Sustainable Transportation Energy Pathways (STEPS)

Costs and Travel Choices in a 3R World

IEA Modeling Disruptions in Mobility Workshop

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2017 STEPS RESEARCH INSIGHTS: Three Revolutions in Urban Transportation (Fulton, Mason, Meroux)

- Automation without electrification and shared mobility saves little energy or CO2
- Automation and electrification can cut CO2 but may still increase traffic
- 3 Revolutions, including more shared trips, active travel, transit use can save the most CO2 and would be the least expensive transportation system – but requires strong policies to achieve.

![Diagram of Passenger Kms of LDV Travel](chart)

### Three Revolutions in Urban TRANSPORTATION

- Automation
- Electrification
- Shared Mobility

Lew Fulton, UC Davis
Jacob Mason, ITDP
Dominique Meroux, UC Davis

May 2017

Research supported by:
ClimateWorks Foundation, William and Flora Hewlett Foundation, Barr Foundation
• 49% to 61% of ride-hailing trips in major U.S. metro areas would have not been made at all, or by walking, biking, or transit.

• Ride-hailing attracts Americans away from bus services (a 6% reduction) and light rail services (a 3% reduction).

• Ride-hailing serves as a complementary mode for commuter rail services (a 3% net increase in use).

• Directionally, we conclude that ride-hailing is currently likely to contribute to growth in vehicle miles traveled (VMT).

Supportive Policies – critical to success of the scenarios

- **3R Scenario (Automation + Electrification + **Sharing**):**
  - Compact Urban Development policies
  - Efficient parking policies
  - Heavy investment in transit/walking/cycling
  - VKT fees (incl. congestion & emission factors):
# The wide range of costs related to mobility choices

<table>
<thead>
<tr>
<th>Out-of-pocket Costs</th>
<th>Hedonic costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle purchase</td>
<td>Travel time (driving)</td>
</tr>
<tr>
<td>Vehicle maintenance</td>
<td>Travel time (passenger)</td>
</tr>
<tr>
<td>Fuel</td>
<td>Parking search time</td>
</tr>
<tr>
<td>Insurance</td>
<td>Walking time</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Driving stress</td>
</tr>
<tr>
<td>Parking</td>
<td>Shared trips (e.g. lack of privacy)</td>
</tr>
<tr>
<td>Driver</td>
<td>EV range, charging anxiety</td>
</tr>
<tr>
<td>MaaS fees</td>
<td>Car ownership negatives (maintenance, registration, inspections etc.)</td>
</tr>
<tr>
<td>Tolls</td>
<td>Car ownership positives (car pride, guaranteed ride; can leave personal belongings in the car)</td>
</tr>
<tr>
<td>Registration-related fees</td>
<td>Perceived Environmental Cost</td>
</tr>
</tbody>
</table>

**Out-of-pocket Costs**
- Vehicle purchase
- Vehicle maintenance
- Fuel
- Insurance
- Cleaning
- Parking
- Driver
- MaaS fees
- Tolls
- Registration-related fees

**Hedonic costs**
- Travel time (driving)
- Travel time (passenger)
- Parking search time
- Walking time
- Driving stress
- Shared trips (e.g. lack of privacy)
- EV range, charging anxiety
- Car ownership negatives (maintenance, registration, inspections etc.)
- Car ownership positives (car pride, guaranteed ride; can leave personal belongings in the car)
- Perceived Environmental Cost
Out-of-pocket costs: Comparison of modes

- **Driven TNC vehicles are premium service, automation makes these competitive**

![Bar chart showing comparison of costs for different modes in 2025 for midsize vehicles](chart.png)

- Private ICE
- Private EV
- Private EV/AV
- MaaS ICE
- MaaS EV
- MaaS EV/AV
- MaaS EV/AV Pooled

- **Cost Components**
  - MaaS fees
  - Driver cost
  - Vehicle cleaning
  - Vehicle parking
  - Vehicle maintenance
  - Vehicle insurance
  - Fuel cost
  - Amortized purchase cost
Added a value of time for driving, travelling, parking

- **Time costs are equal to or in some cases far greater than the out-of-pocket costs**

![Bar chart showing costs for different vehicle types in 2025 for midsize vehicles.](chart.png)
Included only variable costs (daily decision)

- Ignore private car purchase, insurance cost
- The AV/EV private car becomes cheaper than shared mobility
Costs of Mobility…

• Still trying to get a handle on monetary costs of different modes
  – Wide range of fixed and variable costs
  – ICE vs electric and automated vehicles
  – Differences by trip type and location

• But at the same time, we have reason to believe that non-monetary costs are as important or potentially more important.
  – Even harder to quantify
  – But let’s try
### Considering these costs by when, and how often, paid

<table>
<thead>
<tr>
<th>Monetary</th>
<th>Separate from trip</th>
<th>Once per trip</th>
<th>Lumpy</th>
<th>Roughly per-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Insurance</td>
<td>• Parking cost</td>
<td>• Tolls</td>
<td>• Depreciation</td>
<td></td>
</tr>
<tr>
<td>• Registration and other annual or monthly fees</td>
<td>• TNC &quot;first mile&quot; fee</td>
<td>• Vehicle cleaning</td>
<td>• Maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fuel cost</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• TNC per-mile fees</td>
<td></td>
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<td></td>
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<td></td>
<td>• Per-mile road user fees (taxes)</td>
<td></td>
</tr>
<tr>
<td>Non-monetary</td>
<td>• Maintenance and inspections events (time, loss of vehicle use)</td>
<td>• Time spent cleaning time</td>
<td>• Travel time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Car ownership pride and other hedonic ownership benefits</td>
<td>• Recharging search, recharging time, anxiety</td>
<td>• Driving stress/enjoyment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Per-vehicle environmental impacts (vehicle production, disposal)</td>
<td>• Walking to/from vehicle to &quot;door“</td>
<td>• Ride sharing (pooling) stress/enjoyment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Loading/unloading vehicle</td>
<td>• Other in-ride hedonic factors</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>• In-ride productivity</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Per-mile environmental impacts (CO2, air pollutants)</td>
<td></td>
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</tbody>
</table>
## Important when in own vehicle *(positive/negative)*

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<tr>
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<tr>
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<td>• Maintenance and inspections events (time, loss of vehicle use)</td>
<td>• Time spent parking and searching for parking</td>
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<td>• Travel time</td>
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<td></td>
<td>• Other in-ride hedonic factors</td>
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<td></td>
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<td>• In-ride productivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Per-mile environmental impacts (CO2, air pollutants)</td>
</tr>
</tbody>
</table>

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_SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS_
### Important when Ride-hailing (positive/negative)

<table>
<thead>
<tr>
<th>Monetary</th>
<th>Separate from trip</th>
<th>Once per trip</th>
<th>Lumpy</th>
<th>Roughly per-mile</th>
</tr>
</thead>
</table>
| • Insurance  
  • Registration and other annual or monthly fees | • Parking cost  
  • TNC "first mile" fee | • Tolls  
  • Vehicle cleaning | • Depreciation  
  • Maintenance  
  • Fuel cost  
  • TNC per-mile fees  
  • Per-mile road user fees (taxes) |
| **Non-monetary** | • Maintenance and inspections events (time, loss of vehicle use)  
  • Car ownership pride and other hedonic ownership benefits  
  • Per-vehicle environmental impacts (vehicle production, disposal) | • Time spent parking and searching for parking  
  • Walking to/from vehicle to "door“  
  • Loading/unloading vehicle | • Refueling/cleaning time  
  • Recharging search, recharging time, anxiety  
  • Keeping items in vehicle | • Travel time  
  • Driving stress/enjoyment  
  • Ride sharing (pooling) stress/enjoyment  
  • Other in-ride hedonic factors  
  • In-ride productivity  
  • Per-mile environmental impacts (CO2, air pollutants) |
## Cost types where we have poor or no data

<table>
<thead>
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<th>Once per trip</th>
<th>Lumpy</th>
<th>Roughly per-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurance, Registration and other annual or monthly fees</td>
<td>Parking cost, TNC &quot;first mile&quot; fee</td>
<td>Tolls, Vehicle cleaning</td>
<td>Depreciation, Maintenance, Fuel cost, TNC per-mile fees, Per-mile road user fees (taxes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-monetary</td>
<td>Maintenance and inspections events (time, loss of vehicle use), Car ownership pride and other hedonic ownership benefits, Per-vehicle environmental impacts (vehicle production, disposal)</td>
<td>Time spent parking and searching for parking, Walking to/from vehicle to &quot;door&quot;, Loading/unloading vehicle, Refueling/cleaning time, Recharging search, recharging time, anxiety, Keeping items in vehicle</td>
<td>Travel time, Driving stress/enjoyment, Ride sharing (pooling) stress/enjoyment, Other in-ride hedonic factors, In-ride productivity, Per-mile environmental impacts (CO2, air pollutants)</td>
<td></td>
</tr>
</tbody>
</table>
Fixed, lumpy and per-mile costs – for those costs we have

- **Many costs are fixed or lumpy**
- **TNC fees and travel time dominate per-mile costs**

![Graph showing costs for different vehicle types and cost components](image)
Figure with only the trip fixed and per-mile costs shown

- **Private automated vehicle trips starting to look good, especially for shorter trips (this one is 6 miles, 30 mph)**

![Bar chart showing costs for different modes of transportation in 2025 for midsize vehicles. The chart breaks down costs into travel time, TNC per-mile cost, fuel cost, TNC base fare, parking/walking time, and vehicle parking cost. The chart compares private ICE, private EV, private EV/AV, TNC ICE, TNC EV, TNC EV Pooled, TNC EV/AV, and TNC EV/AV Pooled. Each bar is color-coded to represent the cost component.](chart.png)
Same scenario, but shown as total costs for a six mile trip

- Costs range from $2 to $12 per trip; driverless modes below $4
Data converted to per-trip costs for a 20 mile trip

- Fixed costs become less important for longer trips
And for a 2 mile trip

- Fixed costs start to dominate short trips

2025 - Midsize vehicle (total $ - 2 mile trip)

- Travel time cost per passenger
- TNC per-mile cost
- Fuel cost
- TNC base fare
- Parking/walking time
- Vehicle parking cost

<table>
<thead>
<tr>
<th>Mode</th>
<th>Travel time cost per passenger</th>
<th>TNC per-mile cost</th>
<th>Fuel cost</th>
<th>TNC base fare</th>
<th>Parking/walking time</th>
<th>Vehicle parking cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private ICE</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>Private EV</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>Private EV/AV</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>TNC ICE</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>TNC EV</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>TNC EV Pooled</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
<tr>
<td>TNC EV/AV Pooled</td>
<td>$0</td>
<td>$1</td>
<td>$2</td>
<td>$3</td>
<td>$4</td>
<td>$5</td>
</tr>
</tbody>
</table>
What about other non-monetary costs?

- We need to do much in-depth survey work, and maybe experiments to judge behavior in different situations.
- Some aspects will be difficult to assess until situations change:
  - Driverless vehicles:
    - Attitudes about travel, effective time cost penalties
    - Changes in total travel
  - EVs: recharging anxiety in an age of fast charging, abundant charging
  - Shared mobility: attitudes about pooling with no driver
A couple of thought experiments (don’t try this at home)

• **Value of being able to store things in the vehicle**
  - If it takes 2 minutes (twice) to load/unload things like car seats and generally get all your stuff in and out of your car every trip, and it’s an unwelcome hassle, this might be valued $15k/hour. That’s a $1 hedonic cost per trip \((4/60 \times 15)\). For a 6 mile trip, that’s **$0.17 per mile**

• **Cost of an uncertain ride**
  - A “certain” ride means there is a car in a known location and you have the keys. There may be a cost to any uncertainty about available commercial rides, as well as time variance.
  - If one expects to ride hail with vehicle arrival in, say, 5 minutes there might be a hedonic cost if it arrives later than this. Each additional minute might cost \(1/60 \times 15/hr\). This cost may also rise per minute, as frustration (or lateness) mounts. A vehicle that is 4 minutes late would incur a $1 hedonic cost; if it happens (or is expected to happen) every 4^{th} trip, this amounts to an average of about **$0.04 per mile** for a 6 mile trip
Simple $15/hour time cost analysis across activities (Example of a 6 mile, 12 minute trip, 30 miles per hour)

- A few activities stand out as possibly “expensive”

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (mins)</th>
<th>$ / hour</th>
<th>$ / event</th>
<th>Events / trip</th>
<th>$ / trip</th>
<th>$ / mile</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading / unloading</td>
<td>4</td>
<td>15</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td>0.08</td>
<td>2 minutes twice per trip</td>
</tr>
<tr>
<td>Uncertain ride</td>
<td>5</td>
<td>15</td>
<td>1.25</td>
<td>0.25</td>
<td>0.31</td>
<td>0.05</td>
<td>5 minutes wait time, 1/4 of trips</td>
</tr>
<tr>
<td>Maintenance events</td>
<td>30</td>
<td>15</td>
<td>7.50</td>
<td>0.01</td>
<td>0.08</td>
<td>0.01</td>
<td>20 minutes for dropoff, 10 for pickup</td>
</tr>
<tr>
<td>Parking / searching</td>
<td>5</td>
<td>15</td>
<td>1.25</td>
<td>1.00</td>
<td>1.25</td>
<td>0.21</td>
<td>5 mins for parking search and parking, once per trip</td>
</tr>
<tr>
<td>Walking to / from car</td>
<td>3</td>
<td>15</td>
<td>0.75</td>
<td>2.00</td>
<td>1.50</td>
<td>0.25</td>
<td>3 minutes twice per trip (short walks, one could be driveway)</td>
</tr>
<tr>
<td>Refueling / cleaning time</td>
<td>5</td>
<td>15</td>
<td>1.25</td>
<td>0.10</td>
<td>0.13</td>
<td>0.02</td>
<td>Assumes one refueling per 10 trips</td>
</tr>
<tr>
<td>Public recharging search time, anxiety</td>
<td>5</td>
<td>20</td>
<td>1.67</td>
<td>0.20</td>
<td>0.33</td>
<td>0.06</td>
<td>Search time at higher per-hour cost</td>
</tr>
<tr>
<td>Driving</td>
<td>12</td>
<td>15</td>
<td>3.00</td>
<td>1.00</td>
<td>3.00</td>
<td>0.50</td>
<td>General travel time cost</td>
</tr>
<tr>
<td>Driving stress</td>
<td>12</td>
<td>5</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.08</td>
<td>Additional time cost due to stressful driving</td>
</tr>
</tbody>
</table>
Back to our 6 mile trip

- Costs range from $2 to $12 per trip; driverless modes below $4
6 mile trip, now with the additional categories

- The new categories, together, don’t change things much
Conclusions

• Non-market cost factors are many, varied and difficult to measure

• My very simplistic first cut suggests that some may be relatively unimportant, *on average*
  – May still be critical in certain situations, or for certain people

• More research is needed, such as focus groups and surveys
Thank you

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