The End of Traffic and the Future of Access

David Levinson
University of Sydney
Transport Lab
In most industrialized countries, car travel per person has peaked and the automobile regime is showing considerable signs of instability. As cities across the globe venture to find the best ways to allow people to get around amidst technological and other changes, many forces are taking hold — all of which suggest a new transport landscape. Our roadmap describes why this landscape is taking shape and prescribes policies informed by contextual awareness, clear thinking, and flexibility.

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16. Redeeming Transport

The End of Traffic and the Future of Access
A Roadmap to the New Transport Landscape

David M. Levinson  •  Kevin J. Krizek
Transport in Flux
Transport is changing rapidly
“Triple Convergence”

Electrification

Automation

Sharing
Implications

Electrification
Automation
Sharing

Demassification
Delivery
Road Allocation
Land Use
Pricing
Energy Forecasts
Each month, forecasters in The Wall Street Journal’s survey of economists have predicted that oil prices would climb. Each forecast is the average of responses to that month’s survey.

Gusher of Disappointment: Each month forecasters in the Wall Street Journal’s survey of economists have predicted that oil prices would climb. Each forecast is the average of responses to that month’s survey.
Evolution of Brent Oil Price Forecasts
(US$ per barrel)

Note: Each line represents the spot price, the 3 month forecast and the 12 month forecast as available on the survey date indicated in the legend.
Source: Consensus Economics
“The energy world is undergoing massive transformation. Installations of renewable energy have skyrocketed around the world, exceeding most predictions from less than a decade ago.” Source:
Annual PV additions: historic data vs IEA WEO predictions
In GW of added capacity per year - source International Energy Agency - World Energy Outlook

Please send comments to:
a.e.hoekstra@tue.nl
@aukehoekstra
FIGURE 9. LEVELISED COST OF ELECTRICITY FROM SELECTED RENEWABLE ENERGY SOURCES, Q3 2009 TO H2 2016, $ PER MWH

Solar thermal is parabolic trough with storage, PV is crystalline silicon with no tracking
Source: Bloomberg New Energy financea
Summary Findings of Lazard’s 2017 Levelized Cost of Energy Analysis

Selected Historical Mean LCOE Values

Source: Lazard estimates.

Note: Reflects average of unsubsidized high and low LCOE range for given version of LCOE study.

(1) Primarily relates to North American alternative energy landscape, but reflects broader/global cost declines.

(2) Reflects total decrease in mean LCOE since the later of Lazard’s LCOE—Version 3.0 or the first year Lazard has tracked the relevant technology.

(3) Reflects mean of fixed-tall (high end) and single-axis tracking (low end) crystalline PV installations.
Figure 2: Monthly installations, installed solar PV capacity and average system size Jan 2012 – 2018

Source: Clean Energy Regulator (adjusted data), Australian Energy Council analysis, January 2019

Figure 7: Estimated residential PV generation (GWh)

Source: Australian Energy Council analysis, January 2019

Lithium-ion battery price survey results: volume-weighted average

Battery pack price (real 2018 $/kWh)

Source: BloombergNEF

https://www.livewiremarkets.com/wires/part-1-ev-battery-price-falls-expect-pace-to-slow
Lithium-ion battery price survey results: battery pack price (real 2018 kWh/$)

Reciprocal of Data on Previous Slide
Constraints on further battery cost drops

1. “The raw material cost component now makes up 70% of the cost of battery cells, leaving less remaining room for cost reductions. …

2. The vast majority of the battery cost reductions have come from producing batteries in greater volumes and achieving cost efficiencies from scale. …

3. In a bid to secure their position in a rapidly growing market, battery makers have discounted on pricing to lock in contracts with automakers in recent years. …”

— Clement Tseung, Investment Analyst, PM Capital

https://www.livewiremarkets.com/wires/part-i-ev-battery-price-falls-expect-pace-to-slow
BNEF forecasts lithium-ion battery pack prices will fall to as little as $73/kWh

- Intense price competition is leading manufacturers to develop new chemistries and improved processes to reduce production costs.
- Production costs have also come down significantly. Our models calculate that producing a battery in a Korean manufacturing plant in 2017 costs $162/kWh, dropping to $74/kWh in 2030.
- The BNEF battery price survey provides an annual industry average battery price for EVs and stationary storage. The learning rate (the price decrease for every doubling of capacity) is 19%.
Figure 1: Total cost of bus ownership comparison with different annual distance

$ per kilometer

Small city annual mileage
Medium city annual mileage
Large city annual mileage

90km/day - 110kWh e-bus range
200km/day - 250kWh e-bus range
300km/day - 350kWh e-bus range

TCO diesel bus
110 kWh e-bus, wireless charging
110 kWh e-bus, slow depot charging
350 kWh e-bus, slow depot charging
250 kWh e-bus, slow depot charging

Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit Notes: Diesel price at $0.66/liter ($2.5/gallon), electricity price at $0.10/kWh, annual kilometers traveled – variable. Bus route length will not always correspond with city size.
Crossover Point: ICE vs. EV

- “In 2017, a BloombergNEF analysis forecast that the crossover point was in 2026, nine years out.

- In 2018, the crossover point was in 2024 — six years (or, as I described it then, two lease cycles) out.

- The crossover point, per the latest analysis, is now 2022 for large vehicles in the European Union”
The Incredible Shrinking Car Battery
EV battery cost for U.S. medium-size car as a percentage of retail price

Source: BloombergNEF
Note: Includes profit margins and costs other than direct manufacturing costs.

Charging

Full Charging Network - 500+ Destination Chargers [Dark Grey]. Source: Tesla
Dynamic Wireless Power Transfer

EV Sales
Figure 3: Cumulative global passenger EV sales, current and forecast

Million vehicles

Source: Bloomberg NEF
Norwegian Electric Vehicle New Car Market Share

Source: https://en.wikipedia.org/wiki/Plug-in_electric_vehicles_in_Norway
UK Plug In Vehicles Sales % of New Vehicle Sales

0% to 1% took 36 months
1% to 2% took 33 months
2% to 3% took 6 months

Source: https://www.smmt.co.uk/category/registrations/evs-ofvs/
Assumes: 0% Jan 2011 - there were just a few G-Wizz around then ;}
Our New EV Forecasts
EV Sales by Country (EV+PHEV)

- China
- United States
- Norway
- Germany
- Japan
- United Kingdom
- France
- Netherlands
- Sweden
- Canada
- Korea
- Portugal
- Finland
- New Zealand

IEA: Global EV Outlook 2019Table A.4.
|                  | Estimate | Std. Error | t value | Pr(>|t|) |
|------------------|----------|------------|---------|----------|
| (Intercept)      | 1.73e+00 | 2.20e+00   | 7.89e+01| 4.33e-01 |
| [ln(pre.share)]  | 5.14e-01 | 6.45e-02   | 7.97e+00| 1.28e-11 |
| [EV.price]       | -1.50e-04| 5.81e-05   | -2.59e+00| 1.16e-02 |
| [EV.range]       | 2.19e-02 | 5.25e-03   | 4.17e+00| 8.04e-05 |
| [norway]         | 1.84e+00 | 2.71e-01   | 6.77e+00| 2.36e-09 |
| [australia]      | -7.36e-01| 2.46e-01   | -3.00e+00| 3.69e-03 |
| [sweden]         | 7.50e-01 | 2.03e-01   | 3.70e+00| 4.05e-04 |
| [us]             | 1.95e-01 | 2.11e-01   | 9.22e-01| 3.59e-01 |
| [france]         | 2.36e-01 | 1.96e-01   | 1.21e+00| 2.32e-01 |
| [finland]        | 2.43e-01 | 2.04e-01   | 1.19e+00| 2.39e-01 |
| [netherlands]    | 1.06e+00 | 2.32e-01   | 4.56e+00| 1.92e-05 |

Adjusted R-squared: 0.9128
S-Curve of Predicted Market Share

- Norway
- Netherlands
- Sweden
- US
- Japan
- Australia
2020 Superbowl Featured 4 Electric Vehicle Ads

Porsche Taycan

HUMMER EV

THE FUTURE OF EXHILARATION. Welcome to the Stable: All-Electric Mustang Mach-E

Audi e-tron SUV
# Autonomous Autos

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Name</th>
<th>Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes [Geofenced]</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>
Level 0, No Automation  
Level 1, Driver Assistance

Level 2, Partial Automation  
(e.g. adaptive cruise control)
Level 3, Conditional Automation

Level 4, High Automation  
(Self-Driving)
Level 5, Full Automation (Driverless)  
(And may have no passengers)
Benefits and Consequences
Benefits and Consequences

- Safety
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences

- Costs
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Benefits and Consequences
Cumulative km traveled in Autonomous Mode by Google/Waymo Self-Driving Car and Tesla Auto-Pilot

- **Cumulative km Traveled Autonomously (L4) (Waymo)**
- **Cumulative km Traveled with AutoPilot (L2) (Tesla)**
9,000,000+
MILES AND COUNTING
Forecast of Annual Miles Traveled by Autonomous Vehicles Nationally (~2032 is year of 50% total distance driven autonomously)
Forecast of Annual Miles Traveled by Autonomous Vehicles Nationally (~2032 is year of 50% total distance driven autonomously)
Level 2, 2.5 Now (Tesla Auto-Pilot, etc.)
• Level 2, 2.5 Now (Tesla Auto-Pilot, etc.)

• Level 3 ("limited self-driving automation") autonomous vehicles will be on the market by 2020.
  
  • Cadillac SuperCruise 2017

• Level 4 will be available in 2025 and required in new US cars by 2030, and required for all cars by 2040.

• In other words, human driven vehicles will eventually be prohibited on public roads (aside from special events).
New Activities in Motion

New activities becoming possible after self-driving cars (minutes)

- Eating and drinking: 66.6522 minutes
- Tobacco and drug use: 0.3672 minutes
- Participation in religious practices: 2.5532 minutes
- Child care: 3.155 minutes
- Personal care: 46.0118 minutes

Fan (2016)
New Activities in Motion

- A limited set of personal care activity including dressing & grooming, health-related self care, personal/private activities;

![Chart showing new activities becoming possible after self-driving cars](chart.png)
New Activities in Motion
New Activities in Motion
New Activities in Motion
New Activities in Motion

- A limited set of personal care activity including dressing & grooming, health-related self care, personal/private activities;
- A limited set of child care activities including reading to/with children, home schooling, and arts and crafts with children;
- Eating and drinking;
- Tobacco and drug use; and
- Participation in religious practices.

New activities becoming possible after self-driving cars (minutes)

- Eating and drinking: 66.6522
- Tobacco and drug use: 0.3672
- Participation in religious practices: 2.5532
- Child care: 3.155
- Personal care: 46.0118

Fan (2016)
Impacts: Longer trip distances & durations

Mokhtarian and Salomon (2001): Excess travel is more likely to occur as people increase the perceived positive utility of activities
Connectivity
Types of Connectivity
Types of Connectivity

- Vehicle Condition (On-Star)
Types of Connectivity
Types of Connectivity
Types of Connectivity
Types of Connectivity

• Road Condition Information (Ice Patch)
Types of Connectivity
Types of Connectivity
Types of Connectivity
Types of Connectivity
Types of Connectivity
Comparing Nice Ride’s service area in 2010, the first year of operation, and 2014, the most recent year of operation.
Figure 8.3 Growth of Bike Sharing Systems Globally

Figure 8.2 North American Carsharing Growth

Source: Shaheen and Cohen (2015)
NYC Monthly Taxi Pickups
Trailing 28 days

Ride-hailing apps include Uber, Lyft, Juno, Via, and Gett; taxis include yellow and green.

Data via NYC TLC
toddschneider.com
Figure: Lyft’s Rides Per Year (estimated)
Cloud Commuting
Cloud Commuting

- Fleet (Taxi / Uber / ‘Ride-sharing’ / ‘Ride-hailing’ Model) (vs. Individual) Ownership
Cloud Commuting
Cloud Commuting
Cloud Commuting
Cloud Commuting
Cloud Commuting

- electrified so lowered vehicle capital and maintenance costs
Cloud Commuting
Cloud Commuting
Cloud Commuting
Cloud Commuting
A Cambrian Explosion of Vehicle Forms

“Google Car”
Shape-Sifting

MIT “Stackable City Car” Concept
Smaller
Smaller

Toyota iRoad
Smaller

GM Lean Machine

Toyota iRoad
Smaller

Toyota iRoad

GM Lean Machine

Gogoro
And Bigger

“Toyota Swagger”
with Fewer Wheels?
<table>
<thead>
<tr>
<th>Exclusive Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared (Two-to-One) Lane</td>
</tr>
<tr>
<td>Shared (One-to-One) Lane</td>
</tr>
</tbody>
</table>

Alternative Vehicles, Alternative Highways
Delivery
Last Mile

Parcel Lockers
24/7

your parcel

Robot delivery vehicle

Man loading package into car
Up and Out
SAEVs vs. PAEVs
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)

Some deadheading (driverless/passengerless to find next passenger)
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)

Some deadheading (driverless/passengerless to find next passenger)

Less parking
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

- Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)
- Some deadheading (driverless/passengerless to find next passenger)
- Less parking

Private (Personal) Autonomous Electric Vehicles
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)

Some deadheading (driverless/pasengerless to find next passenger)

Less parking

Private (Personal) Autonomous Electric Vehicles

Increased per capita vehicle travel (lower per trip cost, high Fixed, low Variable cost)
SAEVs vs. PAEVs

Shared Autonomous Electric Vehicles

- Reduced per capita vehicle travel (higher per trip cost - no Fixed, high Variable cost)
- Some deadheading (driverless/passengerless to find next passenger)
- Less parking

Private (Personal) Autonomous Electric Vehicles

- Increased per capita vehicle travel (lower per trip cost, high Fixed, low Variable cost)
- Some deadheading (driverless/passengerless to find parking)
Land Use Consequences
(MaaS + AVs)

Up and Out: The Future of Travel Demand and Where We Live
Figure 10.1: The future of transport demand

Demand Curve

Generalized Cost of Transport

Road pricing
Parking pricing
Capacity reduction

Restrictive licensing
US demographic mix
At-home work
Flex scheduling
Tele shopping / Delivery
Dematerialization
Social networks
Better transit, walk, bike

Higher income

Automation
Exurbanization

Population growth

Lower income

Capacity expansion
Energy price reduction
Future EVs

Mobility-as-a-Service
Urbanization
• **Up**: Less vehicle ownership with increased use of MaaS in cities, raising the value of cities.
Up
Up
Up
Up
• The greater value in cities with the new more convenient technology leads to more and taller development. (Hence the use of the word “Up”.)
Out

- **Out**: More vehicle travel with increased exurbanization.
Out

- People will live farther “Out”.
Adapting the Built Environment
Space Now Devoted to Car Storage can be Repurposed
Space Now Devoted to Refueling can be Repurposed
Excess Space Now Devoted to Movement can be Repurposed
Reduce, Reuse, (re)Cycle
Reduce, Reuse, Bicycle

• Most roads are under-used most of the time. There is ample capacity outside the peak.

• Most of the pavement is unused even at peak times; there are large gaps between vehicles both in terms of the headway between vehicles and the lateral spacing between vehicles. Americans drive 6 foot wide cars in 12 foot lanes, often on highways with wide shoulders.

• Most seats in most cars are unoccupied most of the time.

• Most cars contain far more weight than required to safely move the passenger. While bigger cars might be safer for the occupants, they are less safe for non-occupants. This is an inefficient arms race.

• Many roads are so wide we use them for storage of vehicles most of the day.

• There is excessive delay at traffic lights, especially during off-peak periods, wasting time and space.
Dimensions

- Vehicle width/ Lane width
- Vehicle weight
- Vehicle occupancy
- Traffic signals and stop signs

Figure 12.1 Narrowly marked street lane in Palermo, Italy.
Right-sizing Roads

- Five stages of repurposing. A Kübler-Ross model of grief felt by the motorist at the forthcoming loss of automobile roadspace for cycling facilities.

  - **STAGE 1: DENIAL** applies to most communities across the US, whose residents refuse to acknowledge that street space will be or needs to be changing. Examples: Anytown, USA.

  - **STAGE 2: ANGER** is exemplified by the so-called “War on Bikes” and “War on Cars” that are riveting cities trying to make modest changes, like replacing parking with bike lanes or designating ‘bicycle boulevards’. Examples: New York, Washington DC, Toronto.

  - **STAGE 3: BARGAINING** refers to desire to re-design select areas to reduce auto presence. Examples: St. Paul, Minnesota.

  - **STAGE 4: DEPRESSION** builds on Bargaining as the perceived losers in the War on Cars (drivers) stop fighting the extension of non-auto infrastructure into full corridors. Examples: Minneapolis, Minnesota.

  - **STAGE 5: ACCEPTANCE** means community-wide consensus to reduce auto space by removing on-street parking overall, installing parking in former vehicular lanes, or any of a series of other treatments (e.g., buffered bicycle lanes, bulb-outs). Examples: Davis, California and Portland, Oregon.

Figure 12.2. Installation of the street repurposing project in Boulder
Reuse

- Plastics
- Paint
- Plasticity
Bicycle
Electrification Vicious Cycle

Gas Tax per Gallon

Total Cars Paying Fuel Tax
All congestion is unnecessary: Accelerating the end of traffic via pricing

- Fuel Tax
- Implementing Road Pricing One Electric Vehicle at a Time
- Networks of HOT Lanes
- Reservation Pricing
- Roads as a Public Utility
The fuel tax does not

- account for cost inflation in the road sector. *(Unless indexed)*
- account for rising fuel efficiency.
- pay for local roads.
- pay for pollution.
- pay for crashes, which are borne individually through worsened health and life outcomes, and socially through the health care system. *(Pay as you go insurance does this, and is related to fuel tax in some places)*
- raise revenue from vehicles that do not use gasoline for fuel.
- recover pavement damage from heavy vehicles. *(NZ does this though)*
- address congestion, which requires time of day differentiation. Traffic congestion is a problem. It is not getting measurably worse over the past two decades, but it is not getting obviously better.
How to get to a replacement?

- EVs don’t pay fuel tax, yet use roads.

- AVs may pay fuel tax, but don’t pay driver’s time, and may be person-less when traveling.

- Retaining the highway user fee principle requires charging AVs and EVs once a sufficient number make it relevant.

- Vary vehicle mileage charge for EVs and AVs and opt-ins (and eventually all vehicles) by location and time-of-day.
Redeeming Transport

• How can we still get the gains of auto-mobility without the costs?

• Change from outside rather than inside (DOT follows, does not lead)
Policy Implication:

- Increased throughput per square meter of pavement (along with flattened demand) indicates fewer square meters of pavement are required.
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¿Questions?