + \beta_1 * (cost_{cj}/income_i) + \beta_{2c} * TTT_{cj}$$

Variable	**Coefficient Estimate**	**Standard Error**	**T**	**p-value**
Transit Intercept	-1.13	0.116	-9.73	0.00
Walking Intercept	1.48	0.204	10.05	0.00
Cost / Income	-37.2	5.24	-7.10	0.00
Total Travel Time Car	-0.0161	0.00478	-3.36	0.00
Total Travel Time Transit	-0.000377	0.00117	-0.32	0.75
Total Travel Time Walking	-0.0844	0.00568	-14.86	0.00
Initial Log Likelihood: -3002.171 Final Log Likelihood: -1775.045 AIC: 3562.091 BIC: 3599.915				
Note: Car Intercept fixed at zero for identification purposes				

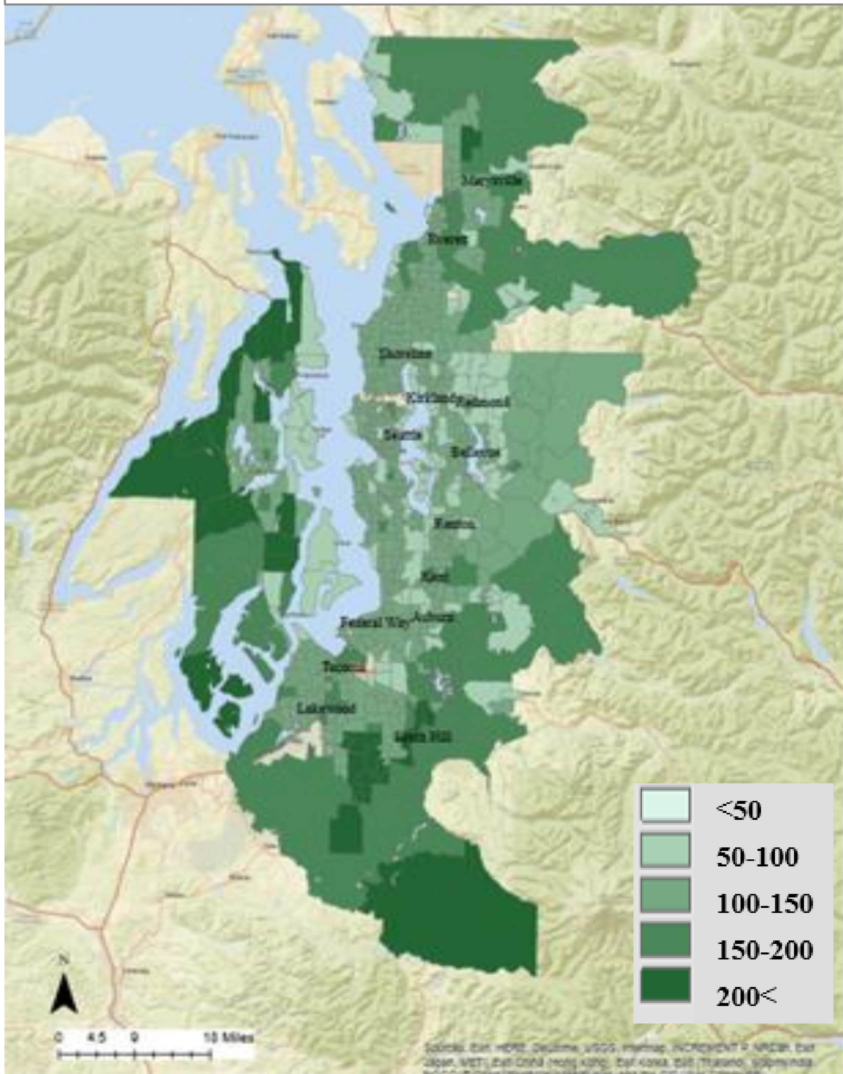
$$A_j^{Ret} = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{(Number\ of\ retail\ jobs_k)^{\gamma_{Ret}}}{(Impedance_{jk})^{\beta_{Ret}}}\right)$$

$$V_{ijk}^{Ret} = \gamma_{Ret}.\ln\left(number\ of\ jobs_k\right) - \beta_{Ret}.\ln\left(impedance_{ijk}\right)$$

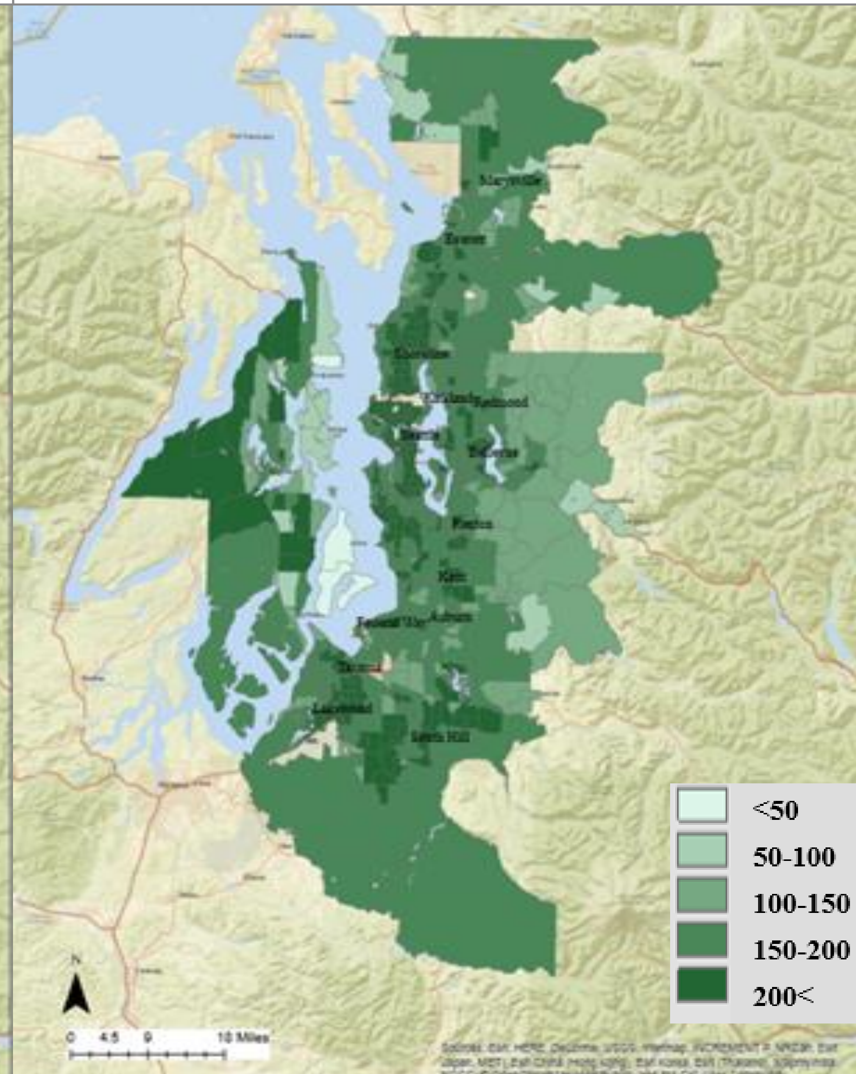
Name	**Value**	**Std err**	**t-test**	**p-value**
γ_{retail} (log of number of retail jobs)	0.22	0.0406	5.43	0.00
β_{retail} (log of impedance)	3.87	0.102	37.91	0.00
β (transit weight)	1.03	0.0249	41.38	0.00
γ (walking weight)	0.715	0.0302	23.69	0.00
Init log likelihood: -14366.327 Final log likelihood: -4014.462 AIC: 8036.923 BIC: 8064.881				

The equivalent changes in price($)/SqFt to maintain utility in each tract the same

Magic carpets replace private cars



Magic carpets as an additional service



Magic carpets replace private cars ≡ an average reduction of $126/sqft, Magic carpets as an additional new on-demand service ≡ an average reduction of $188/sqft.