Energy and Environmental Impacts of Automated Vehicles: Framework and Preliminary Results

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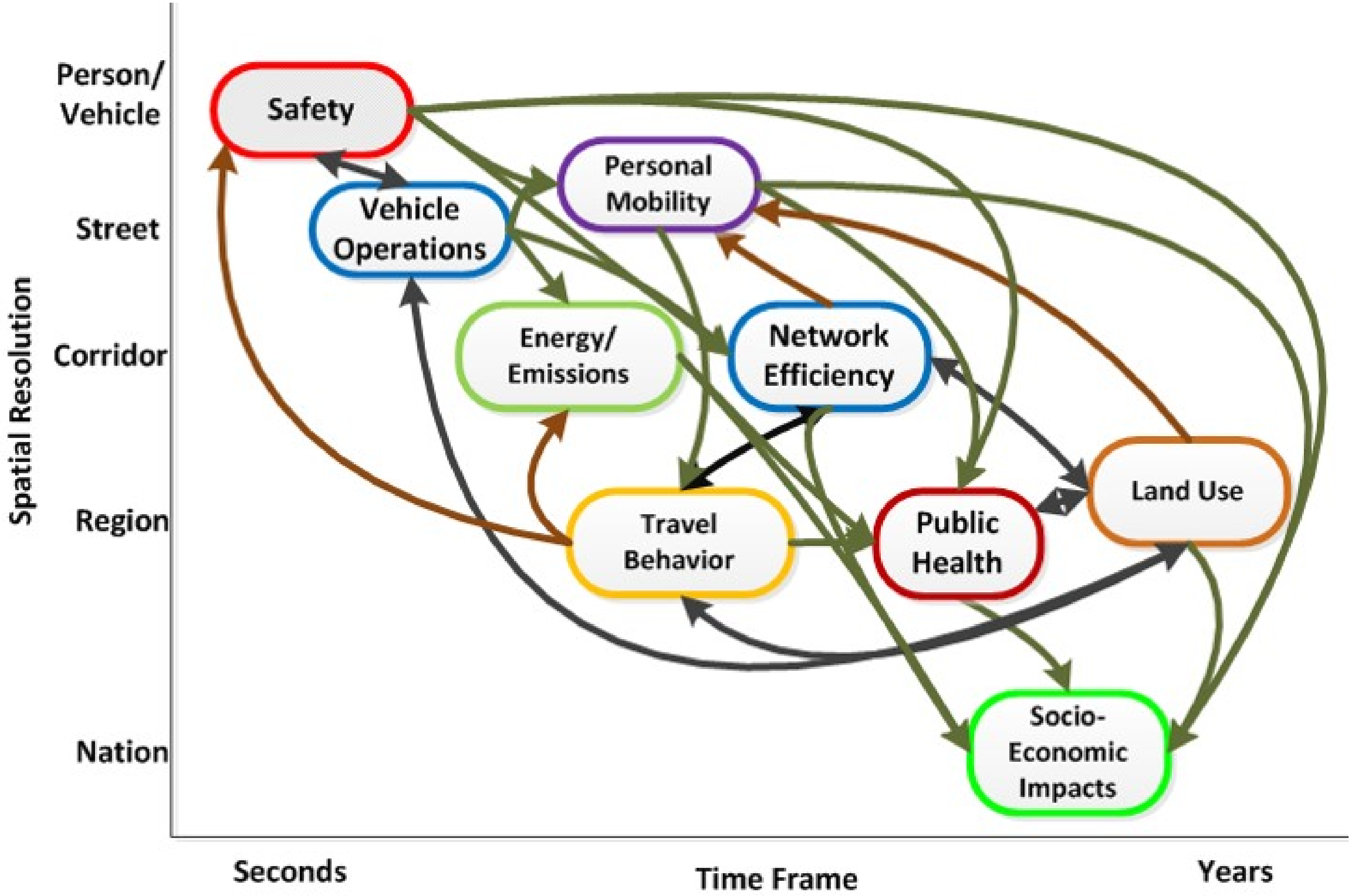
Automated vehicle impacts

- “Big picture” of automation impacts
- Direct and Indirect
- A framework breaks a complex problem into (somewhat) manageable pieces



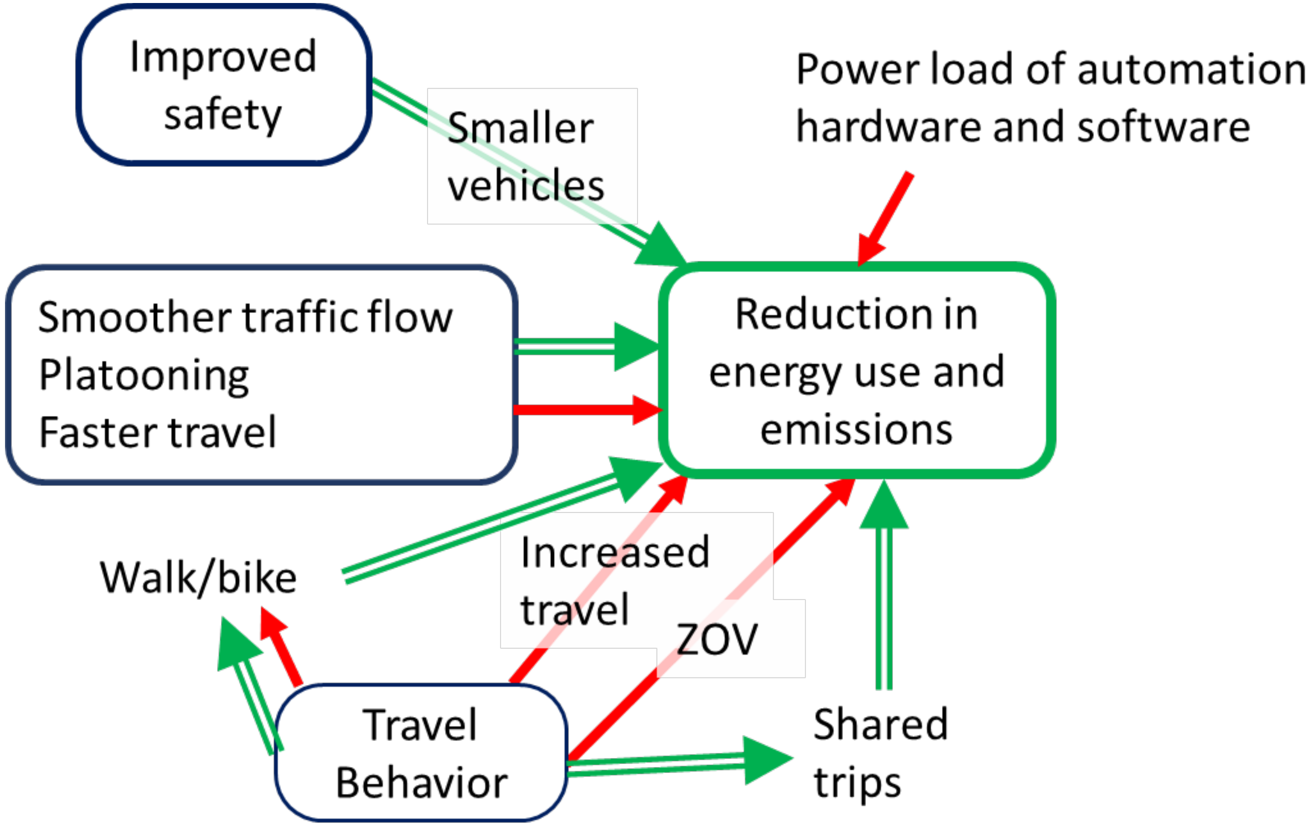
Source: US DOT Benefits Estimation Model report and poster from 2017 Automated Vehicles Symposium

Potential benefits and disbenefits

Impact Area	Potential Benefit	Potential Disbenefit
Safety	Reduction in crashes	New types of crashes
Vehicle Operations	More responsive vehicle following and lane keeping	Conflicts in mixed traffic, driver acceptance of technology
Personal Mobility	More options, especially for those unable/unwilling to drive, possibly cheaper	Can ***everyone*** access the automated vehicles?
Energy Use and Emissions	Smoother speed profiles, platooning, light-weighting could improve efficiency	Increases in VMT could increase fuel use/pollution
Network Efficiency	May increase throughput, decrease travel time, and shorten headways	May increase congestion due to induced demand for trips
Public Health	Improved access to medical care, work and recreation for non-motorists	May reduce use of active modes
Travel Behavior and Vehicle Ownership	May decrease need for ownership, potentially reducing fleet size	May lead to more trips, with ability to safely multi-task enroute
Land Use	May encourage density by freeing up space currently devoted to parking	May encourage sprawl

Energy/emissions – complex impacts

- Vehicle fuel consumption per mile
  - Vehicle / powertrain resizing
  - Smoother traffic flow
  - Faster travel
  - Power load of automation hardware and software
- Vehicle-miles traveled
  - Increased travel
  - Shared or not shared
  - Zero-occupant vehicles (ZOV)
- Self-repositioning of AVs can facilitate electric vehicle use



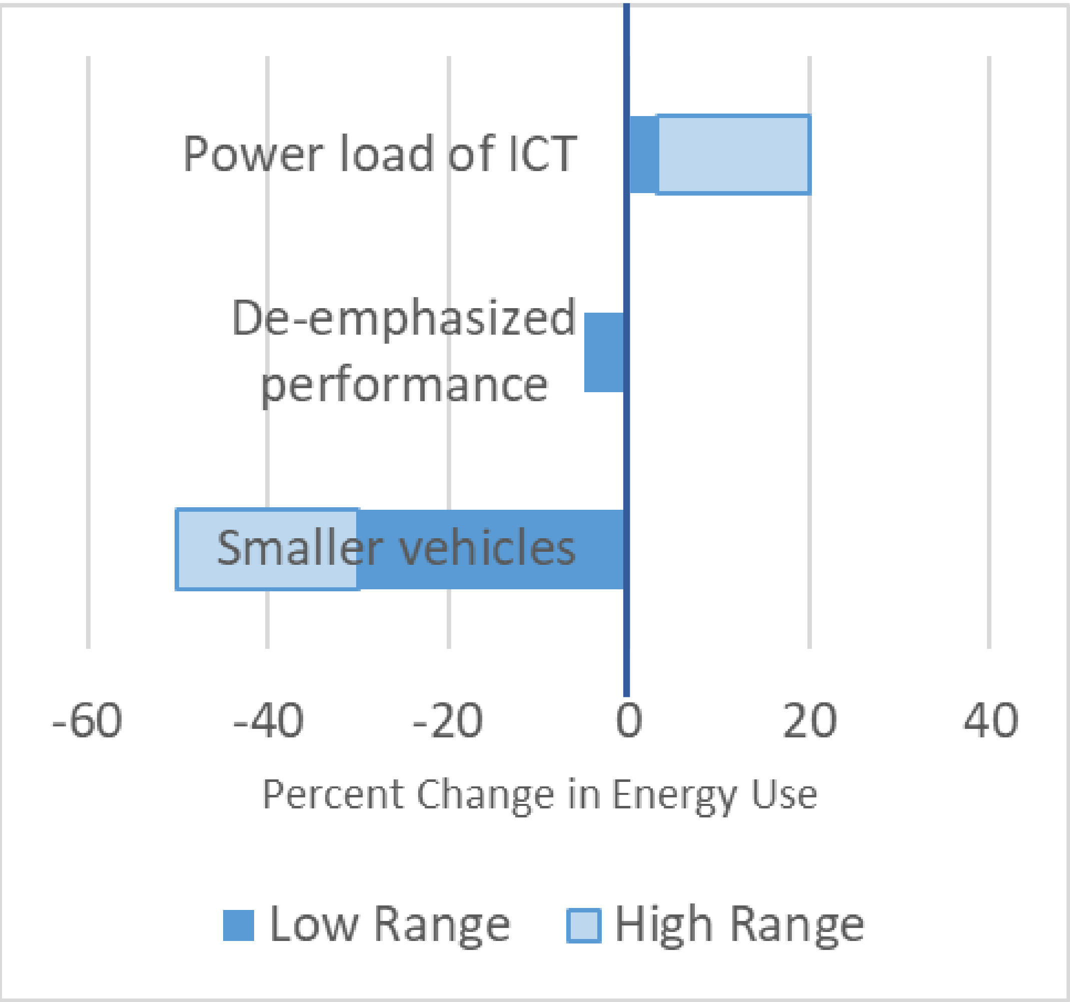
There are many papers and reports on this topic. A useful review paper is Taiebat et al. (2018)

Caveats and uncertainties

- We are "measuring" the impact of something that (mostly) does not exist yet
- Most of the results have come from:
  - Traffic microsimulations
  - Macroscopic models
  - Thought experiments (e.g., using proxy modes)
- A limited number of on-road tests have measured energy and emissions
- Therefore, reporting broad ranges of impacts is appropriate

Evolving vehicles and powertrains

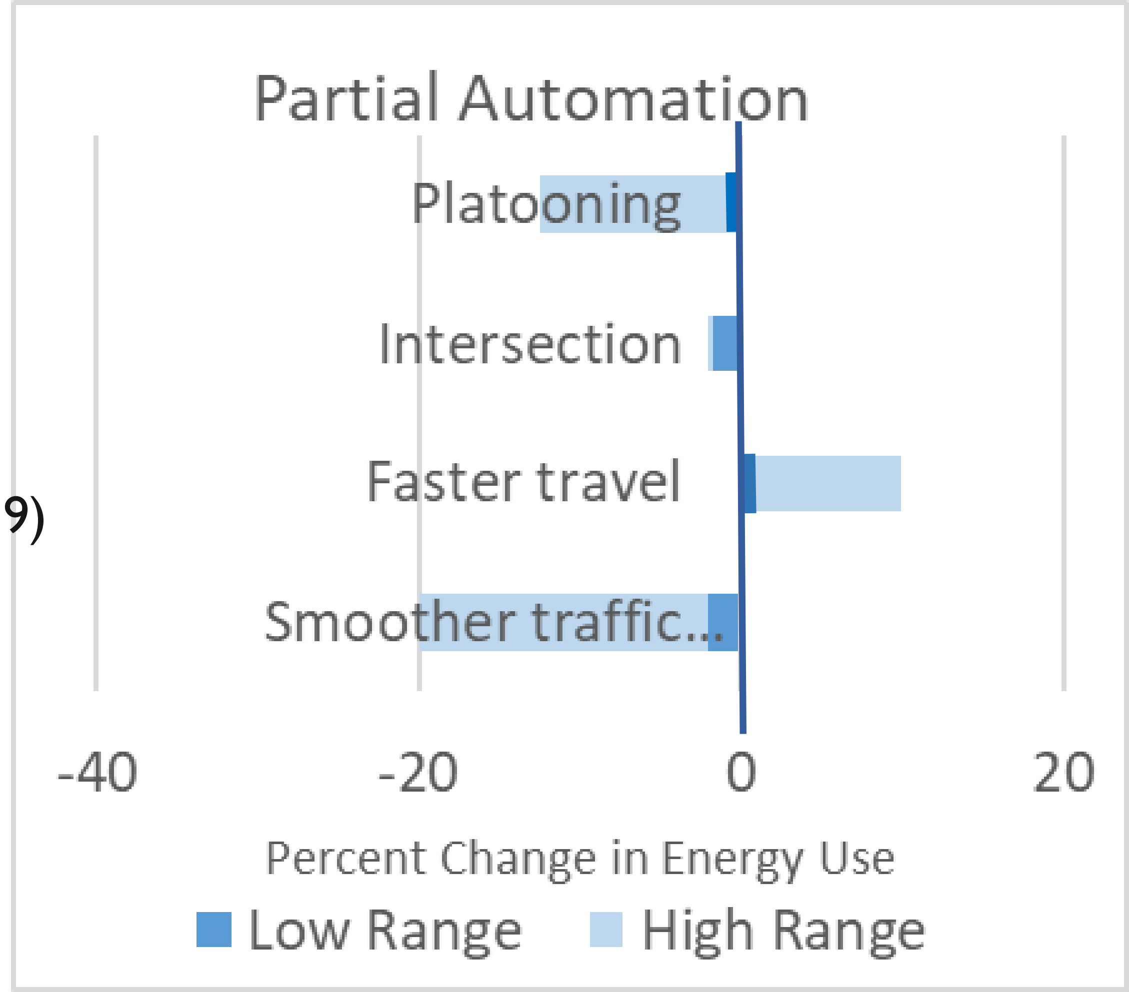
- Smaller vehicles
  - With reduced crashes, less need for massive vehicles for occupant protection
  - Most trips have 1 – 2 occupants
  - Potential savings under several idealized scenarios
    - 30 – 35% (Greenblatt and Saxena, 2015)
    - 45% (Wadud et al., 2016)
    - 50% (Stephens et al., 2016)
- Shift to electric vehicles
  - How is the electricity generated?
- "De-emphasized performance"
  - 5% (Wadud et al., 2016)
- But, information and communications technology (ICT) may add significantly to the power load
  - 3 – 20% (Gawron et al., 2018)



Vehicle operations

- Smoother traffic flow
  - Our meta-analysis of ACC and CACC papers (Eilbert et al., 2019)
    - ACC: 5 – 15% savings
    - CACC: 2 – 20% savings
- Faster travel (Stephens et al., 2016)
  - Effect at higher speeds (free flow conditions)
- Intersection V2I / I2V (Altan et al 2017, Feng et al 2019)
  - Vehicles communicate with traffic signals and other connected roadway infrastructure
- Platooning
  - Little energy benefit for automobiles
  - Some for trucks (~10%) (McAuliffe et al 2017)

Significant role of cooperative automation



Analysis of ACC and CACC tests

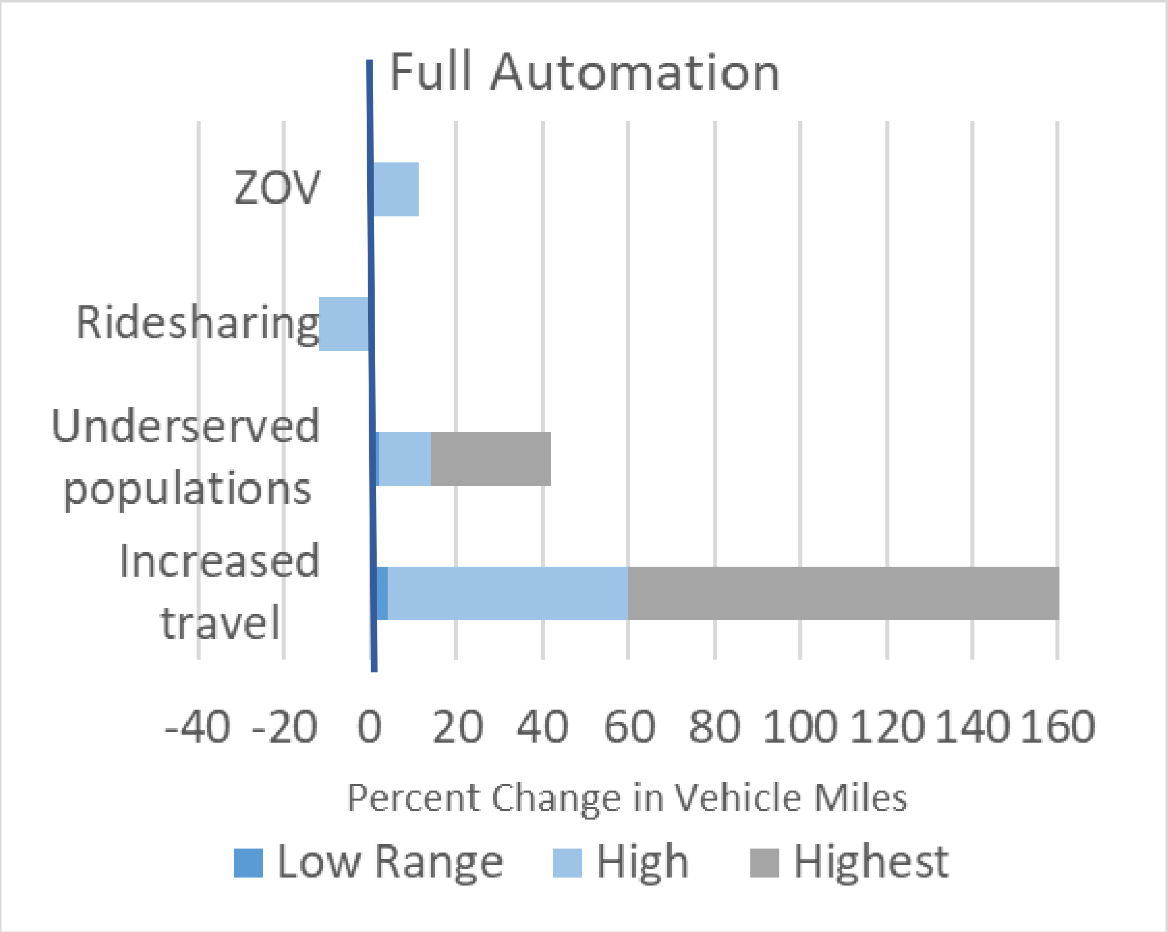
- CACC has less fluctuations in speed but some instances of jerkiness
- Highly responsive following of CACC may lead to potential tradeoffs
  - Shorter gaps likely to increase road capacity and reduce travel time
  - However, it may not yield maximum user comfort or energy/emissions reductions
- A cruise control system with smoother acceleration/deceleration could have greater environmental benefits and a more enjoyable user experience

Source: Eilbert et al., 2020

Travel behavior

- Categories (from Stephens et al., 2016)
  - Search for parking (in urban driving)
  - Increased travel due to ease of travel
  - Increased travel by underserved populations
  - Mode shift from non-motorized, transit, air
  - Increased ride-sharing
  - Increased empty miles (ZOV)

Sources: Stephens et al. (2016), Harper et al. (2016), Wadud et al. (2016), Lee and Kockelman (2019)



Summary

- Potential for energy savings and reduced emissions due to:
  - Smoother traffic (especially with cooperative automation)
    - Many published papers use simulations; fewer actually test vehicles on the road
  - Shift to electric vehicles—highly dependent on the electricity source(s)
  - Opportunities for ride-sharing
  - Potential shift to smaller vehicles
- May be offset by:
  - Increased travel, including by underserved populations
  - Faster travel
  - Zero-occupant trips
- Mode shift and land use changes may also have large and uncertain effects

Selected references (1/2)

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