Distributions of Real-World Vehicle Travel

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Overview

Timeline	Barriers
• Project start date: 10/01/2019 • Project end date: 09/30/2022 • Percent complete: 20%	• Evaluate energy and emission benefits of vehicle/fuel systems • Overcome inconsistent data, assumptions, and guidelines
Budget	**Partners**
• Funding for FY20: $150 K • Funding for FY21: $150 K (presumptive – subject to change) • Funding for FY22: $150 K (presumptive – subject to change)	• National labs: ORNL, LBNL

Project Overall Objectives

- Driving behavior is not homogenous, and using a single mileage schedule for all calculations related to lifecycle emissions, cost of ownership, and vehicle survivability does not yield full understanding of fleet-wide fuel consumption. Optimal vehicle choices from a levelized-cost-of-driving standpoint may vary depending on differing use cases. New technologies are more likely to be useful to a subset of consumers before the whole market, e.g., a battery electric vehicle driven more intensively than the average may have an easier time reaching cost parity than a “typical” vehicle.
- This project will 1) quantify variations in vehicle miles traveled (VMT), considering vintage, vehicle characteristics, and demographic characteristics; 2) quantify levelized cost of driving (LCOD) for vehicles with different use intensities; 3) estimate how variations in VMT impact national-scale metrics such as fuel consumption and emissions, both for today’s vehicles and potential future scenarios; and 4) assess variations in vehicle survivability.

Milestones

- Project began in October 2019

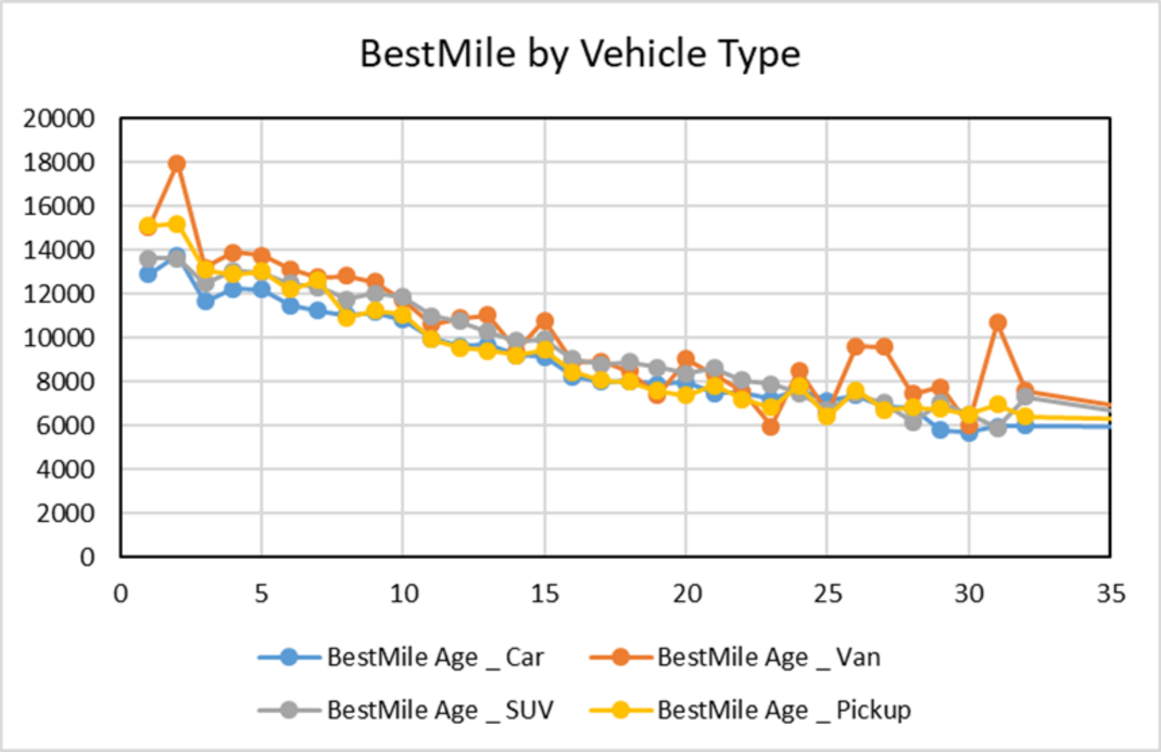
Date	Description	Status
12/2019	Compile data sources for light-duty VMT distributions	Complete
3/2020	Quantify average VMT as a function of vehicle age and other characteristics	Complete
3/2020	Develop mathematical framework for LCOD	Complete
6/2020	Presentation to HQ: Distribution of VMT as a function of vehicle age	In progress
9/2020	Report to HQ: Distribution of VMT as a function of vehicle characteristics	In progress

Project Approach

- Using available data, examine what vehicle attributes and demographic characteristics are correlated with annual vehicle driving distance
  - Use National Household Travel Survey (NHTS) where possible
  - Link with previous project with ORNL and LBNL to explore VMT as a function of vehicle fuel economy, using odometer data from Texas and Massachusetts
- **Compare variations across vehicle population, rather than examining only average driving patterns**
- Quantify a format for levelized cost of driving (LCOD) which accounts for variations in driving, to be able to tie with other analyses
  - Other analyses include EERE-funded work on market segmentation and VTO-funded work on total cost of ownership (TCO)

Project Approach – VMT assessment

- Compare vehicle data by year, and aggregate across many vehicles to find mileage schedules, where VMT is presented as a function of vehicle age.
- Using NHTS data, compare VMT across different vehicle classes:



- Interestingly, preliminary analysis shows that older cars and pickup trucks are driven approximately the same distance

Project Approach – LCOD calculations

- LCOD can be broken up into an upfront cost (vehicle purchase) and an ongoing operating cost (fuel purchase). We discount future expenditures, and treat each year's fuel expenditures separately:

$$LCOD = Vehicle\ cost + \sum_{i=1}^{Analysis\ window} \frac{Fuel\ cost}{(1+d)^i}$$

- The annual fuel cost is the product of the miles driven (VMT), by the fuel consumption in gallons per mile (GPM), by the cost of fuel ($/gallon).

$$LCOD = Vehicle\ cost + \sum_{i=1}^{n} \frac{VMT_i \times GPM_i \times \left(\frac{\$}{gallon}\right)_i}{(1+d)^i}$$

- Assuming that fuel efficiency remains constant and fuel price remain constant throughout the analysis window:

$$LCOD = Vehicle\ cost + GPM \times \left(\frac{\$}{gallon}\right) \times \sum_{i=1}^{n} \frac{VMT_i}{(1+d)^i}$$

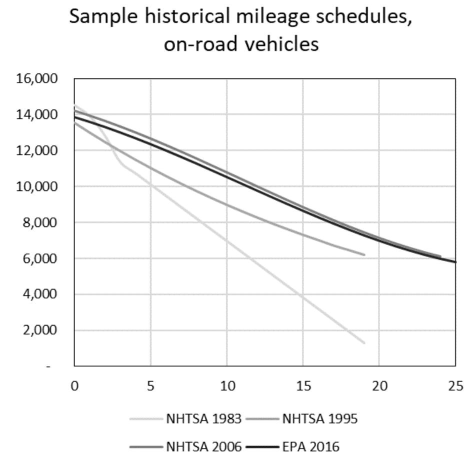
- This summation at the end of the equation can be viewed as a correction factor to the VMT, and is impacted by assumptions made in the modeling.

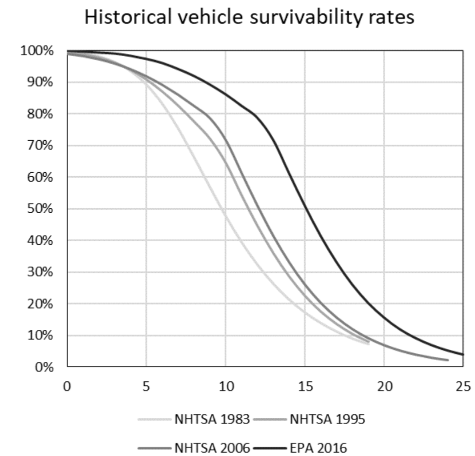
Accomplishments – Data source identification

- Data for real-world VMT by vehicle can be acquired (or attempted to be acquired) from the following types of sources:
  - Federal government statistics (e.g. Federal Highway Administration)
  - State registration data
  - Aggregated registration data
  - Travel surveys
  - Used car auctions
  - Used car online postings
  - National Motor Vehicle Title Information System
  - Service centers
  - Insurance companies
- This project will determine which of these routes are tractable, and compare data availability and usefulness

Accomplishments – VMT and LCOD linkage

- Historical data show an increase in VMT intensity since the late 1970s, and a drastic increase in both vehicle survivability and in annual mileage for surviving vehicles





Data from EPA and NHTSA, 1983-2016

- Mileage schedule, accounting for vehicle survivability (scrappage), analysis window, and assumption of discount rate all impact LCOD calculations

LCOD correction factor, α 30-year analysis window	Ignore scrappage	Account for scrappage	Ignore scrappage	Account for scrappage	Ignore scrappage	Account for scrappage	Ignore scrappage	Account for scrappage
Discount rate	0%		3%		7%		15%	
NHTSA, 1983	100.00%	71.72%	82.19%	62.36%	65.72%	52.92%	46.40%	40.46%
NHTSA, 1995	100.00%	67.24%	78.52%	56.71%	59.74%	46.54%	39.41%	33.88%
NHTSA, 2006	100.00%	60.38%	74.50%	50.13%	53.96%	40.45%	33.74%	28.74%
EPA, 2016	100.00%	64.40%	71.45%	51.96%	50.08%	40.69%	30.54%	27.82%

The LCOD correction factor acts as a weighting factor in the equation:

$$LCOD_{total} = LCOD_{initial} + \alpha \cdot LCOD_{operational}$$

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Accomplishments – LCOD calculations

- Given equations on Slide 7, LCOD for two vehicles can be set equal to find point for cost parity. Example here of LCOD for a battery electric vehicle (EV) vs. an internal combustion engine (ICE) vehicle. The key parameter being found is the necessary battery cost.
- With certain simplifying assumptions, battery cost can be presented in a closed form:

$$Battery\left(\frac{\$}{kWh}\right) = \left(\frac{Usable\ battery\ \%}{FC_{EV} \times Range}\right) \times \left[\left(ICE_{Body,Powertrain,Other} \times RPE_{ICE} - EV_{Body,Powertrain,Other} \times RPE_{EV}\right) + \left(FC_{ICE} \times \left(\frac{\$}{gallon}\right) - FC_{EV} \times \left(\frac{\$}{kWh}\right)\right) \times VMT \times \left(\frac{1-(1+d)^{-n}}{d}\right)\right]$$

- The benefit of having a single equation allows for a parametric exploration of these terms, shown on next slide for two comparisons.
  - Higher cost parity (in green) means that the EV will be cost competitive to ICE vehicles sooner, while lower values represent greater need for continued battery R&D. The vertical axis represents the values of the variable on the left side, while the horizontal axis represents the values for that variable in each column

Accomplishments – LCOD calculations

- Annual mileage assumptions can change the calculations for LCOD. As annual mileage increases (left side to right side), EVs can more easily reach cost parity with ICE vehicles. Even for very short annual driving distances, it is possible for EVs to be cost effective if they have an appropriately-sized battery.

EV battery cost parity ($/kWh)		Annual VMT (miles)										
		4k	6k	8k	10k	12k	14k	16k	18k	20k	22k	24k
EV Range (miles)	50	$298	$327	$355	$383	$412	$440	$468	$496	$525	$553	$581
	100	$149	$163	$177	$192	$206	$220	$234	$248	$262	$276	$291
	150	$99	$109	$118	$128	$137	$147	$156	$165	$175	$184	$194
	200	$75	$82	$89	$96	$103	$110	$117	$124	$131	$138	$145
	250	$60	$65	$71	$77	$82	$88	$94	$99	$105	$111	$116
	300	$50	$54	$59	$64	$69	$73	$78	$83	$87	$92	$97
	350	$43	$47	$51	$55	$59	$63	$67	$71	$75	$79	$83
	400	$37	$41	$44	$48	$51	$55	$59	$62	$66	$69	$73
	450	$33	$36	$39	$43	$46	$49	$52	$55	$58	$61	$65
	500	$30	$33	$35	$38	$41	$44	$47	$50	$52	$55	$58
	550	$27	$30	$32	$35	$37	$40	$43	$45	$48	$50	$53

- It is easier for an EV to be cost competitive with an inefficient ICE vehicle, but as fuel economy of the ICE vehicle increases, the battery target for cost parity drops. For the most aggressive ICE fuel economy compared with the worst EV fuel economy (bottom right corner), the per-mile cost of the EV is actually higher than the ICE vehicle.

EV battery cost parity ($/kWh)		Fuel Economy (miles per gallon)										
		19	22	25	28	31	34	37	40	43	46	49
Electricity consumption (kWh/mi)	0.18	$146	$131	$121	$112	$105	$100	$95	$91	$87	$84	$82
	0.22	$117	$105	$96	$89	$84	$79	$75	$72	$69	$66	$64
	0.26	$96	$87	$79	$73	$68	$65	$61	$59	$56	$54	$52
	0.3	$82	$73	$67	$61	$57	$54	$51	$49	$47	$45	$43
	0.34	$70	$63	$57	$53	$49	$46	$43	$41	$40	$38	$37
	0.38	$61	$55	$50	$45	$42	$40	$37	$35	$34	$32	$31
	0.42	$54	$48	$43	$40	$37	$34	$32	$31	$29	$28	$27
	0.46	$48	$43	$38	$35	$32	$30	$28	$27	$25	$24	$23
	0.5	$43	$38	$34	$31	$29	$27	$25	$23	$22	$21	$20
	0.54	$39	$34	$31	$28	$25	$24	$22	$21	$20	$19	$18
	0.58	$35	$31	$27	$25	$23	$21	$19	$18	$17	$16	$15

For comparison, battery prices were $197/kWh in 2018, and VTO has a target of $80/kWh (VTO, 2019 AMR)

Responses to Reviewer Comments

- This project is a new start and has not been previously reviewed

Collaboration and Coordination

- This project builds off of previous work with ORNL and LBNL to compare VMT as a function of vehicle fuel economy
- This project will be informed by VTO’s Total Cost of Ownership working group, including LBNL, ORNL, NREL, and SNL
- Results will be shared publicly as available. The information from this project would have several likely audiences. In particular, this research would be useful for EERE program managers who are looking to understand technical requirements and potential markets for new technologies.

Remaining Challenges and Barriers

- A key challenge is to find adequate data sources that nationally representative and show variations in driving behavior
  - This is why 9 different pathways for finding data were listed on Slide 8. Combining data from different sources will allow for supplementary information when data has gaps.
- Driving behavior can change rapidly due to economic and social impacts, such as recessions or the COVID-19 outbreak
  - It will be important to distinguish factors that are related to the vehicle from those that are related to sociodemographic and economic concerns.

Proposed Future Research

- Future work includes:
  - Exploring how using distributions of vehicle miles (rather than averages) impacts calculations of national-scale metrics such as fuel consumption and emissions
    - This task will utilize the VISION model at Argonne
  - Exploring vehicle survivability
    - Using historical sales data, see which vehicle attributes and other factors are correlated with accelerated removal from service

Any proposed future work is subject to change based on funding levels

Summary

- Variations in vehicle miles traveled (VMT) can have major impacts on when new technologies will be cost-effective in the market, with these variations allowing markets for advanced vehicle technologies
- Understanding real-world VMT is necessary for any calculations of national-scale metrics for fuel consumption, vehicle emissions, or consumer costs.