Autonomous Vehicles

Seminar: Digitalisation and the Rebound Effect

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28/10/2020

Content

Many concepts around autonomous vehicles:

- Safety
- Liability
- Technology
- Societal
- Infrastructure
- Economics
- Ecological

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Structure of this talk is heavily derived from Austin Brown et al. *An Analysis of Possible Energy Impacts of Automated Vehicles* [1] because they try to quantify different ecological aspects with the same baseline

Content

- Framework to quantify effects
- Individual Effects
- Widespread adaptation
- Wider context

Autonomous Driving

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Note: Other sources classify AVs from L0 to L4
Slides are self contained

[28]

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Assumptions:
- L5 automation
- AVs are not electric
- Connected and coordinated
- Disregard periods of L0 - L4
- Include period where L5 coexists with CVs

CV: Conventional vehicle
AV: Autonomous vehicle

Note: Other sources classify AVs from L0 to L4
Slides are self contained

[28]

Quantifying ecological impact: Kaya identity

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

F: Global CO2 emission

G: GDP

P: Population

E: Energy Consumption

[1] [29]

Quantifying ecological impact: Kaya identity

$$F = P \times \underbrace{\frac{G}{P}}_{\text{GDP Per capita}} \times \overbrace{\frac{E}{G}}^{\text{Energy per unit GDP (Energy Intensity)}} \times \underbrace{\frac{F}{E}}_{\text{Carbon per unit Energy (Carbon Intensity)}}$$

F: Global CO2 emission

G: GDP

P: Population

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[1] [29]

Modifying Kaya identity to AVs

1) Replace CO2 usage with liquid fuel usage
2) Split up identity to AVs and CVs

$$Liquids = Liquids_{AV} + Liquids_{CV}$$

[1]

Modifying Kaya identity to AVs

$$Liquids = \overbrace{k \times \frac{VMT_{AV}}{AVs} \times \frac{E_{AV}}{VMT_{AV}} \times \frac{Liquids_{AV}}{E_{AV}}}^{Liquids_{AV}} + \overbrace{(1-k) \times \frac{VMT_{CV}}{CVs} \times \frac{Liquids_{CV}}{VMT_{CV}} \times \frac{Liquids_{CV}}{E_{CV}}}^{Liquids_{CV}}$$

$$Liquids = \#vehicles \times \left(k \times \frac{VMT_{AV}}{AVs} \times \frac{E_{AV}}{VMT_{AV}} \times \frac{Liquids_{AV}}{E_{AV}} + (1-k) \times \frac{VMT_{CV}}{CVs} \times \frac{Liquids_{CV}}{VMT_{CV}} \times \frac{Liquids_{CV}}{E_{CV}}\right)$$

k: fraction of AVs
VMT: vehicle miles traveled
E: energy use
AVs/CVs: number of vehicles
#vehicles: number of vehicles

[1]

Modifying Kaya identity to AVs

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Mistake by the authors?

k: fraction of AVs
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Modifying Kaya identity to AVs

We care about 3 quantites: UI, EI and FI (for AV and CV)

$$Liquids = \#vehicles \times \left(k \times \overbrace{\frac{VMT_{AV}}{AVs}}^{\text{UI: Use intensity}} \times \underbrace{\frac{E_{AV}}{VMT_{AV}}}_{\text{EI: Energy Intensity}} \times \overbrace{\frac{Liquids_{AV}}{E_{AV}}}^{\text{FI: Fuel intensity}} + (1-k) \times \frac{VMT_{CV}}{CVs} \times \frac{Liquids_{CV}}{VMT_{CV}} \times \frac{Liquids_{CV}}{E_{CV}}\right)$$

[1]

Modifying Kaya identity to AVs

We care about 3 quantites: UI, EI and FI (for AV and CV)
Many concepts are connected, analysis tries to isolate and quantify them
Presentation does not include every element of [1] so conclusion values differ

$$Liquids = \#vehicles \times \left(k \times \overbrace{\frac{VMT_{AV}}{AVs}}^{\text{UI: Use intensity}} \times \underbrace{\frac{E_{AV}}{VMT_{AV}}}_{\text{EI: Energy Intensity}} \times \overbrace{\frac{Liquids_{AV}}{E_{AV}}}^{\text{FI: Fuel intensity}} + (1-k)\times \frac{VMT_{CV}}{CVs} \times \frac{Liquids_{CV}}{VMT_{CV}} \times \frac{Liquids_{CV}}{E_{CV}}\right)$$

[1]

Content

- Framework to quantify effects
- Individual Effects
- Widespread adaptation
- Wider context

Individual Effects

Assume mix of Level 5 AVs and CVs on the roads

Content:

- Efficient driving
- Platooning

[1]

Efficient driving

AVs are able to drive more efficient by planning ahead when to accelerate and decelerate based on road layout, road signs, and traffic conditions. They don't drive abruptly or aggressively.

EI: 0 UI: 0 FI: 0

Efficient driving

AVs are able to drive more efficient by planning ahead when to accelerate and decelerate based on road layout, road signs, and traffic conditions. They don’t drive abruptly or aggressively.

Eco driving means by [6] [8]:

- Anticipate traffic flow and signals
- Drive with *correct* speed
- Regular vehicle maintenance such as checking tyre pressure
- Eliminate stop and go driving

- Already present in modern cars:
  - Slow acceleration (shift between 2000-2500 RPMs)
  - Eliminate excessive idling

EI: 0 UI: 0 FI: 0

[6] [8]

Efficient driving

15% EI (energy intensity: Energy/VMT) saved by [1]

up to 10% fuel savings according to [6]

15% fuel savings according to [7] without lower travel times

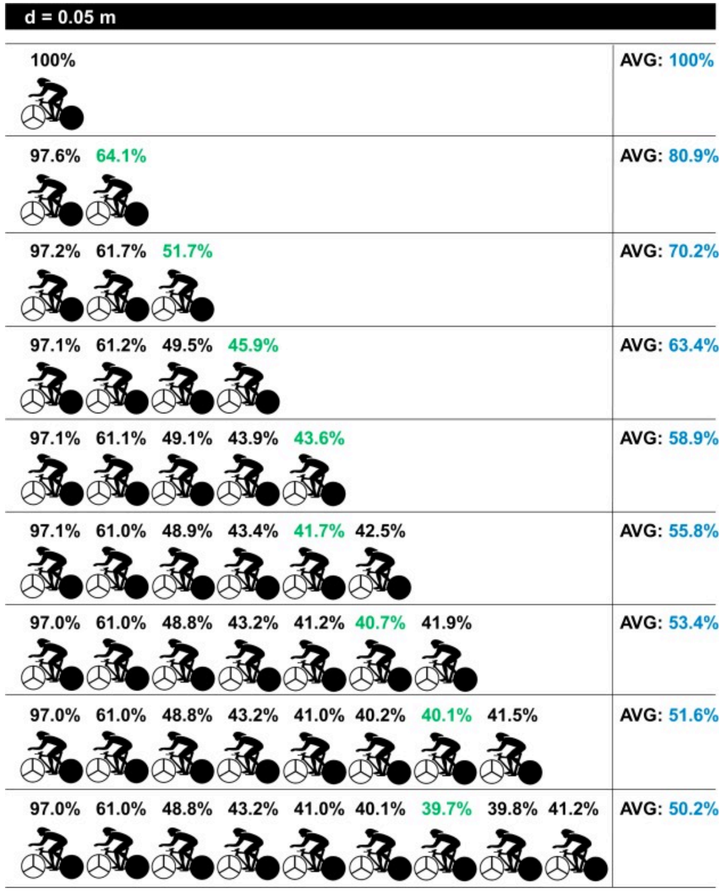
[8] even claims 30% fuel savings for autonomous vehicles

EI: -15% UI: 0 FI: 0 [6] [7] [8]

Platooning

In cycling riders form platoons (peloton) and regularly switch the head cyclist to reduce aerodynamical drag on the group

Example of platoons in cycling time trials

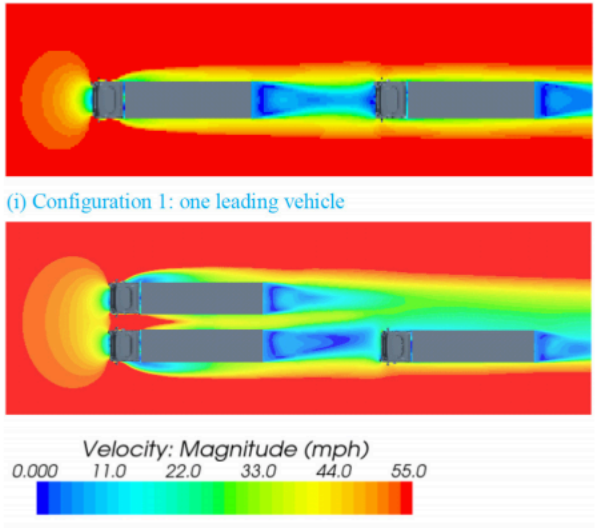


Drag for different lengths of platoons with a fixed wheel to wheel distance

EI: -15% UI: 0 FI: 0 [2]

Platooning

The same can be done if enough AVs find themselves on highways. 3 different methods show such an effect: CFD, wind tunnel, road test



Visualisation of CFD for heavy vehicles with 0° yaw headwind. Plotted are velocities, compared are two truck combinations [3]

EI: -15% UI: 0 FI: 0 [3]

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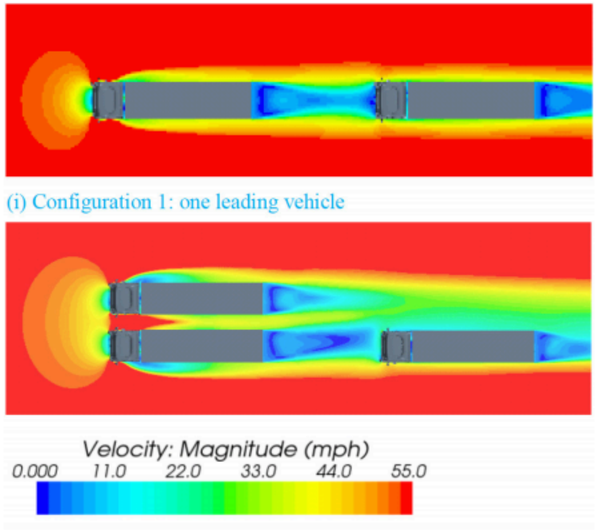

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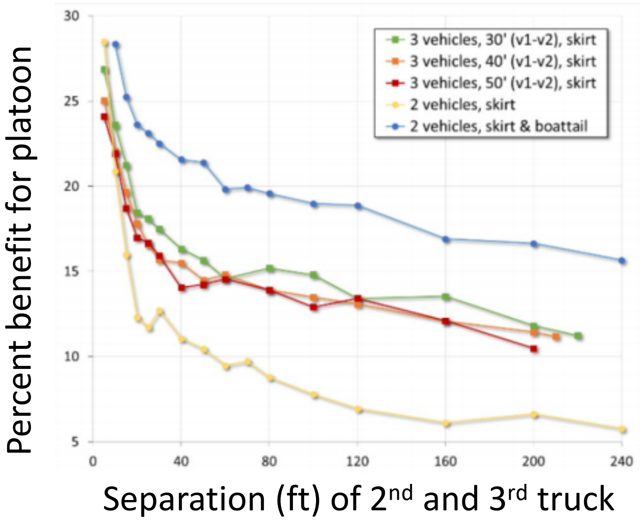

Model trucks in windtunnel. Percent benefit in wind averaged drag coefficient for the entire platoon (relative to isolated vehicles without trailer boattail) as a function of vehicle spacing. Spacing between 1st and 2nd is 30’ 40’ 50’, and second and third ranges from 5’ to 220’. Higher is better [4]

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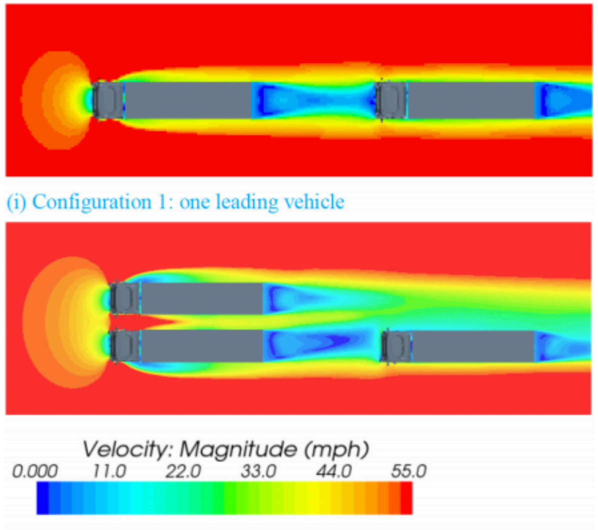

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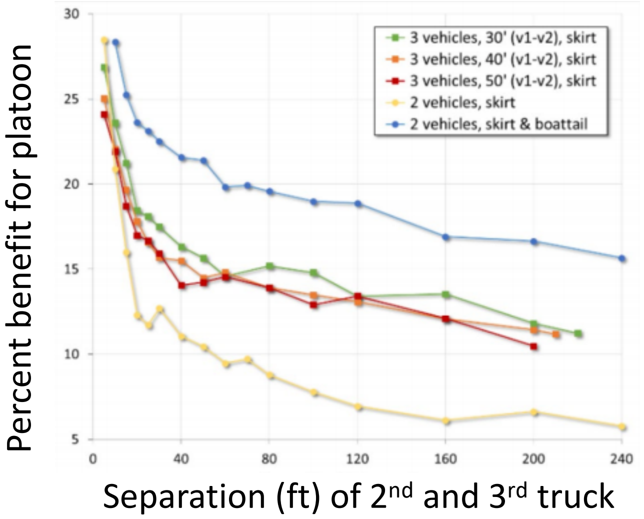

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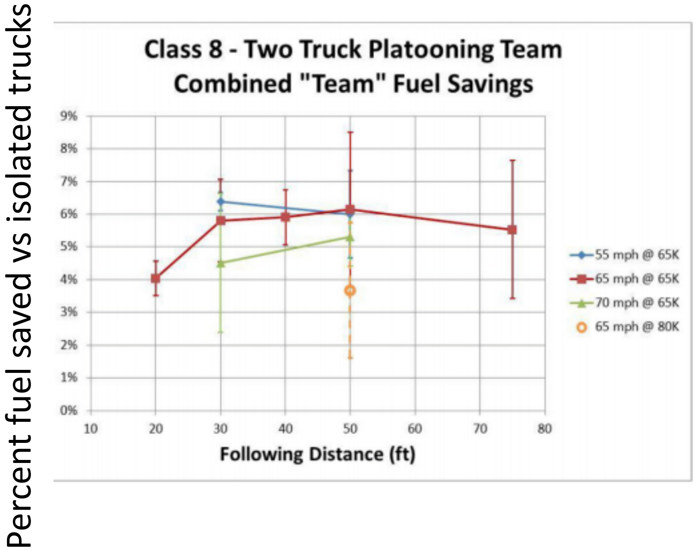


Relative fuel saved on real track with trucks for different following distances, speeds, and gross vehicle weights. Higher is better [5]

EI: -15% UI: 0 FI: 0

[3] [4] [5]

Platooning

Platooning is heavily dependent on:

- Aerodynamic shape of vehicles
- Number of vehicles
- Time in formation
- Actual formation (e.g. distance and speed between vehicles)

Estimated EI savings of 10% for light vehicles. Also possible for heavy vehicles as seen before, but no value from this study [1]

EI: -25% UI: 0 FI: 0 [1]

Content

- Framework to quantify effects
- Individual Effects
- Widespread adaptation
- Wider context

Widespread adaptation

Virtually all vehicles on the road are AVs

We look at

- Efficient driving
- Faster travel
- Increased travel
- Specialised vehicles
- Vehicle sharing
- Electrification

EI: -25% UI: 0 FI: 0

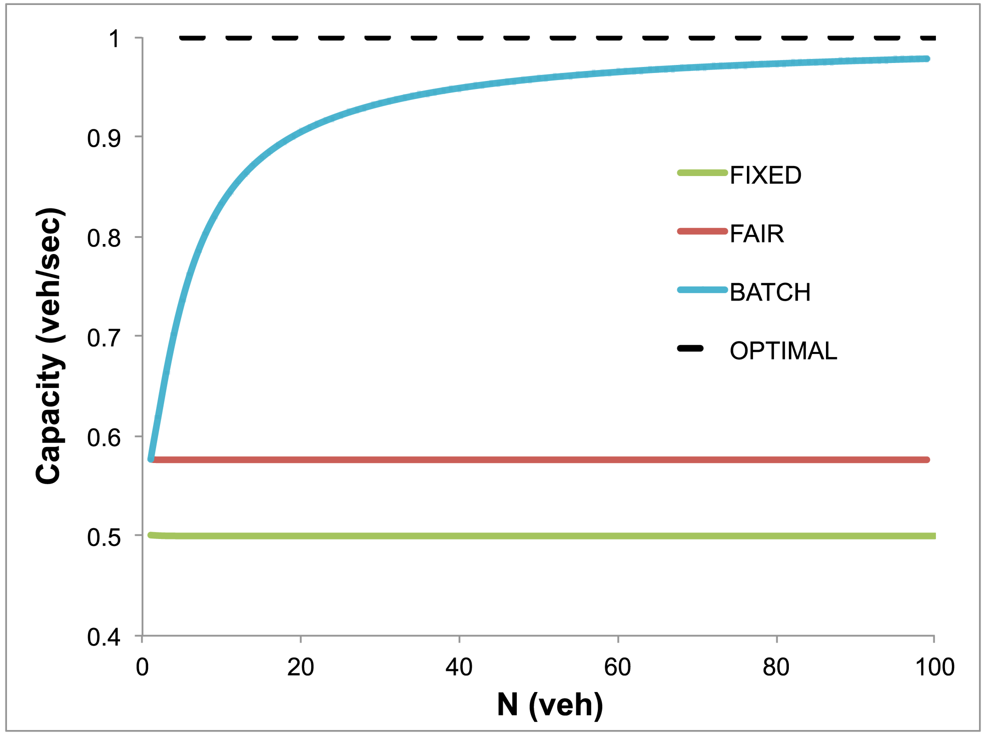
Efficient driving

Cars still drive individually efficient. However, there are enough AVs to coordinate and achieve effects such as no stops intersections

EI: -25% UI: 0 FI: 0

[1] [9]: Tachet, Remi, et al. "Revisiting street intersections using slot-based systems." PloS one 11.3 (2016)

Efficient driving

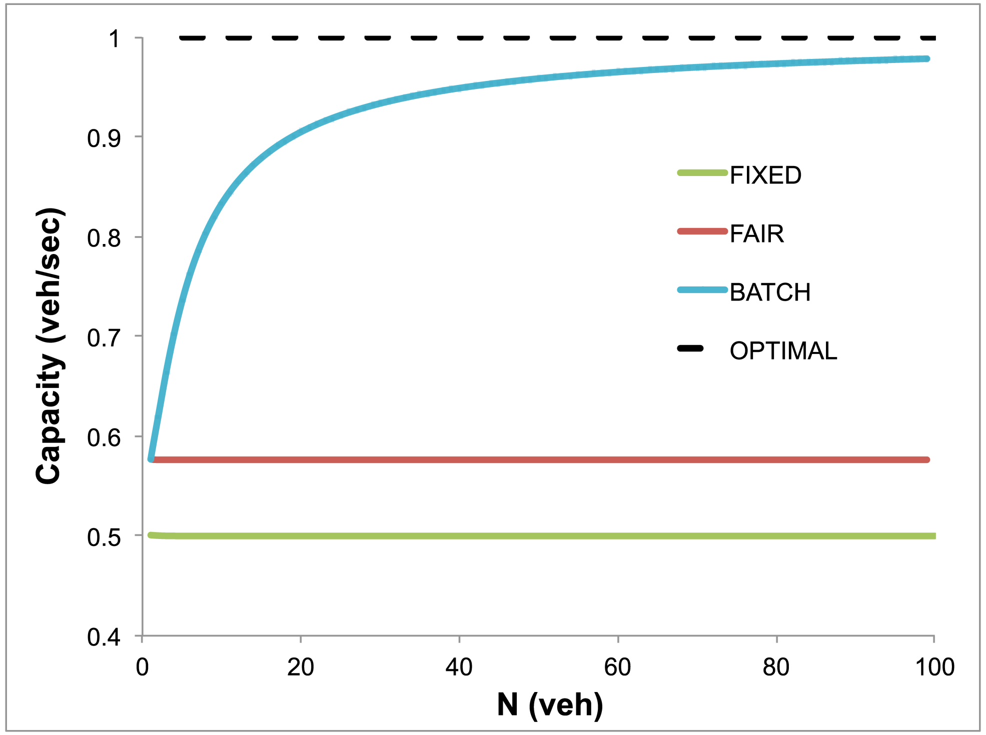


Capacity of three strategies for an intersection.

- Fixed: traffic lights where each cycle has a fixed duration
- Fair: Slot based FIFO
- Batch: slot based with adaptive platooning converges to optimum [9]

EI: -25% UI: 0 FI: 0 [1] [9]

Efficient driving



Capacity of three strategies for an intersection.

- Fixed: traffic lights where each cycle has a fixed duration
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[1] says that there's an additional 30% EI savings
What are people doing with the time they gain?

EI: -55% UI: 0 FI: 0 [1] [9]

Faster travel

Cars can drive faster and safer, but this creates more drag

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

F_D: drag force

ρ : density

v^2: velocity

C_D: drag coefficient

A : cross sectional area

EI: -55% UI: 0 FI: 0 [1] [11]

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[1] estimates 30% decrase in EI.

Faster and safer travel has related concepts:

- Increase in travel distance
- Lower EI by lighter cars

EI: -25% UI: 0 FI: 0 [1] [11]

Increased travel

Two concepts that will potentially increase the amount of travel:

- Consistent time in traffic
- Travel by underrepresented demographics

EI: -25% UI: 0 FI: 0

Increased travel: Consistent time in traffic

In [1] Schaefer et al. note:

“People are willing to spend the same amount of time in traffic”

EI: -25% UI: 0 FI: 0 [1]

Increased travel: Consistent time in traffic

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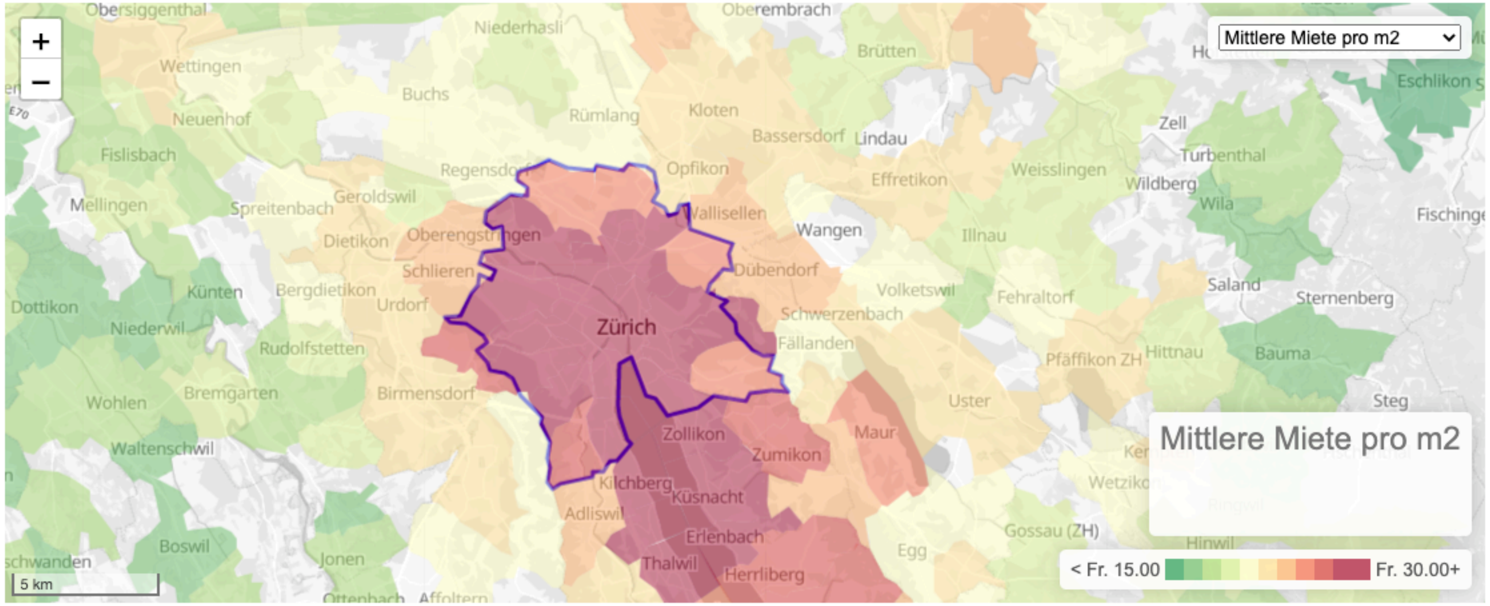


Quelle: Von ImmoMapper gefundene Wohnobjekte. In der Statistik berücksichtigt ist die spezielle Zimmerzählmethode im Kanton Genf. Siehe Disclaimer unten.

Map showing rents per m2 in Zurich and outskirts [12]

EI: -25% UI: 0 FI: 0 [1] [12]

Increased travel: Consistent time in traffic

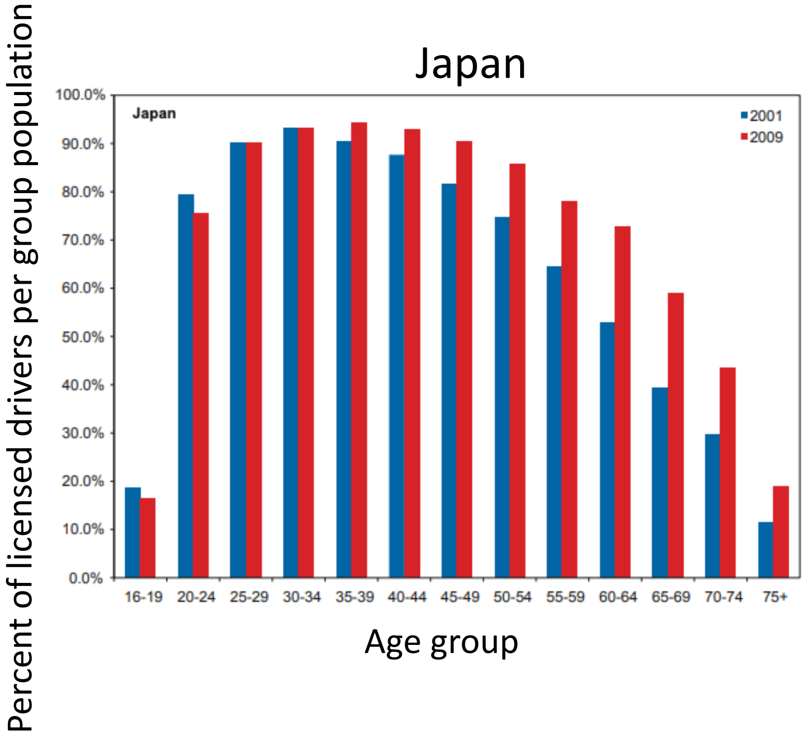
In [1] Schaefer et al. note:

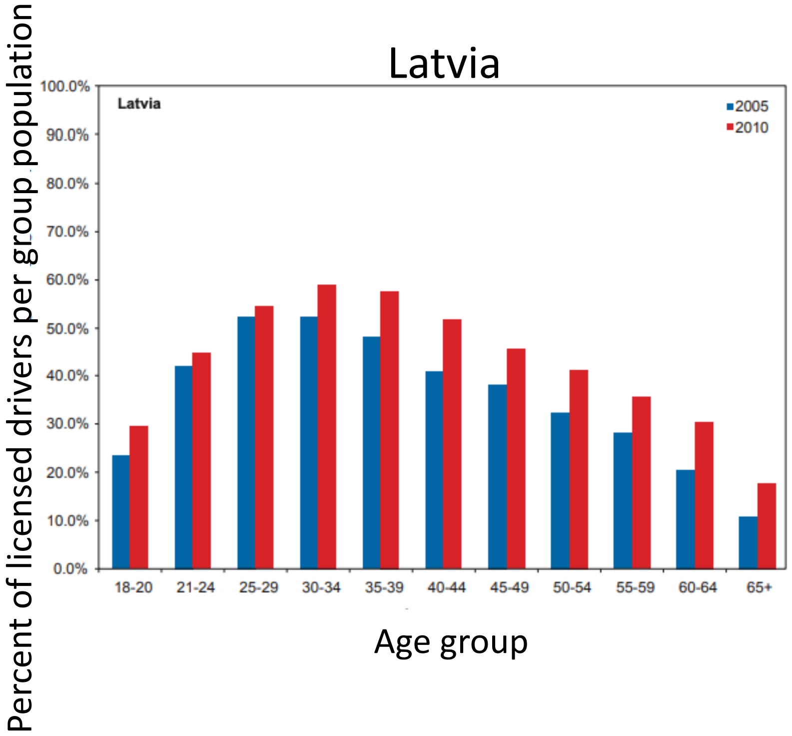
"People are willing to spend the same amount of time in traffic"

In addition, time spent in cars can be productive and people are willing to travel longer. This is an example of time rebound and we have a +50% UI (use intensity: VMT/vehicle) by [1]

EI: -25% UI: 50% FI: 0 [1]

Increased travel: Underrepresented demographics





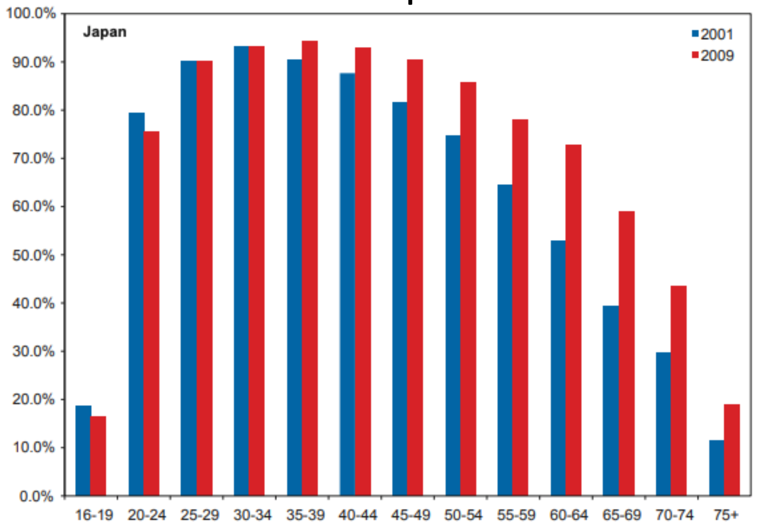
[14] Licensed drivers as percentage of their age group population

EI: -25% UI: 50% FI: 0 [14]

Increased travel: Underrepresented demographics

Japan

Percent of licensed drivers per group population



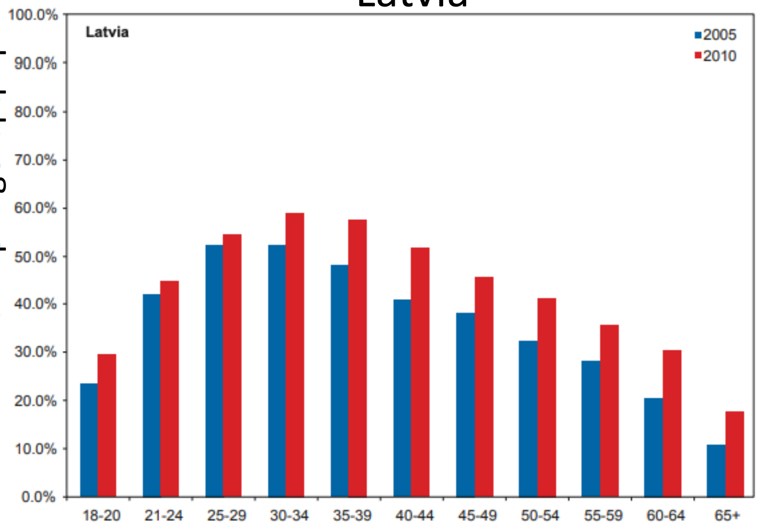
Age group

We see that

1) Some age groups have more licensed drivers
2) There is a big difference in countries
3) There is a shift over the years

Latvia

Percent of licensed drivers per group population



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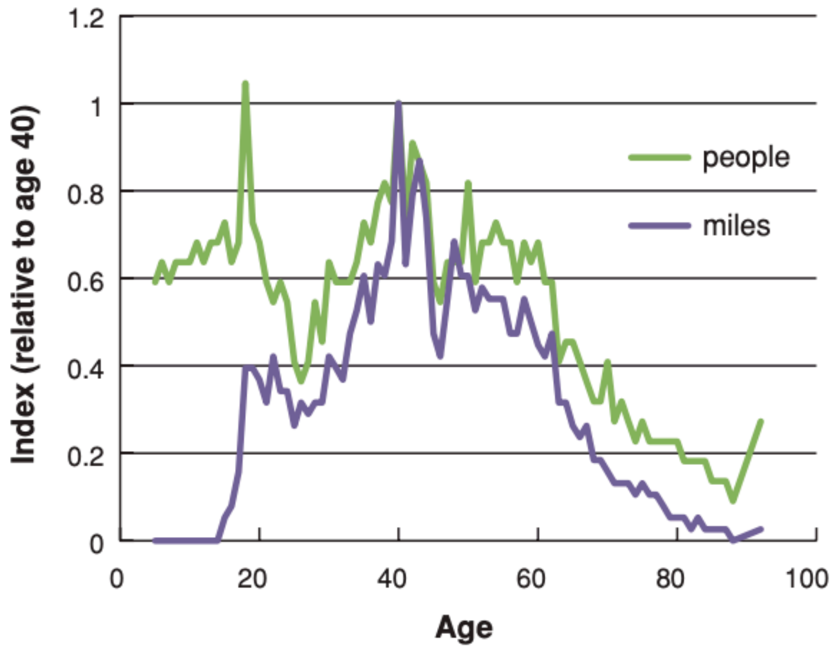
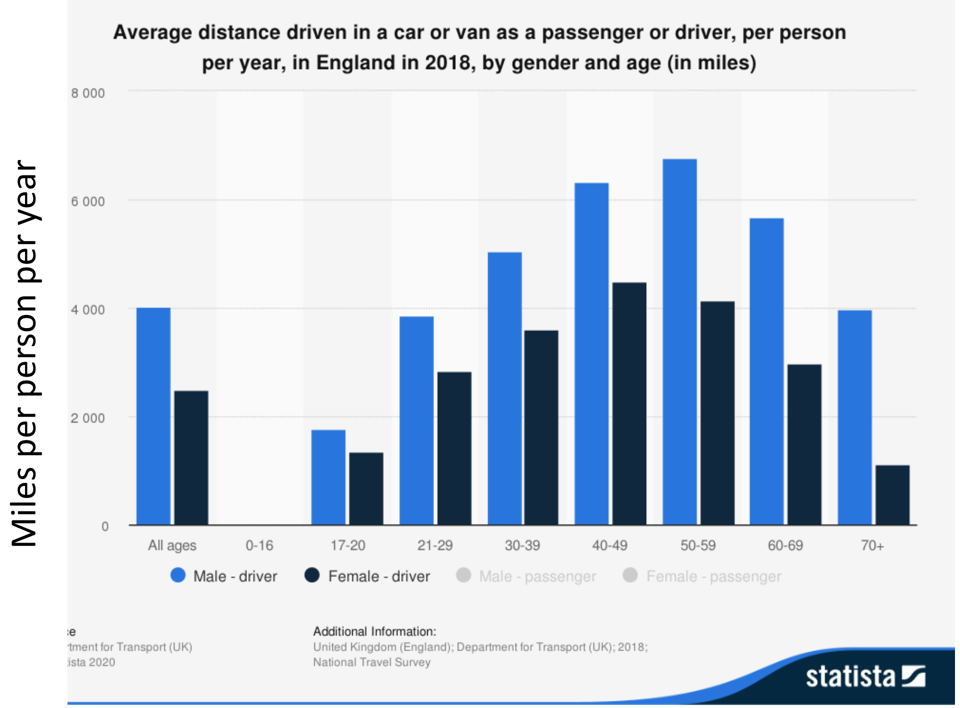


[1] Relative travel by age



[13] Average distance driven in car per person per year in England 2018

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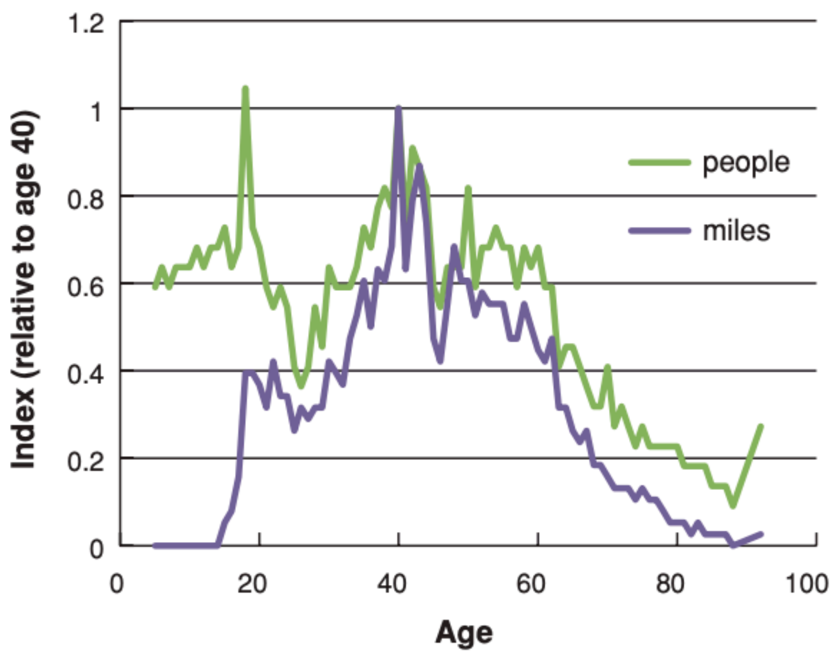
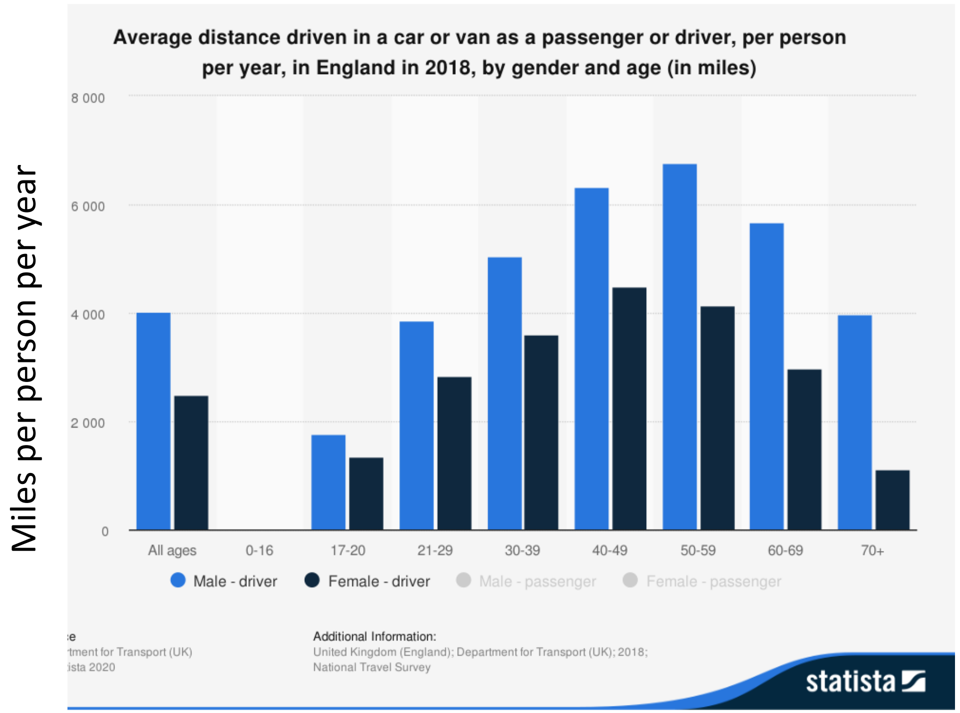
Increased travel: Underrepresented demographics



[1] Relative travel by age

Although a lot of people have license, most kilometers are driven by a narrow age group



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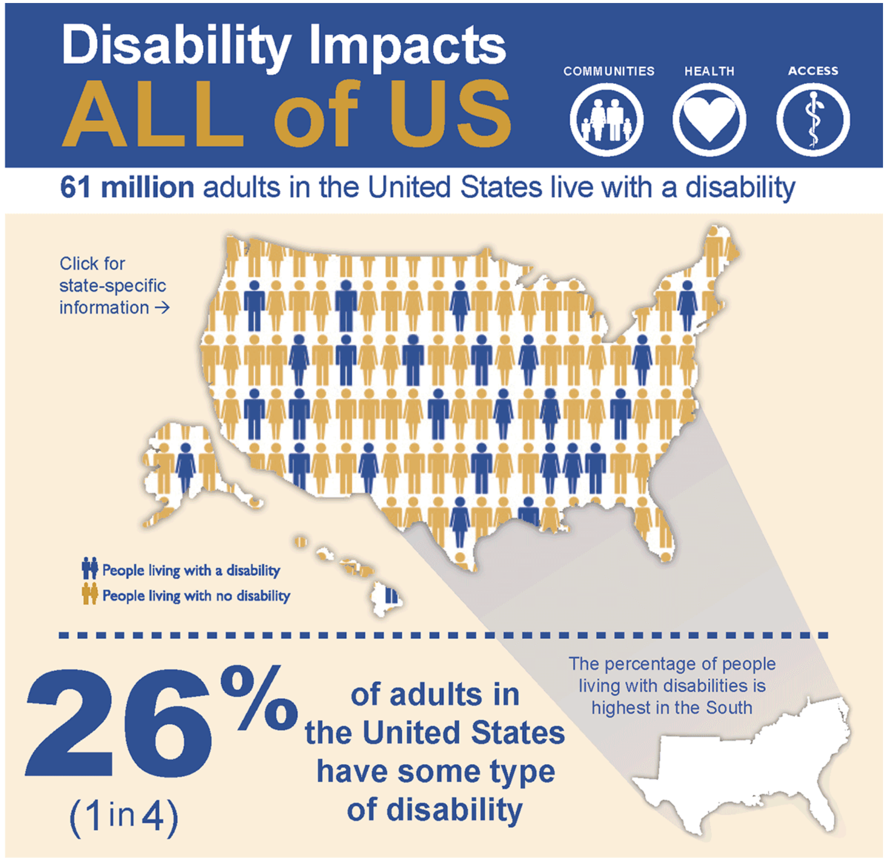

1/4 of US population has a disability [15]. Those are less likely to travel by car and take fewer long distance trips [1]

EI: -25% UI: 50% FI: 0 [1] [15]

Increased travel: Underrepresented demographics

What if the elderly, young people, and disabled people drive as much as the current 40 year olds? This results in an +40% UI increase

Rebound effect: Easier to use -> More travel

EI: -25% UI: 90% FI: 0 [1]

Increased travel: Underrepresented demographics

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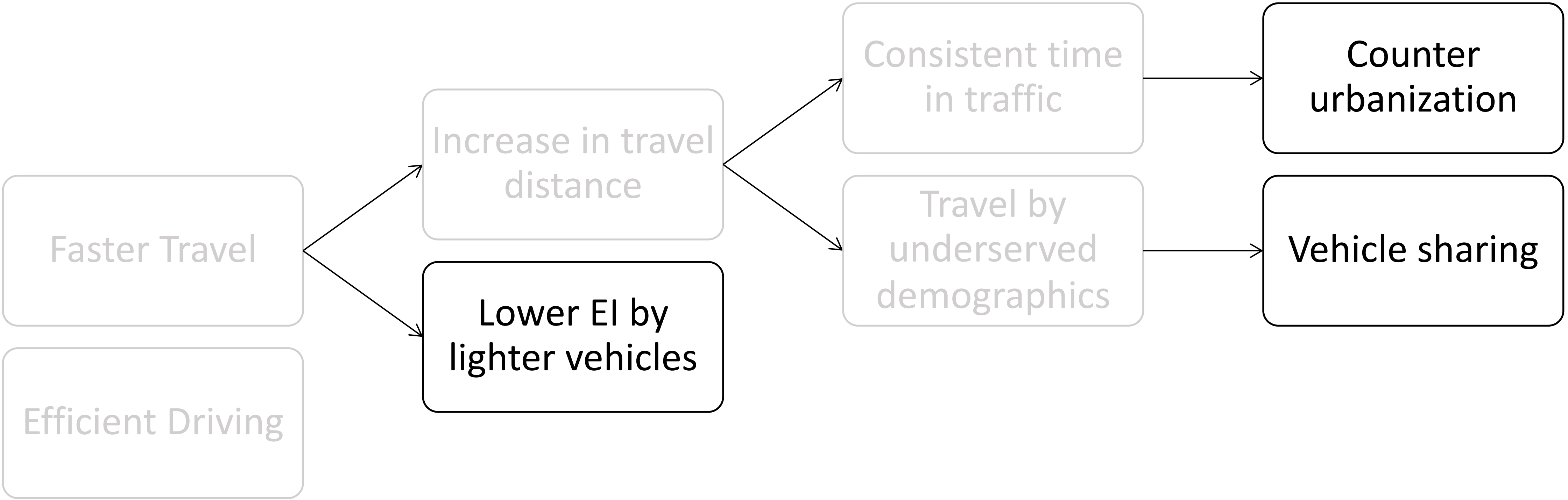
Rebound effect: Easier to use -> More travel

Indirect: What activities are those people doing, and what is their social and ecological impact?

However, those people probably won't own a car: Related concept is vehicle sharing

EI: -25% UI: 90% FI: 0 [1]

Overview of widespread adaptation so far



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Specialised vehicles

Specialisation: one person car, two person cars, long distance, short distance, transportation,…

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Specialised vehicles

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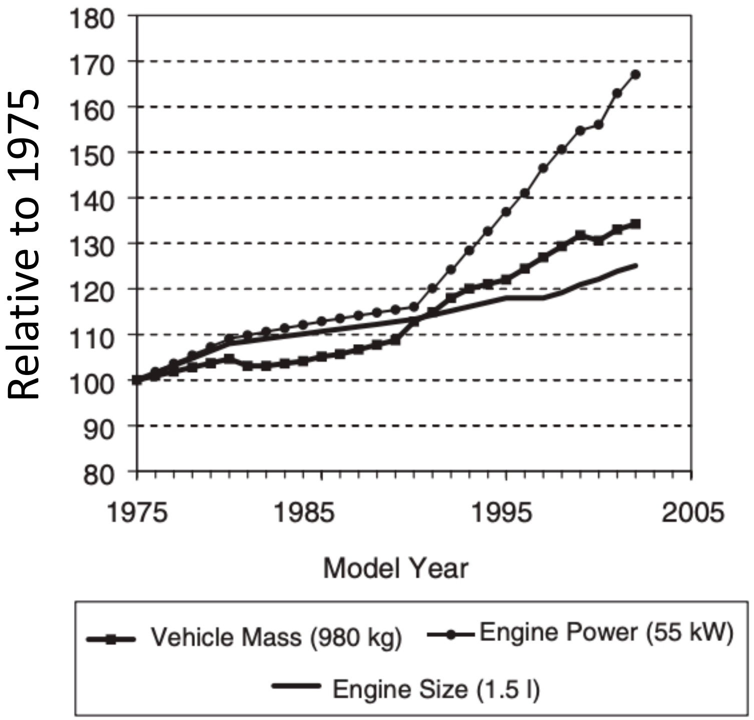
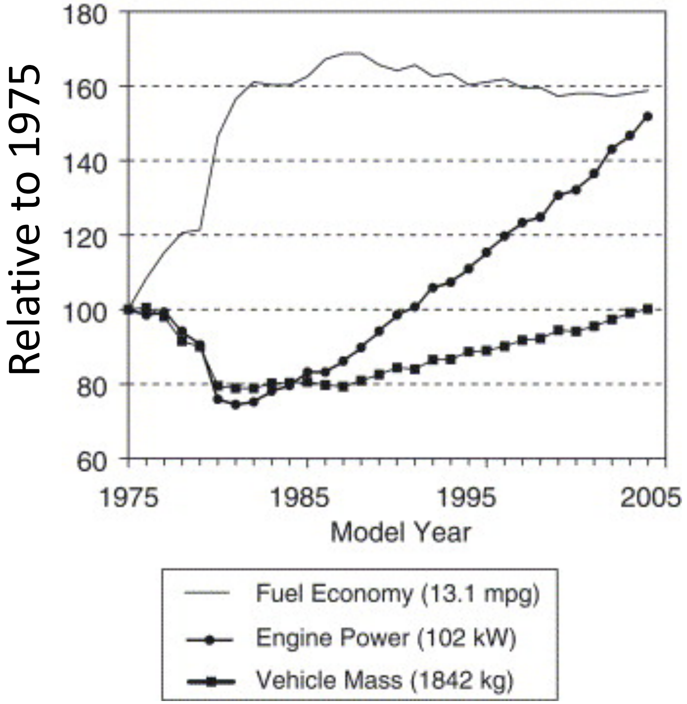


Relative evolution of sales-weighted average vehicle mass, engine power, engine size in the European Union [17]



Relative evolution of sales-weighted average vehicle mass, engine power, fuel economy of light dity vehicles in the US [17]

EI: -25% UI: 90% FI: 0 [1] [17]

Specialised vehicles

Specialisation: one person car, two person cars, long distance, short distance, transportation,…

Vehicles can be lighter as they are safer, and specialised for different tasks as any “driver” can now use any type of vehicle

We could get rid of e.g. [16] Airbags (up to 30kg), solid frames and crumble zones. Thus cars are not only lighter and save fuel, but require less resources to produce

-50% EI by reducing weight of 75%. Each reduction of 10% brings 6-8% EI reduction [1]

EI: -75% UI: 90% FI: 0 [1] [16]

Vehicle sharing

Only at peak times, 12% of all the vehicles are on the road [1]

Private cars are used on average 50-60mins per day, the rest is spent parking somewhere [16] Can we make each car useful?

In addition, cities have therefore 15% or in extreme cases up to 33% of space dedicated to parking [16]

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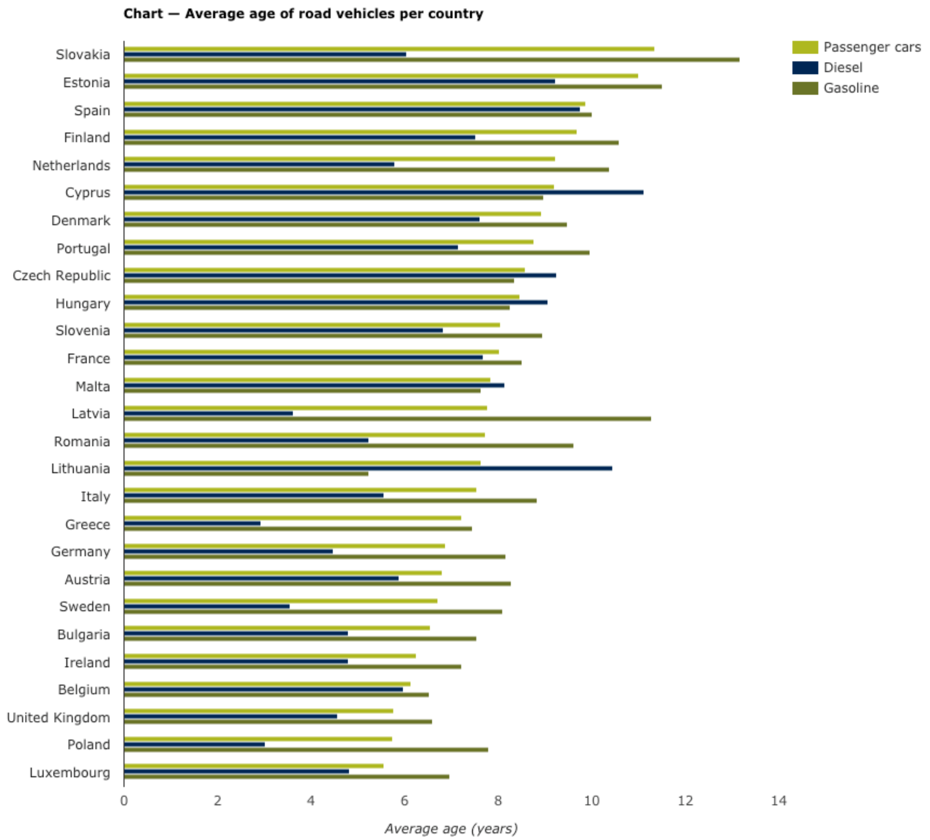
Ride sharing allows higher occupancy of cars, which gives a 12% UI reduction. More convenient than public transport as the destinations and times are flexible

EI: -75% UI: 78% FI: 0 [1] [16]

Vehicle sharing: Reduced time to market



Average age of road vehicles by country and vehicle type [18]

EI: -75% UI: 78% FI: 0 [18]

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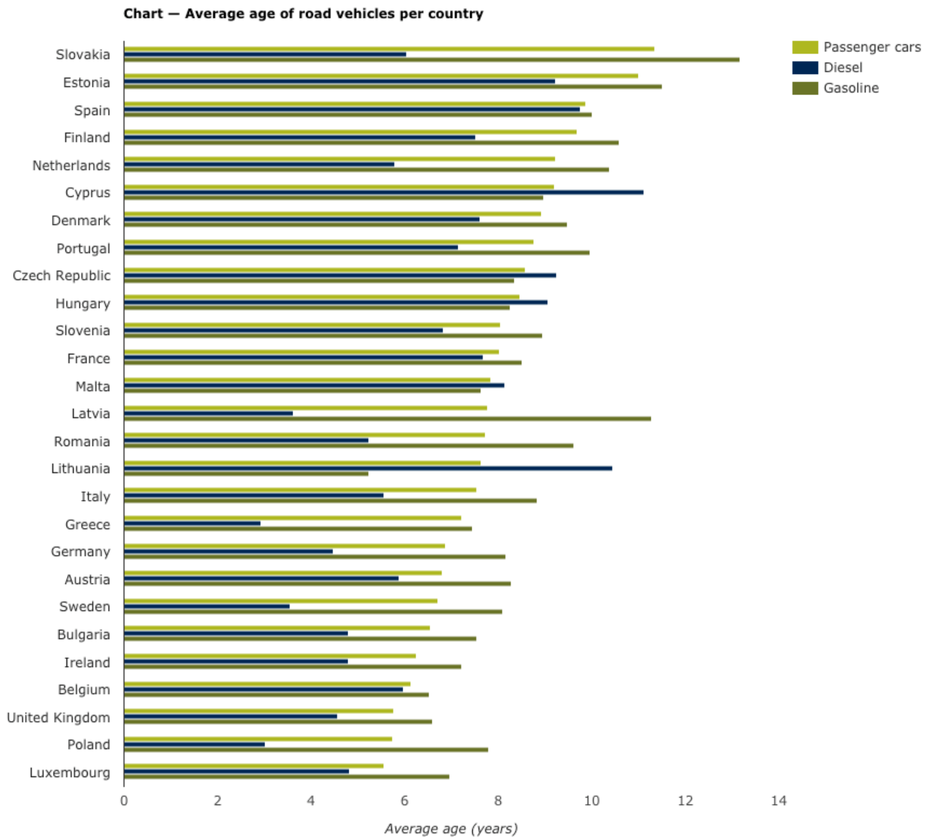

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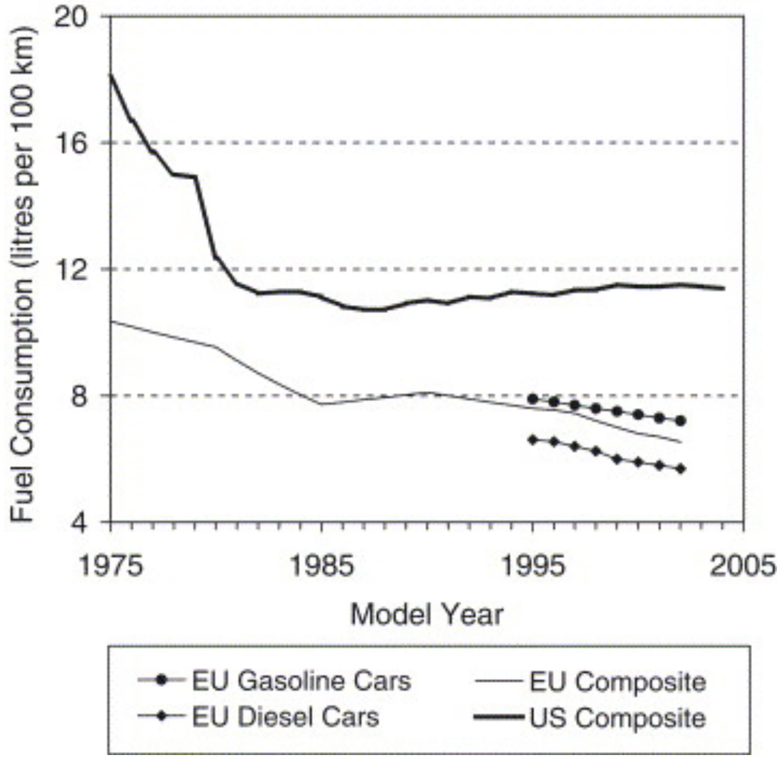

Evolution of fuel consumption of new cars in the EU and USA from 1975 to 2002. Two data sets for EU. Lower is better [17]

EI: -75% UI: 78% FI: 0 [17] [18]

Vehicle sharing: Reduced time to market

“Due to the major expense of purchasing a car, only about 7% of our vehicles are replaced in a single year […], making improvement very gradual and incremental.” [6]

EI: -75% UI: 78% FI: 0 [1] [6]

Vehicle sharing: Reduced time to market

“Due to the major expense of purchasing a car, only about 7% of our vehicles are replaced in a single year [...], making improvement very gradual and incremental.” [6]

If we reuse the same carpool, the time to market of new inventions is shorter and we can benefit faster of new inventions and more efficient vehicles

EI: -75% UI: 78% FI: 0 [1] [6]

Electrification

Issues in electric vehicles:

- Range
- Cost

EI: -75% UI: 78% FI: 0 [1] [6]

Electrification

Issues in electric vehicles:

- Range
- Cost

In vehicle sharing, the cost is ammortized over many people. In addition, the optimal car can be chosen, thus leading to a higher electrifcation rate.

Assuming that trips below 65km use electric vehicles, we get a 75% decrease in FI (fuel intensity: fuel/energy) [1]

EI: -75% UI: 78% FI: -75%

[1] [6]

Recap so far

- Efficient driving: -15% EI
- Platooning: -15% EI
- Efficient driving (widespread): -30% EI
- Faster travel: +30% EI
- Increase in travel distance: +50% UI
- Increase in travel by other demographics: +40% UI
- Special vehicles: -50% EI
- Vehicle sharing: -12% UI
- Electrification: -75% FI

EI: -75% UI: 78% FI: -75%

Content

- Framework to quantify effects
- Individual Effects
- Widespread adaptation
- Wider context

Content

Gloss over relevant topics:

- Urban infrastructure
- Counter urbanization
- Freed space
- Job loss

Urban infrastructure

How does the urban infrastructure change with AV?

Urban infrastructure

AVs need less room to operate and store. For on demand fleets, we need parking and charging stations, well connected to arrive fast at a user

[19] wants separate CVs from AVs. For AVs: remove intersections and replace with merge/diverge network.

[19]: Hesselgren, Lars, et al. "NuMo–New Urban Mobility: New urban infrastructure support for autonomous vehicles." (2019).

Urban infrastructure

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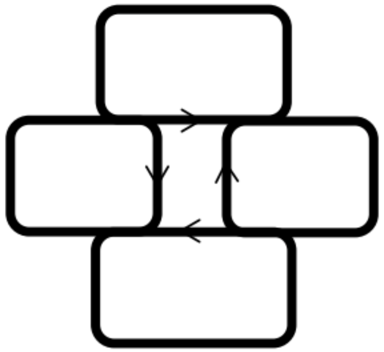
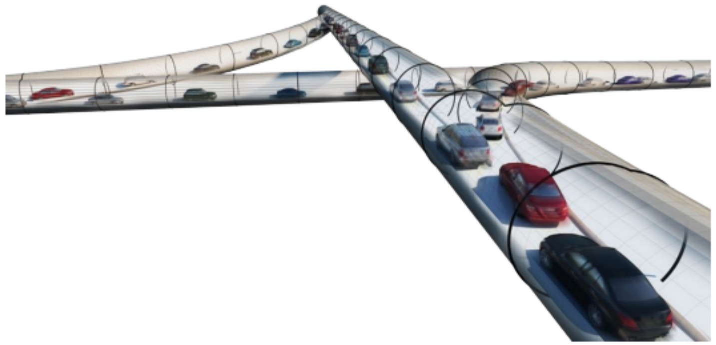


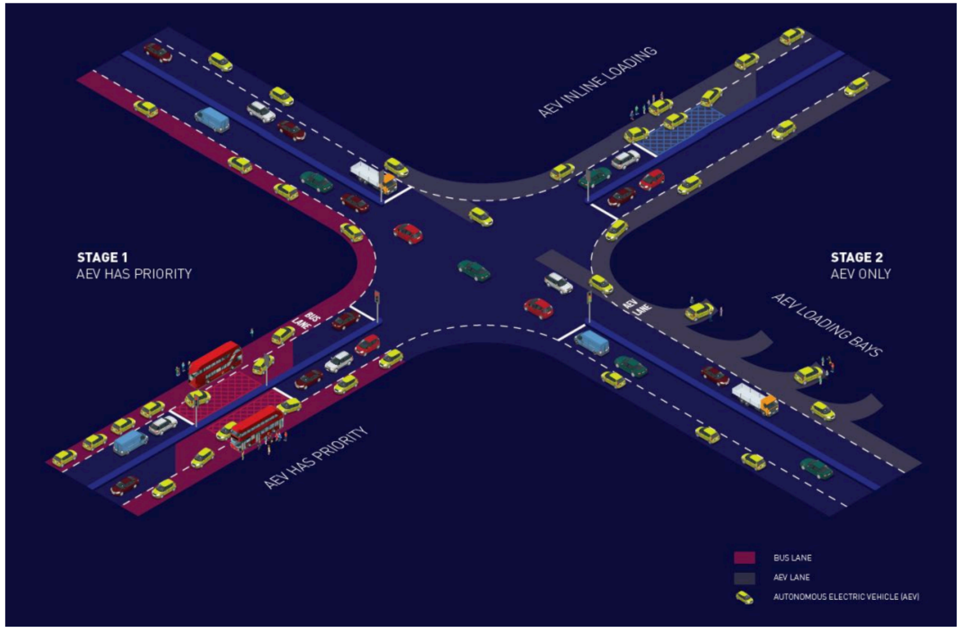
Remove intersections by only merging vehicles



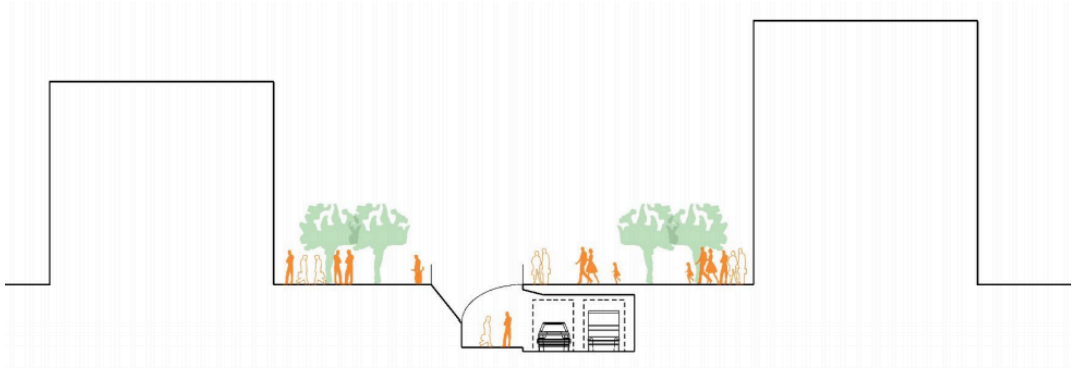
Efficient merging design by sloped ramps in 3D

[19]

Urban infrastructure



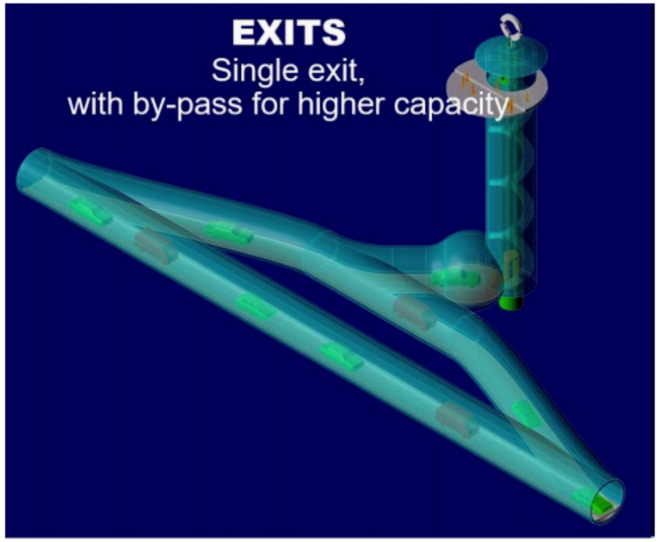
Sharing and isolation of AV and CV traffic for safety and efficiency

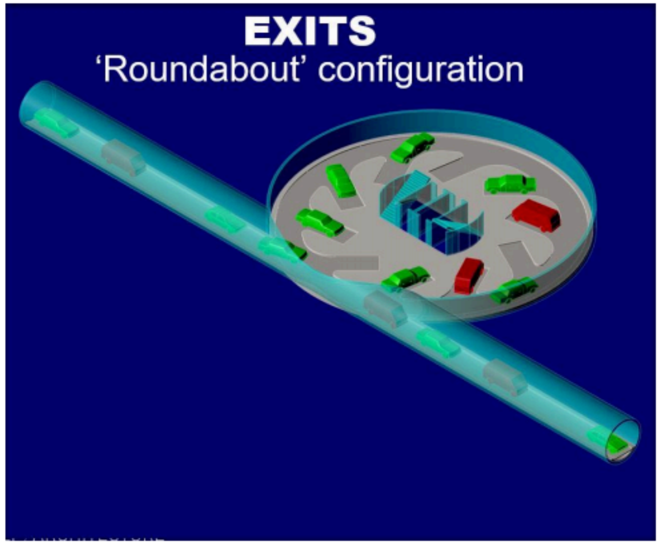


Underground road network. Similar to metro, but easier to maintain as it’s ”just” tunnels without additional infrastructure

[19]

Urban infrastructure





More complex designs for AVs: Single vehicle exists on the left, high capacity exits on the right

[19]

Urban infrastructure

Isochrono maps of 30min reachtime in Stockholm. Left: conventional, Right: with proposed changes

[19]

Urban infrastructure

What is the cost of this additional infrastructure?

Urban infrastructure

“Each year, more than 4 billion tonnes of cement are produced, accounting for around 8 per cent of global CO_2 emissions” [20]

[20]

Counter urbanization

People probably tend to driver longer distances. What if people move out of cities?

Counter urbanization

People probably tend to driver longer distances. What if people move out of cities?

“Sprawling requires the expansion of the road system as well as other physical infrastructures, such as water supply and waste removal—in general, sprawling tends to have negative environmental effects—increasing energy use and decreasing water and air quality” [21]

[21]

What to do with free space?

Cities are notorioulsy hotter than surrounding area. Can we combat those heat islands by adding trees on freed up parking space?

“surface temperatures are higher in urban areas than in surrounding rural areas, represents one of the most significant human-induced changes to Earth’s surface climate” [23]

[23]

What to do with free space?

Cities are notorioulsy hotter than surrounding area. Can we combat those heat islands by adding trees on freed up parking space? If we add trees, we get additional benefits:

"

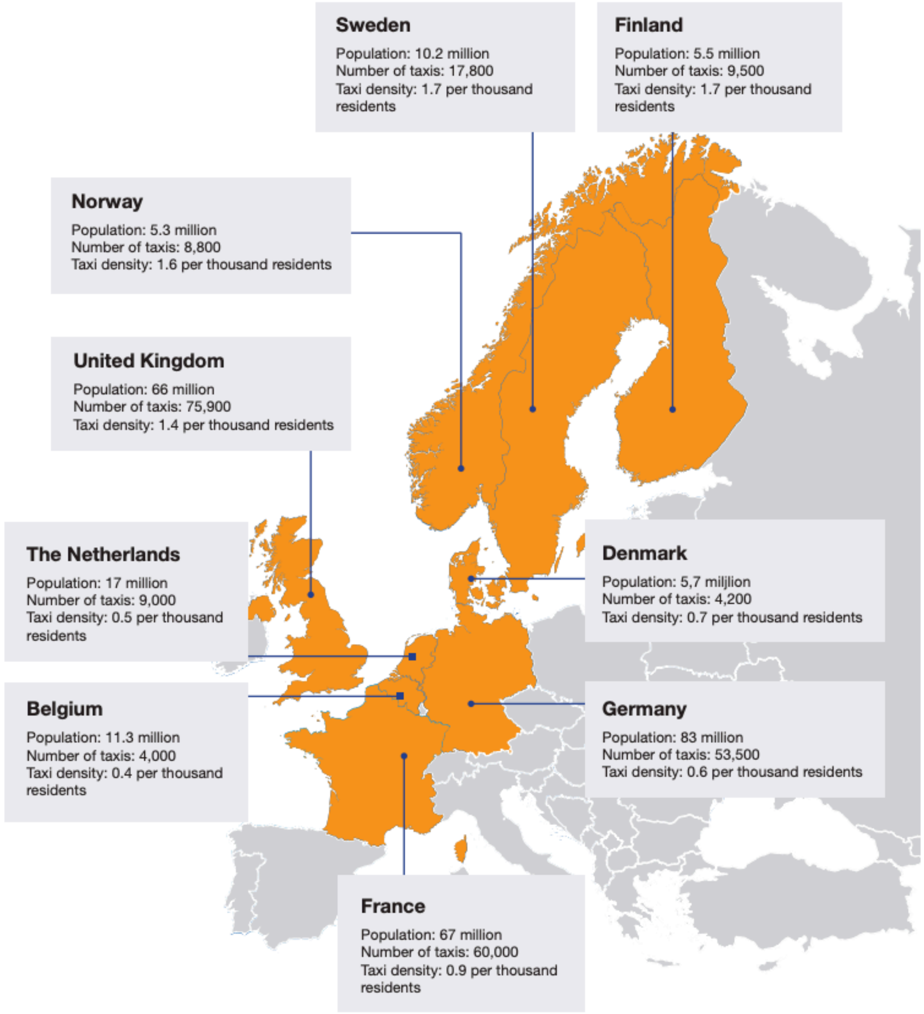
- Proximity and accessibility of greenspace affects the overall levels of physical activity
- Greenspaces reduce the heat island effect
- Being able to view greenspaces seems to have positive effects in stress reduction

" [24]

"The […] converge to indicate that different everyday outdoor environments can have quite different influences on stress recovery. […] recuperation was faster and more complete when subjects were exposed to the natural settings rather than the various urban environments. " [25]

[24] [25]

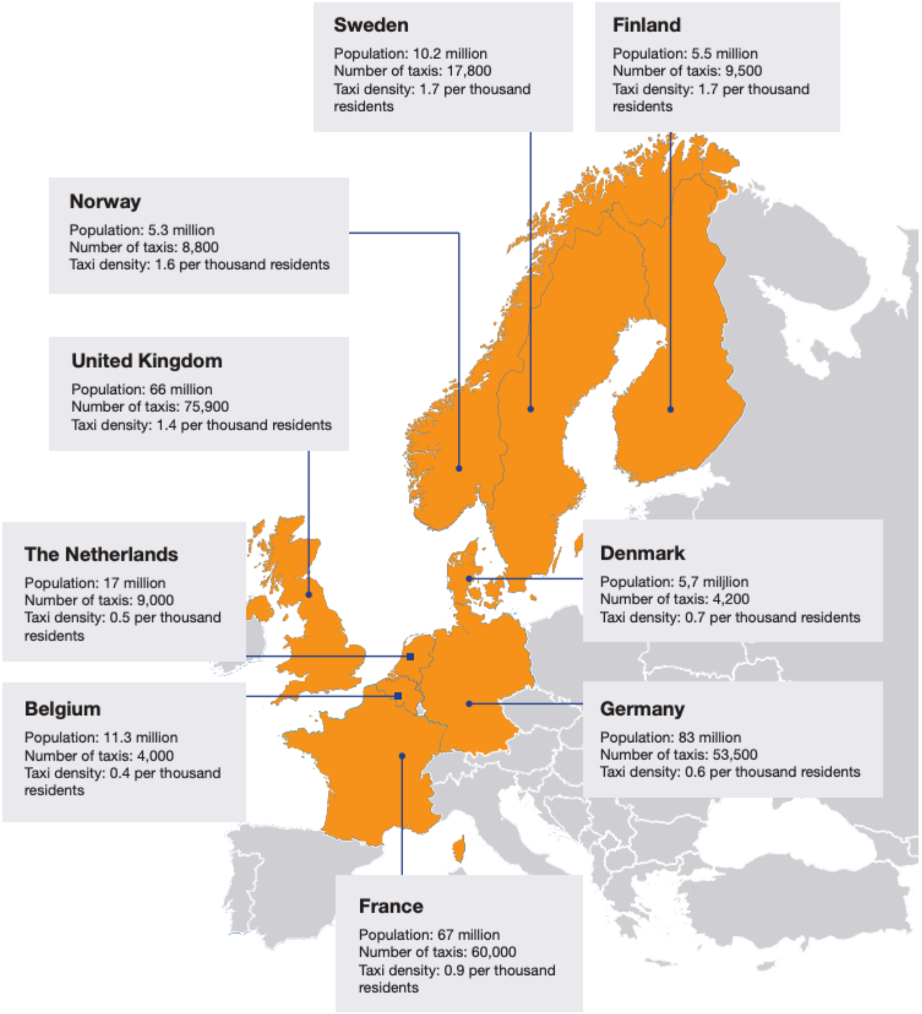
Job losses



Number of taxis across europe [26]

[26] [27]

Job losses



Number of taxis across europe [26]

"Heavy truck driving is a major employment occupation in the US and Europe. In Europe around **3.2 million** were employed as heavy truck drivers in 2015, which represents 1.5% of the employed population
In the US around **2.4 million** people or 1.7% of the employed population are estimated to drive heavy trucks." [27]

[26] [27]

Much more…

- Additional electronics and sensors in AVs
- Additional infrastructure for redundancy and communication
- How many servers and data processing is needed for the cooperative algorithms
- If everyone can drive anywhere, how does this increase in leasure and tourism impact the environment?
- Who owns the AVs? How does this monopoly care about the environment?
- Does every social class have fair access to AVs?

Conclusion

“which will lead to a rebound effect that is difficult to estimate” [16]

[16]

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Extra slides

Efficient driving

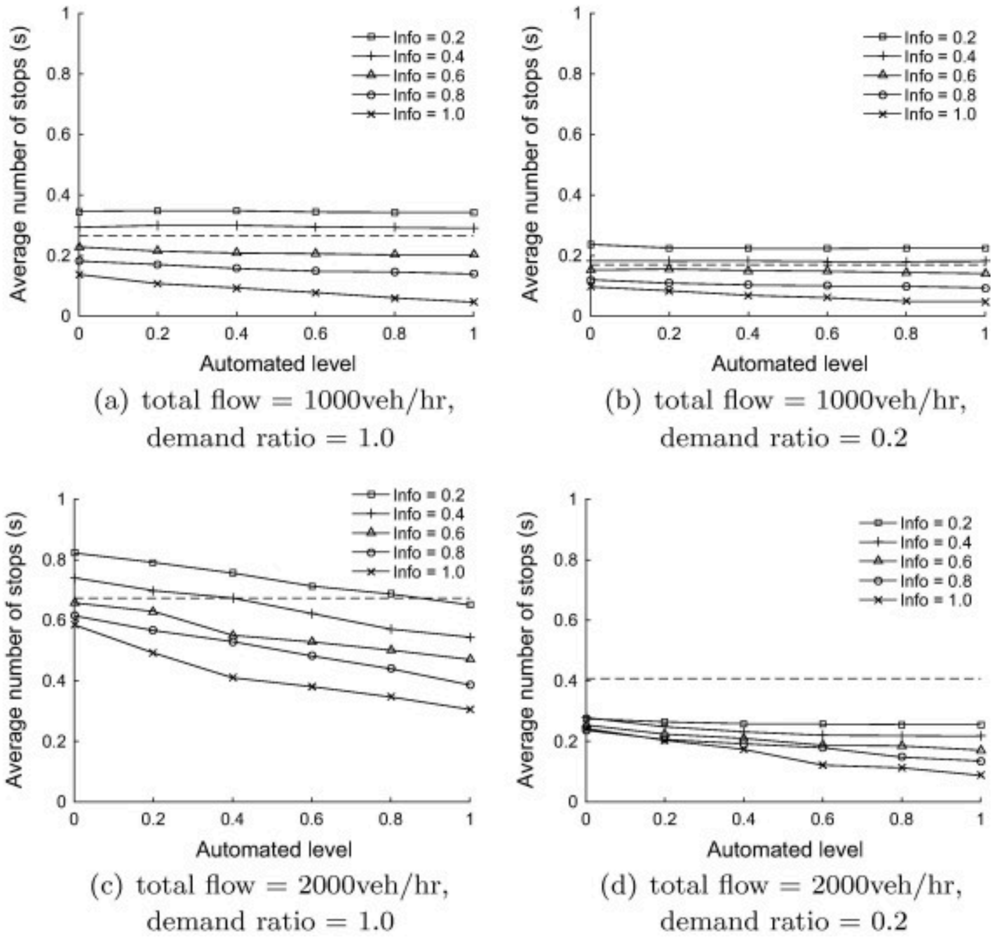
AVs as individual agents are not enough to achieve such *futuristic* scenarios. The vehicles have to communicate and coordinate as we assumed at the beginning. [10] worked on an algorithm for efficient intersections and simulate it for different vehicle flows and information levels

EI: -25% UI: 0 FI: 0 [1] [10]

Efficient driving

AVs as individual agents are not enough to achieve such *futuristic* scenarios. The vehicles have to communicate and coordinate as we assumed at the beginning. [10] worked on an algorithm for efficient intersections and simulate it for different vehicle flows and information levels

Number of stops for different flows, demand rations, autpmation level, and information sharings. AVs are not enough, we need coordination to increase efficiency. Lower is better [10]



(a) total flow = 1000veh/hr, demand ratio = 1.0

(b) total flow = 1000veh/hr, demand ratio = 0.2

(c) total flow = 2000veh/hr, demand ratio = 1.0

(d) total flow = 2000veh/hr, demand ratio = 0.2

EI: -25% UI: 0 FI: 0

[1] [10]

Counter urbanization

People probably tend to driver longer distances. What if people move out of cities?

Change of land due to urbanisation affects risk of flooding. Removal of soil and vegetation, filling the soil with concrete and channeling all the water into nearby rivers by drainage networks means that

1) The volume
2) The frequency
3) The peak discharge

in floods increases [22]

Counter urbanization

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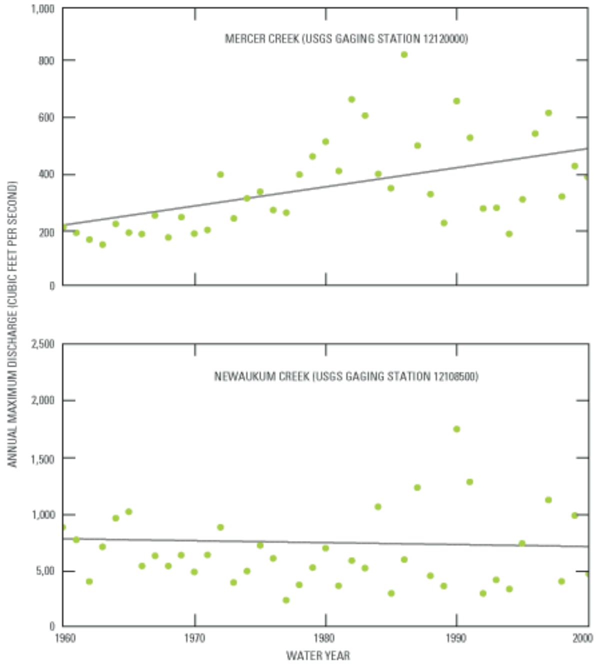
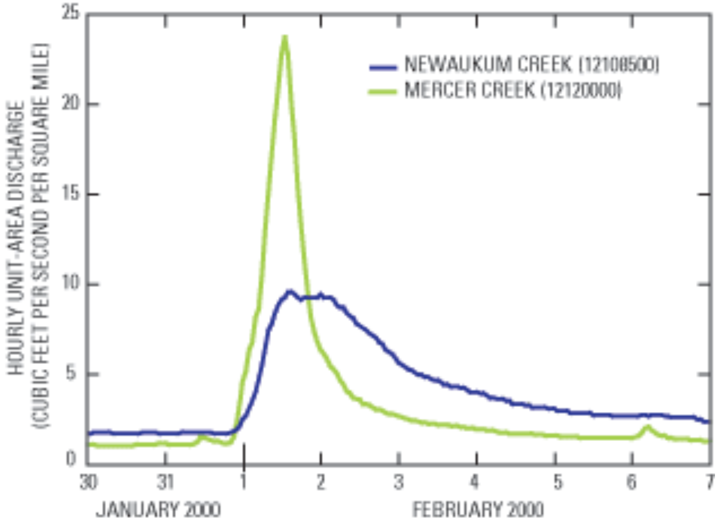
Annual maximal discharge



Year

Comparison of annual maximal discharge for two nearby rivers. One is affected by urbanization, the other not [22]

Hourly unit area discharge



Comparison of hourny discharge for two nearby rivers in the US. One is affected by urbanizatoin, the other not [22]

[22]