An Analytic Method for Estimation of Electric Vehicle Range Requirements, Electrification Potential and Prospective Market Size*

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*Population Statisticians and Behavioral Economists, please hold all criticism until the speaker has left the venue.

The Core Issue

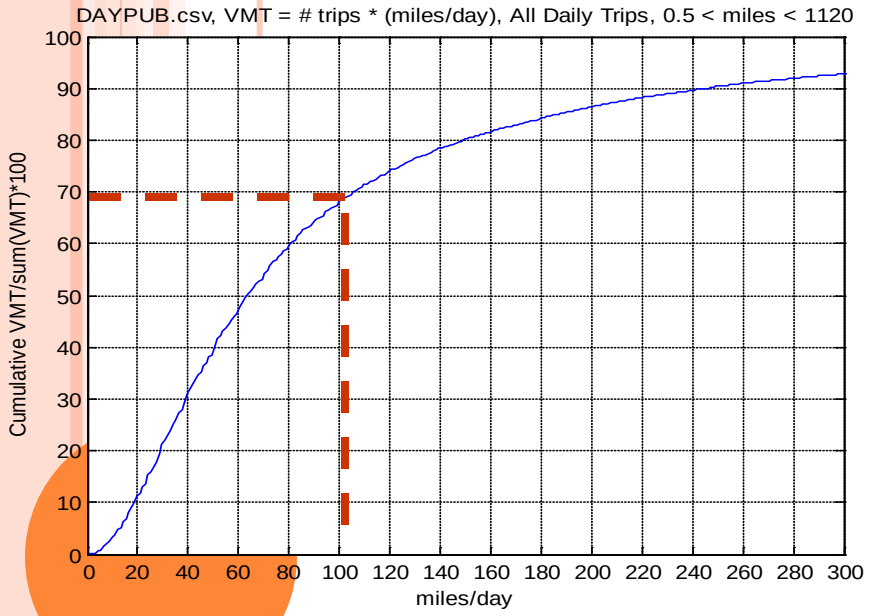
- The 'Electric Vehicle Paradigm' is inverted relative to a chemically fueled vehicle: the 'fuel' can be very cheap while the 'fuel tank' is extremely expensive.
  - Traditional means of determining requisite attributes, most importantly range, customer willingness-to-pay and ultimate market acceptance may not apply.
  - Because of the extreme cost sensitivity to range, and variability of use, estimates based on the ensemble behavior of large populations may be misleading.

America's Favorite Ensemble: the National Household Travel Survey (NHTS)

Data Collected (from ~200,000 household interviews)
The NHTS/NPTS serves as the nation's inventory of daily travel.
Data is collected on daily trips taken in a **(single) 24-hour period 4 am – 3:59 am)**, and includes:

purpose of the trip (work, shopping, etc.);
means of transportation used (car, bus, subway, walk, etc.);
how long the trip took, i.e., travel time;
time of day when the trip took place;
day of week when the trip took place; and
if a private vehicle trip:
- number of people in the vehicle , i.e., vehicle occupancy;
driver characteristics (age, sex, worker status, education level, etc.);
- vehicle attributes (make, model, model year, amount of miles driven in a year).

(Mis)Interpretation of Ensemble Data: Cumulative Daily Distance Distribution



"100 miles electric range can electrify 69% of all driving"

"100 miles electric range can electrify 93% of all trips"

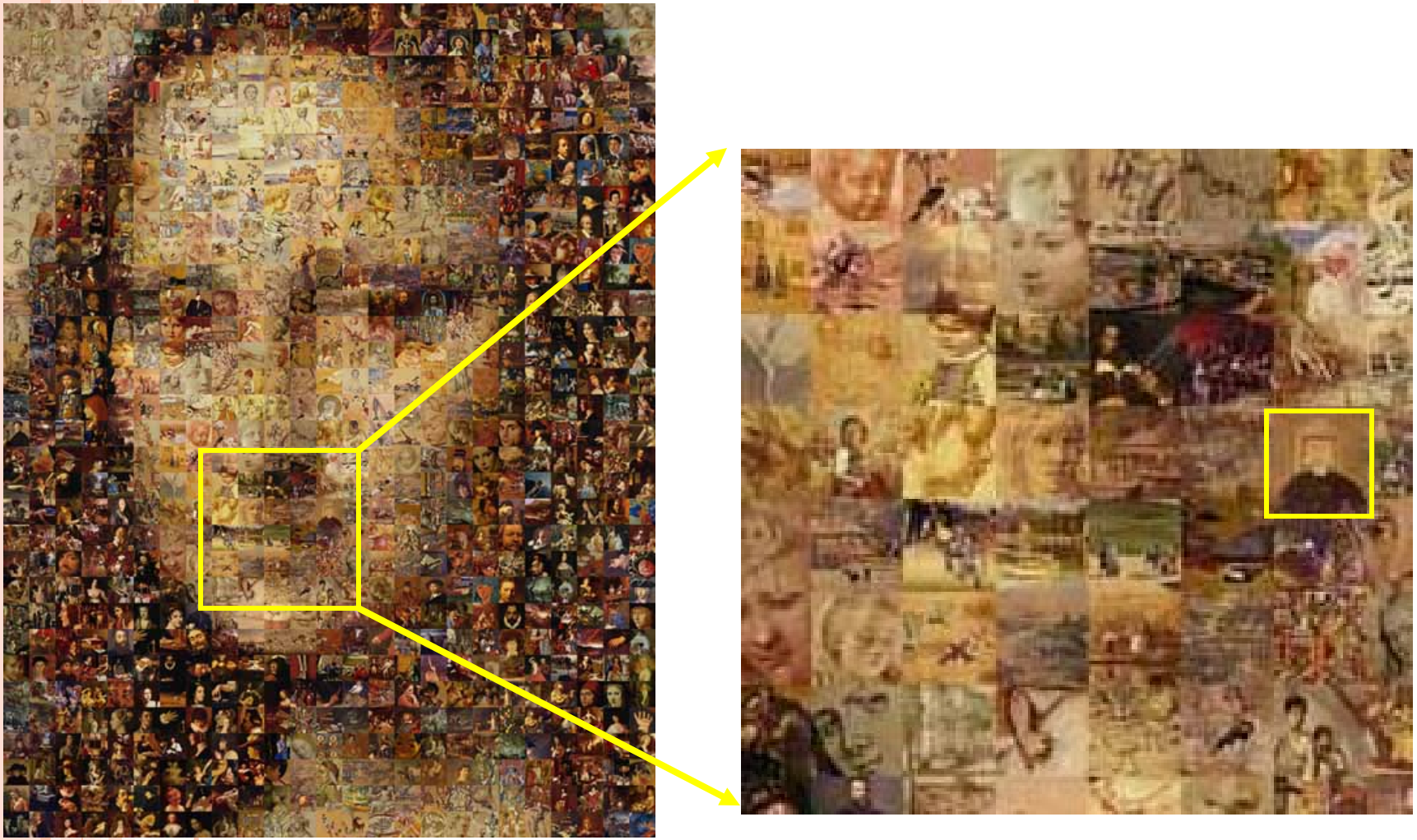
"100 km autonomy range satisfies more than 80% of daily use globally"
http://www.udel.edu/udaily/2011/may/electric-vehicles-051711.html

These statements hold for the ensemble if every respondent had the same EV whether or not it benefited him/her.

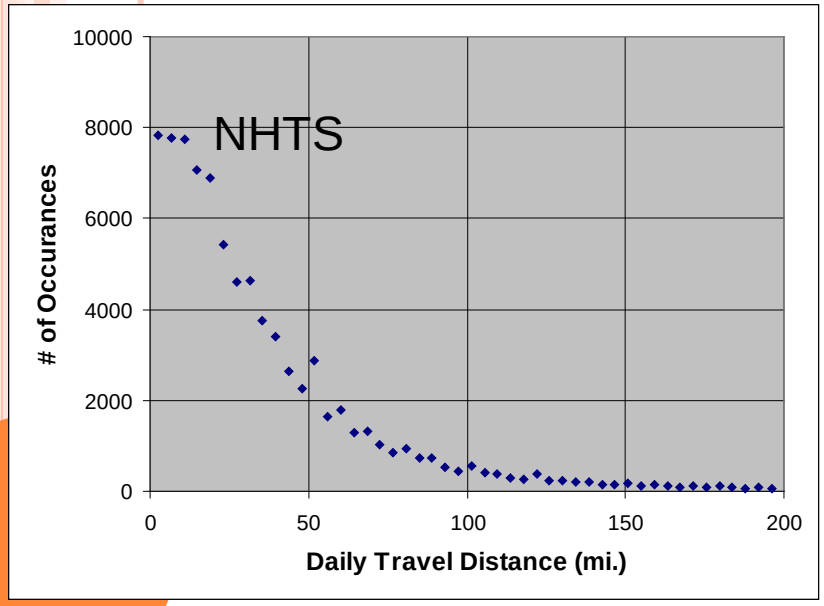
These statements hold for an individual if he/she had the EV and drove a distribution of trip lengths matching the ensemble.

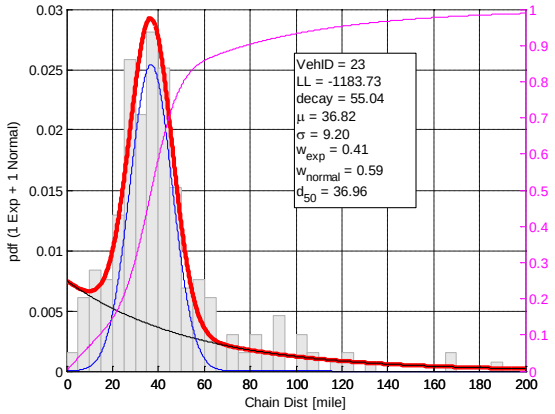
Neither condition is met in the real world.

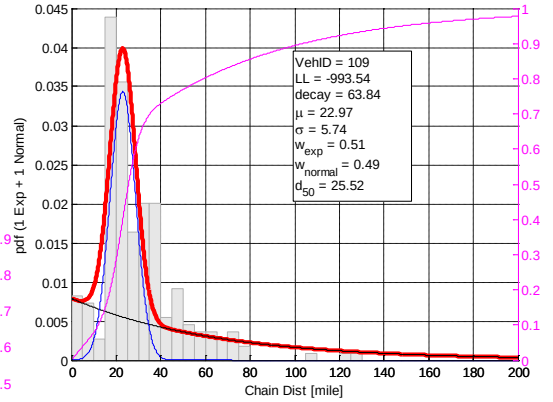
The Parts are Much More Complex than the Whole: we must treat people as individuals

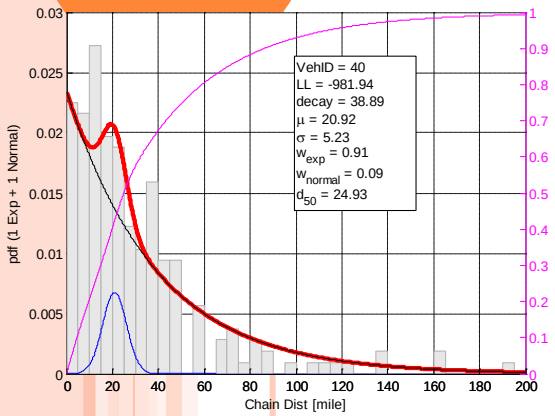


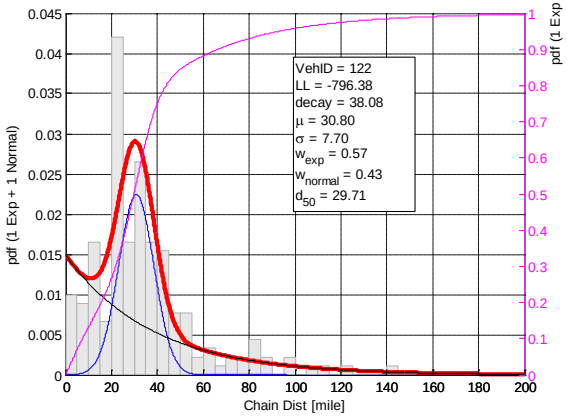
Individual Trip Chain Frequency Distributions do Not Resemble the Ensemble!





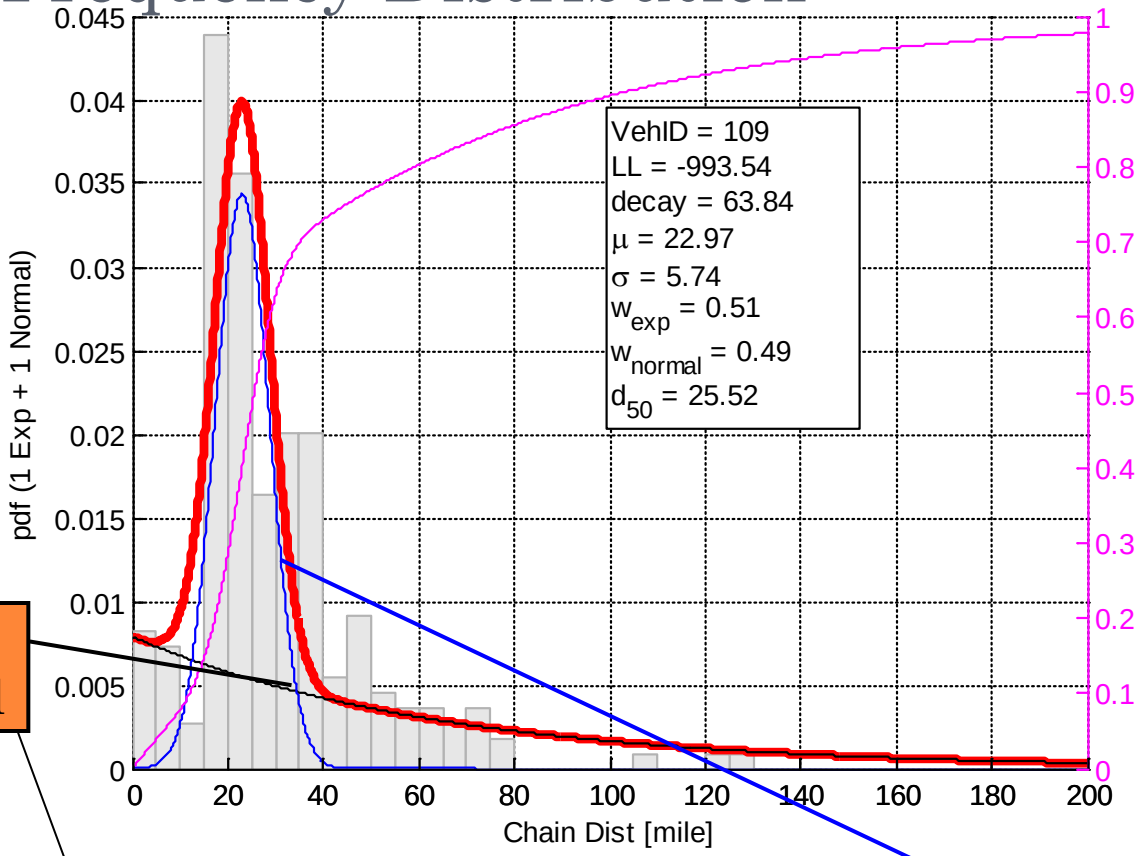






Example: Four of 132 vehicles instrumented for ~1year in Minnesota

Generic Parameterization of the Individual Trip Chain Frequency Distribution

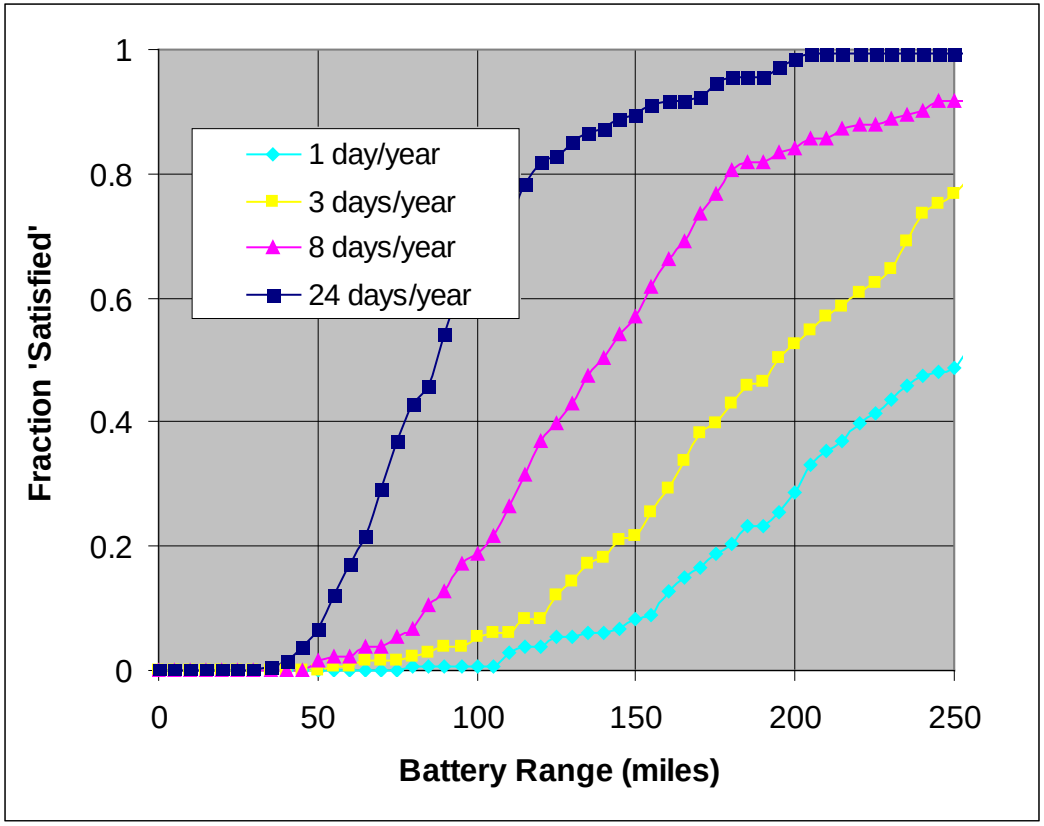


Random Background

Habitual Peak

$$p(x) = \frac{w}{k} e^{-x/k} + (1-w) \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/2\sigma^2}$$

How Many Will Accept EV Range Limitations?

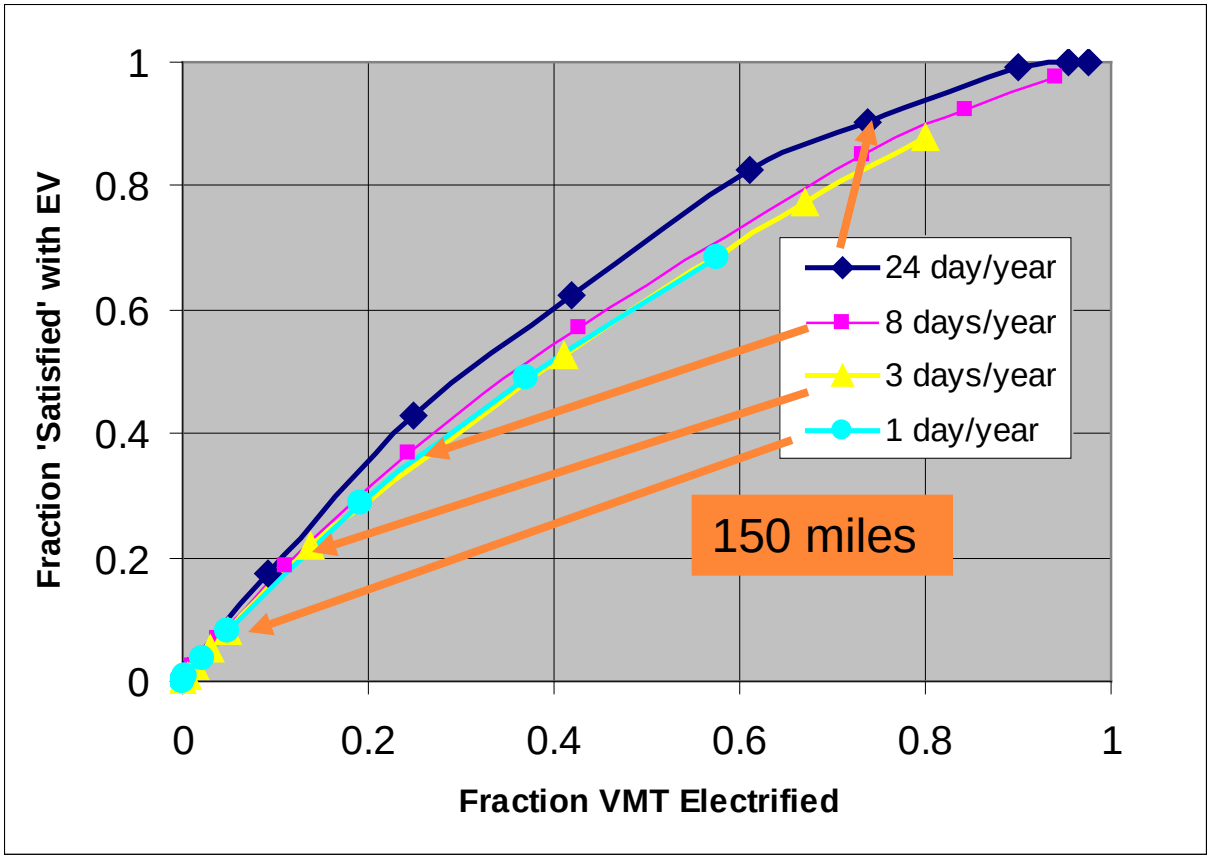


Acceptance of EVs is expected to be sensitive to customer reactions to the need for alternative transportation.

Market studies must capture the needs and alternatives for occasional uses rather than focus on typical usage!

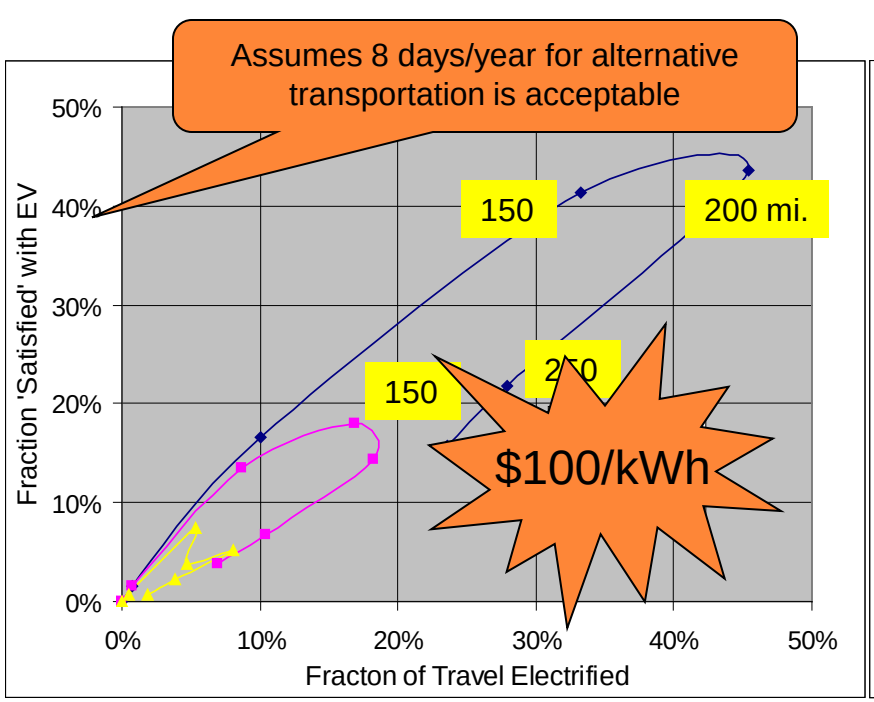
How Much Range is Enough*?

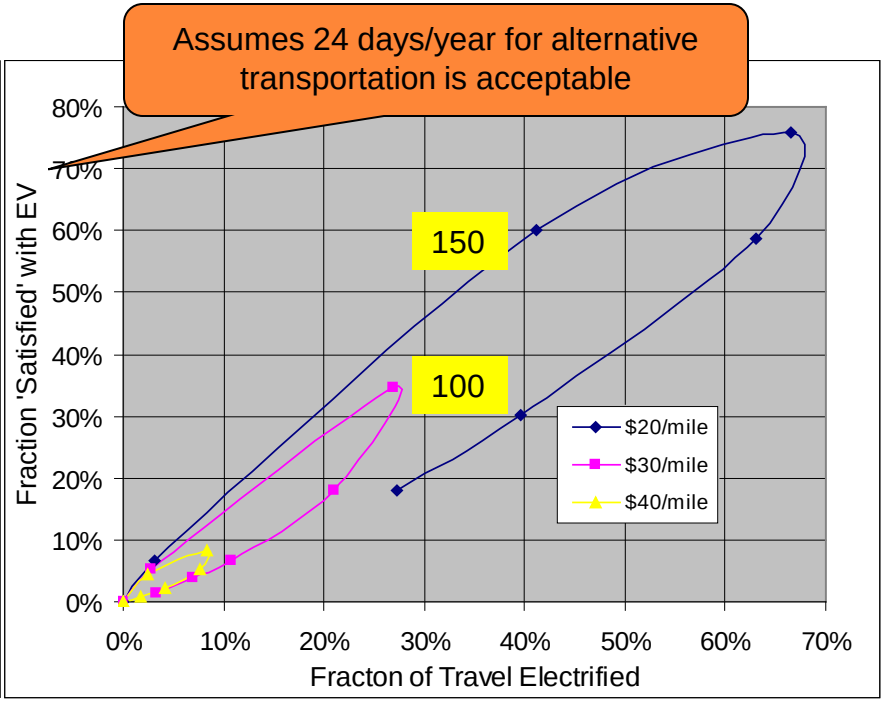
*to achieve a given level of electrification



- The electric range required to achieve a given level of electrification is extremely sensitive to the threshold for EV 'acceptance'.

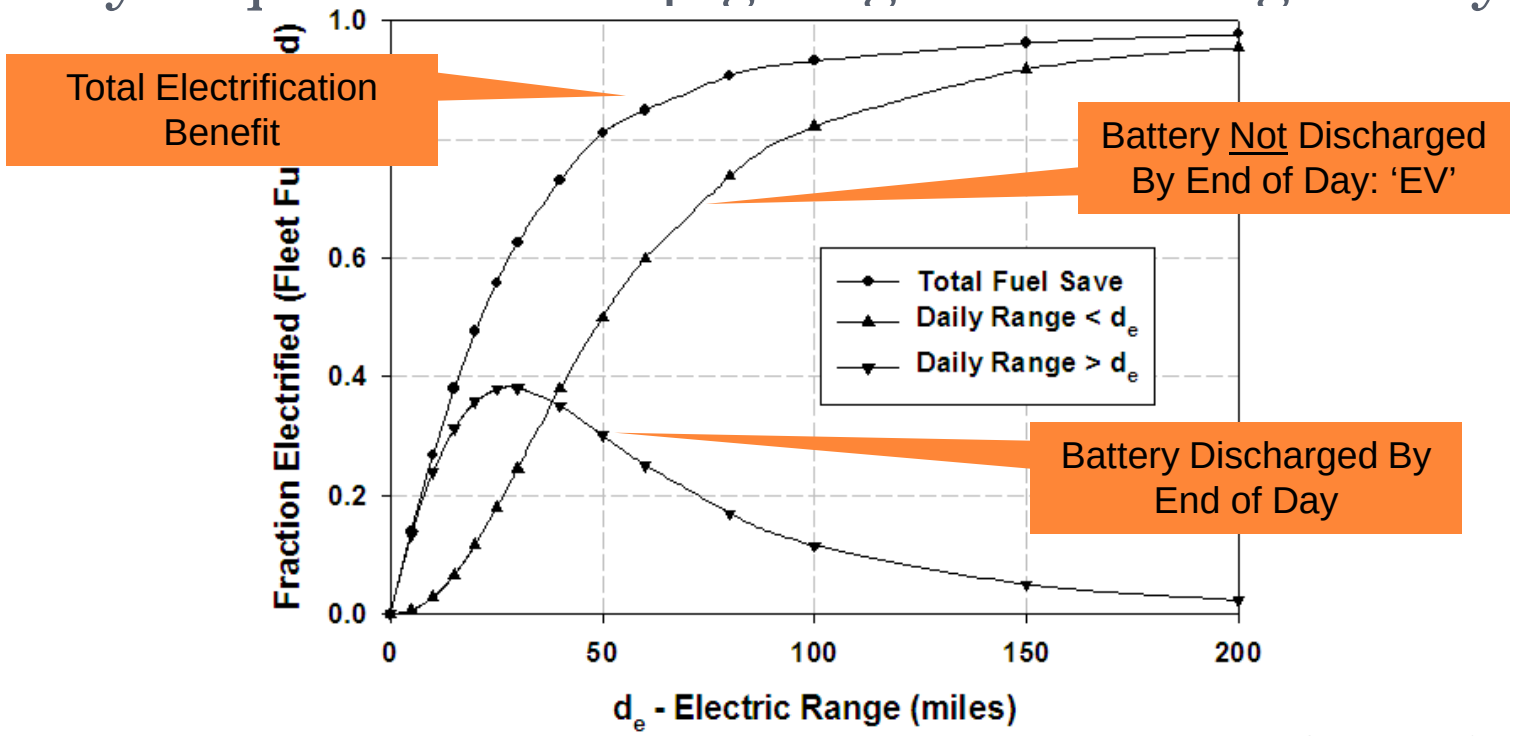
How Much Range is Too Much?





- With no economic penalty for choosing a larger battery, customer acceptance of EV, and total electrification is limited only by vehicle range.
- With finite cost, 'optimum' range is roughly 150-200 miles (~independent of cost)
  - This is near the limits of what is feasible with near-future Li-ion technology.
- **If customers demand cost breakeven AND high functionality, battery cost must be impossibly low (<$100/kWh).**

What if you could electrify the first N-miles of every trip … and keep going? The Plug-In Hybrid



- Only 20 miles electric range would electrify 50% of travel!
- 100% 'acceptance' (no range issues)
- Faster payback because battery capacity used much more.
- **Total electrification potential of PHEV is vastly greater than that of EV!**

What else can we do with this method?

- By identifying correlations between the four fit parameters, it is possible to generate synthetic driving population data.
  - Estimation of average and distribution of real-world fuel economy reports for comparison to labels.
  - Analytic estimates of EV acceptance and electrification potential to guide marketing and infrastructure priorities.
- By asking the right questions, we can estimate the fit parameters and generate a trip length distribution for an individual.
  - Better prediction of individual fuel economy.
  - **Personal estimate of electrification benefits.**

Individual Electrification Benefit Estimation

- The 'Four Questions'
  - How many miles do you drive annually?
  - Roughly how many days per year do you use your vehicle?
    - Typically 240-300
  - How many days per week do you commute?
    - Multiply by 0.8 to reflect vacation, holidays, etc.
  - What is the round-trip distance of your commute?

Vehicle & Driver Data Input

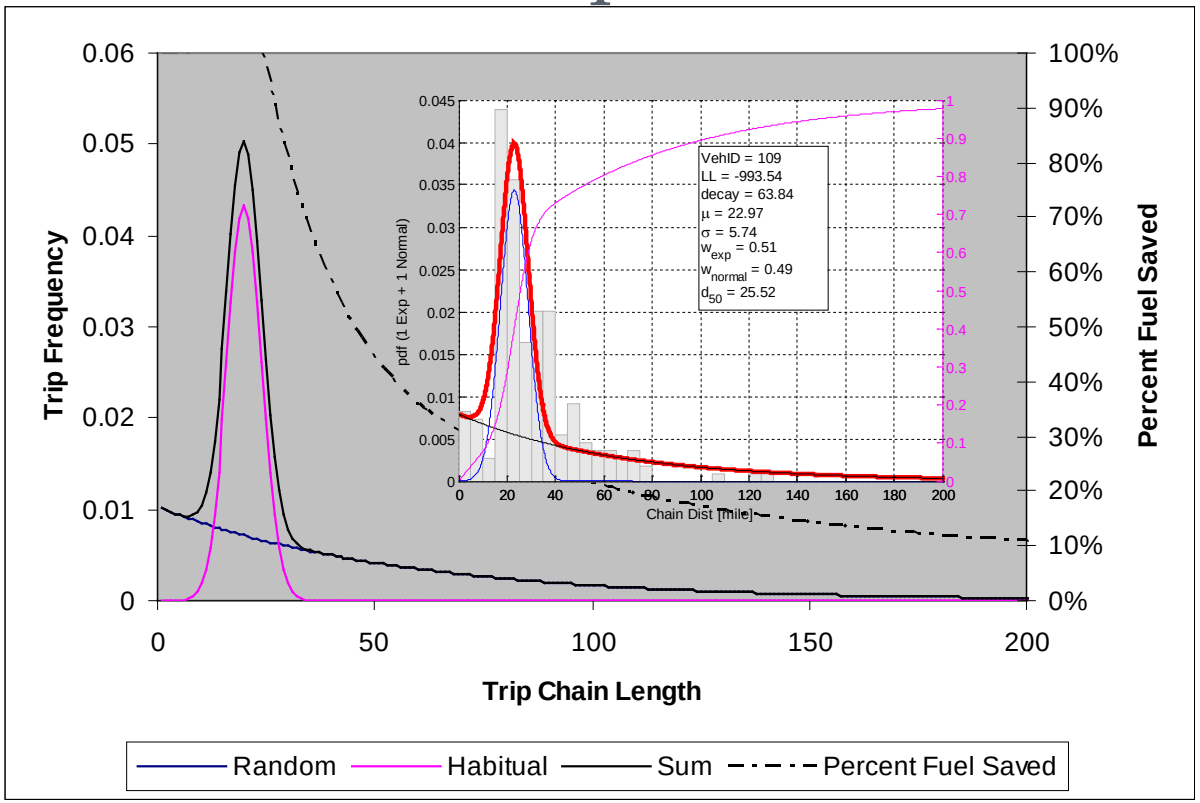
How do you drive?		
On average, the number of days per week you commute	5	days
Round drip distance of your commute	20	miles
Average Annual Commuting Distance	5200	Miles
Annual Miles Driven	12000	Miles
On average how many days a year do you drive your car?	300	days

What kind of PHEV do you want?		
Fraction of City driving electrified	1	Fraction from 0 to 1
Fraction of highway driving electrified	1	Fraction from 0 to 1
Miles per gallon city - sustaining	51.2	Miles per gal
Miles per gallon highway - sustaining	36.6	Miles per gal
Average Electrical Consumption per mile city - full electric	0.26	kWh per mile
Average Electrical Consumption per mile high way- full electric	0.36	kWh per mile
Usable Battery Capacity	7	kWH

PHEV Benefit Estimator Output

Calculated model parameters

w	0.566667	
lamda	0.821918	
mu	20	
sigma	4	
k	55.29412	
g_HF_s	1	kWh/mile
g_HF_d	0	kWh/mile
g_HE_d	0.357143	kWh/mile
g_CF_s	0.714286	kWh/mile
g_CF_d	0	kWh/mile
g_CE_d	0.255102	kWh/mile
phi_s	0.7	
x_s=	60	miles
	0.09841	
R_d	24.61295	Depletion F
y_R	1.153237	



Annual Savings.

Fuel Consumption standard HEV	284.1688	Gallons
Fuel Consumption PHEV	156.3891	
Fuel Savings	127.7796	Gallons
Percent Fuel Saved	44.97%	

- Note this is a crude prototype. Final version can have vehicle data base including non-HEV, including depletion strategy assumptions (Volt vs. Energi).

Summary (too soon for 'Conclusions')

- Estimates based on aggregate information are poor predictors of individual electrification needs and benefits.
- Statistical characterization of individual usage data can be used to generate realistic synthetic populations.
  - Methodology can be used to improve estimates of individual benefit, EV market penetration and ultimate electrification potential.
- **Market studies must capture occasional use and individual transportation alternatives.**
- Work in progress examines similar data from multiple regions to determine generality and scalability of the driver population model.

- **We need a lot more data!**