TranLIVE

Transportation for Livability by Integrating Vehicles, Drivers and the Environment:

What is the Level of Volatility in Instantaneous Driving Decisions?

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Editor in Chief, Journal of Intelligent Transportation Systems

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Tier 1 University Transportation Center

TranLIVE

- Competitively awarded UTC, focused on energy and environment
- Collaborative Partners include:
  - University of Idaho
  - Old Dominion University
  - Texas Southern University
  - Virginia Tech
  - Syracuse University
- Thanks to USDOT

NIATT

TRI Transportation Research Institute

Texas Southern University

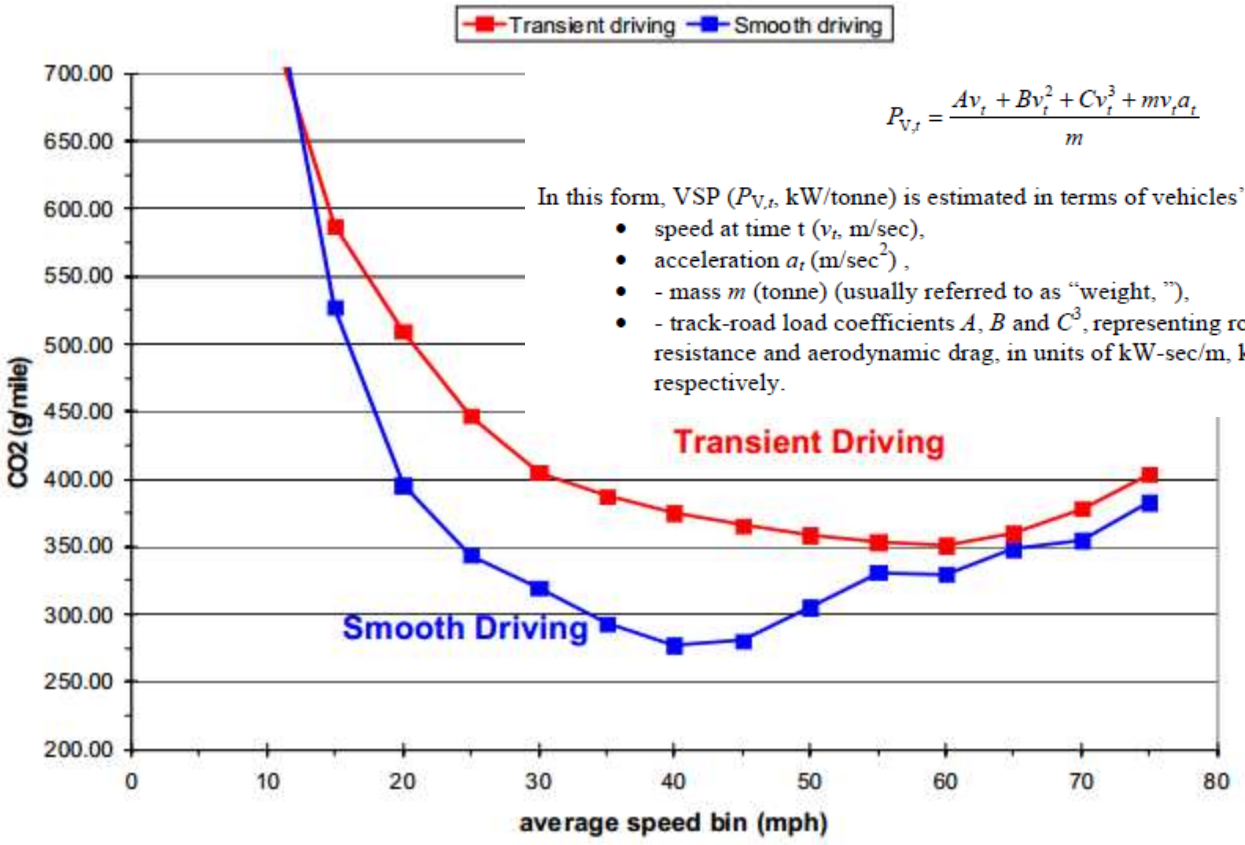
Virginia Tech Transportation Institute
Driving Transportation with Technology

Syracuse University L.C. Smith College of Engineering and Computer Science

Background

- AERIS: Sustainability & Intelligent Trans Sys
- Volatile driving →fuel consumption, tailpipe emissions, safety issues
- Understanding instantaneous driving decisions
  - Big data enabling deeper insights
- How to properly measure volatility in drivers' instantaneous driving decisions?
  - Volatility profile for driver, road, region

Literature: Speed vs. Emissions



$$P_{V,t} = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{m} \qquad 1\text{-}1$$

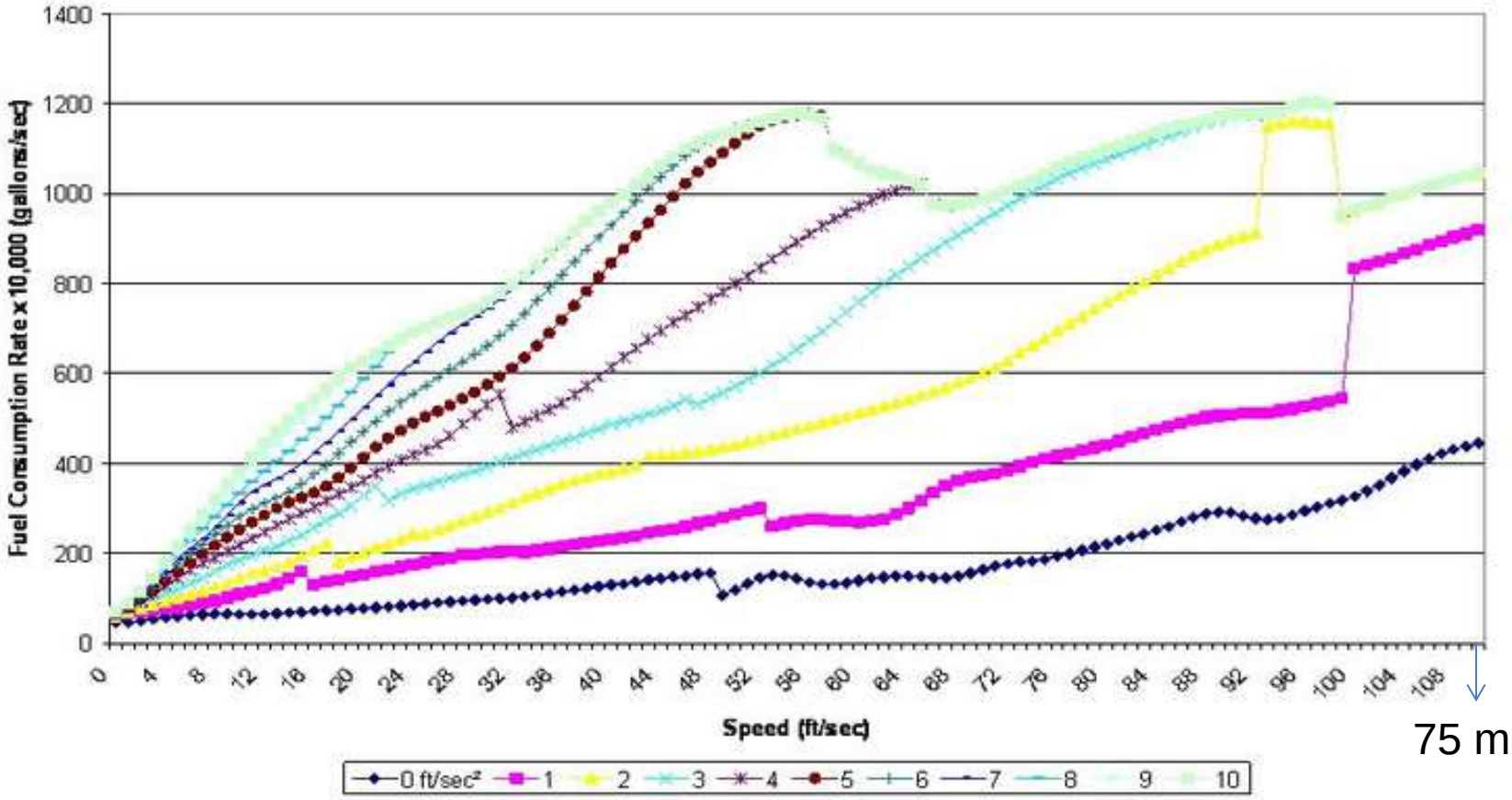
In this form, VSP ($P_{V,t}$, kW/tonne) is estimated in terms of vehicles':

- speed at time t (v_t, m/sec),
- acceleration a_t (m/sec^2) ,
- - mass m (tonne) (usually referred to as "weight, "),
- - track-road load coefficients A, B and C^3, representing rolling resistance, rotational resistance and aerodynamic drag, in units of kW-sec/m, kW-sec^2/m^2 and kW-sec^3/m^3, respectively.

Figure 4: CO2 vs. average speed curve for smooth and transient driving

http://www.epa.gov/otaq/models/moves/MOVES2010a/paper137-tap2010.pdf

Lit: Speed vs. Fuel consumption

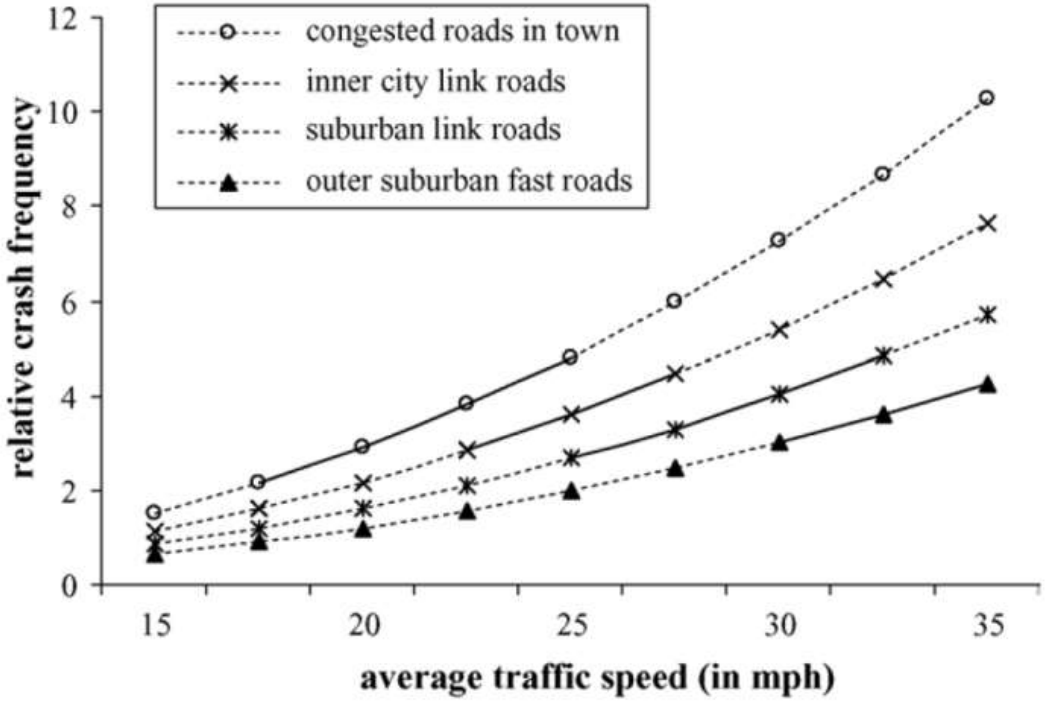


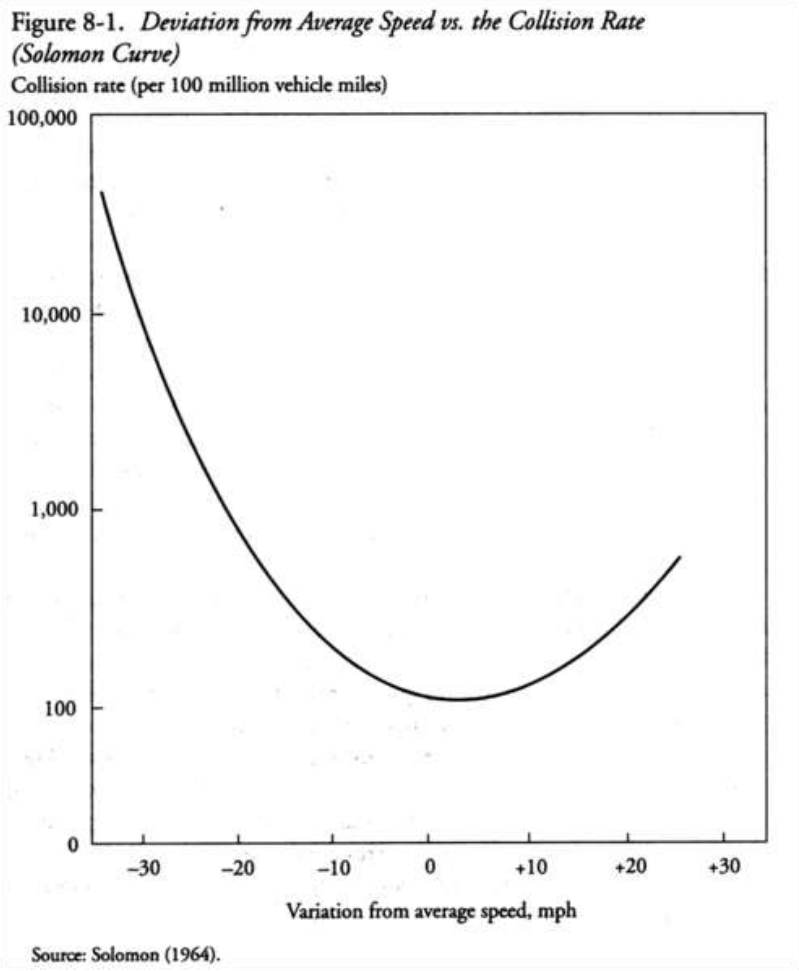
75 mph

Figure 66. Graph. Fuel consumption for different acceleration rates for performance index 1.

http://www.ops.fhwa.dot.gov/trafficanalysistools/tat_vol4/app_a.htm

Possible relationship: Speed vs. Crashes



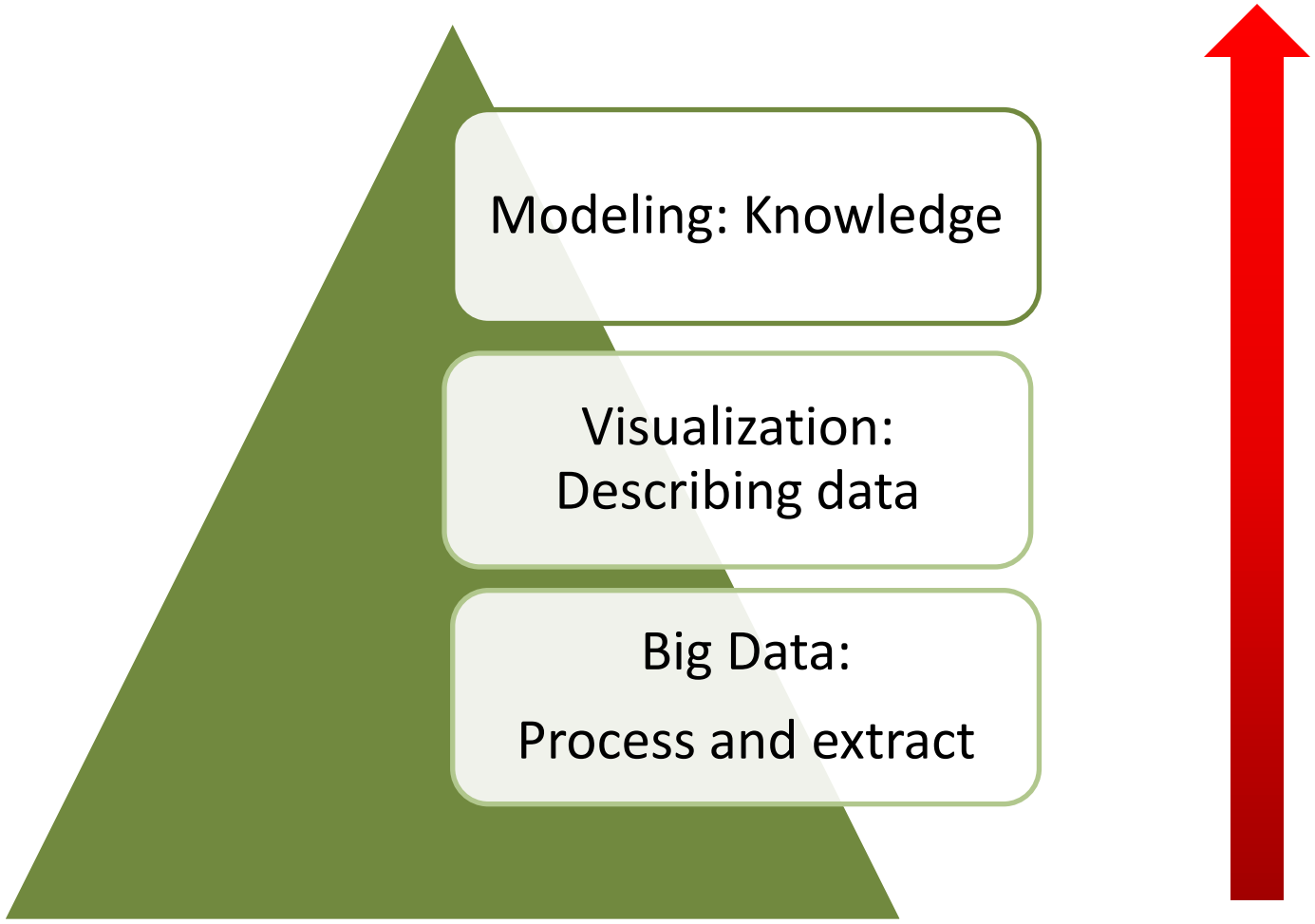


Aarts, L. and I. van Schagen (2006). "Driving speed and the risk of road crashes: A review." Accident Analysis & Prevention **38(2): 215-224.**

“Big” Data

- Atlanta Regional Commission— Regional Travel Survey with GPS Sub-Sample, Feb. – Oct. 2011
- Full sample
  - 10,278 households, 25,810 Persons, 21,270 Vehicles, 93,713 Trips
- GPS sub-sample
  - 51,371 trips with sec-by-sec GPS tag→**36 million sec**
  - 1652 drivers from 850 households

Big Data→ Knowledge



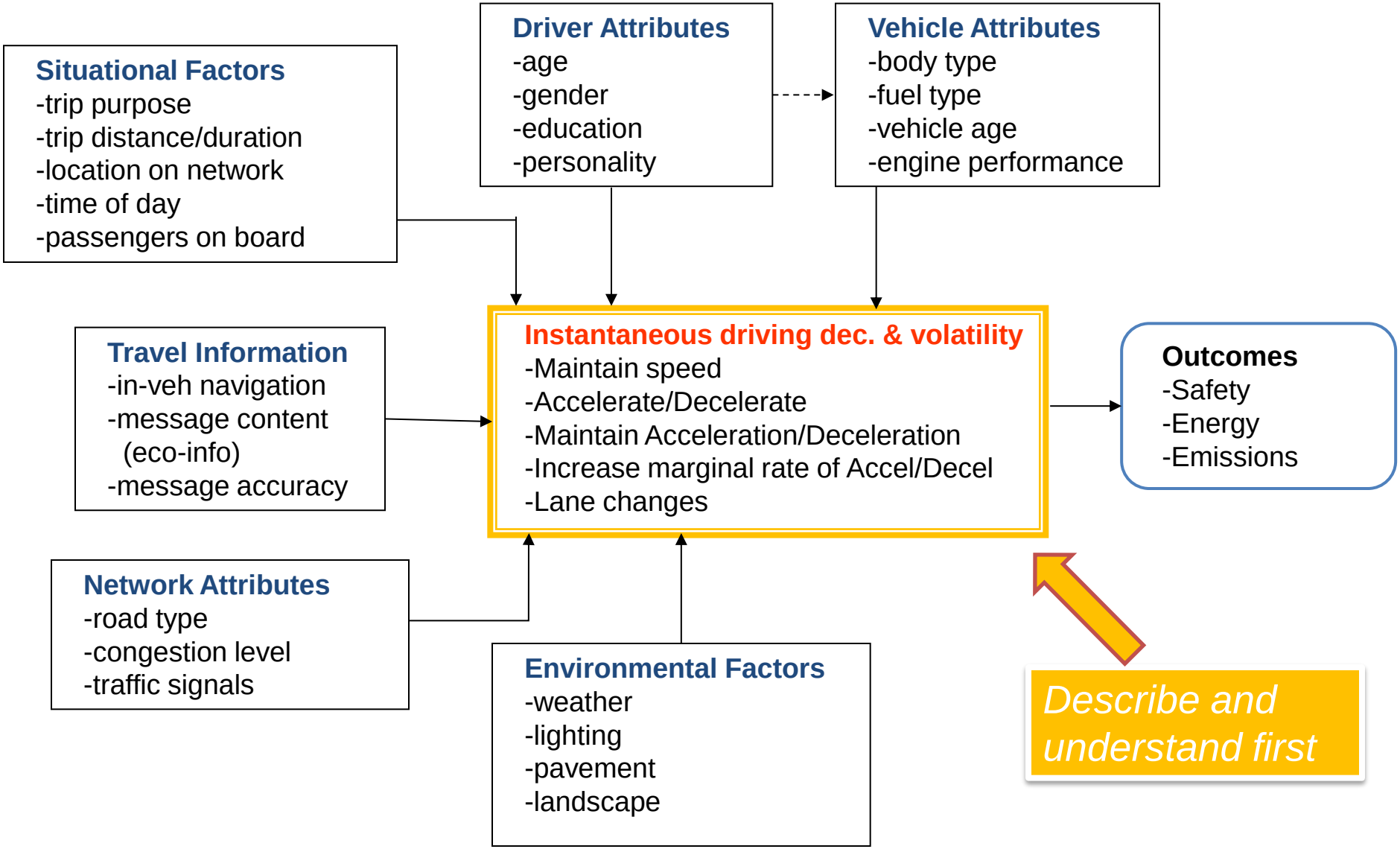
Data structure

- Household
- Person
- Vehicle
- Trip
- *GPS data for each trip (used in this study)
- *Micro-trip (future work)

Geo-codes, road type, congestion info—NOT available

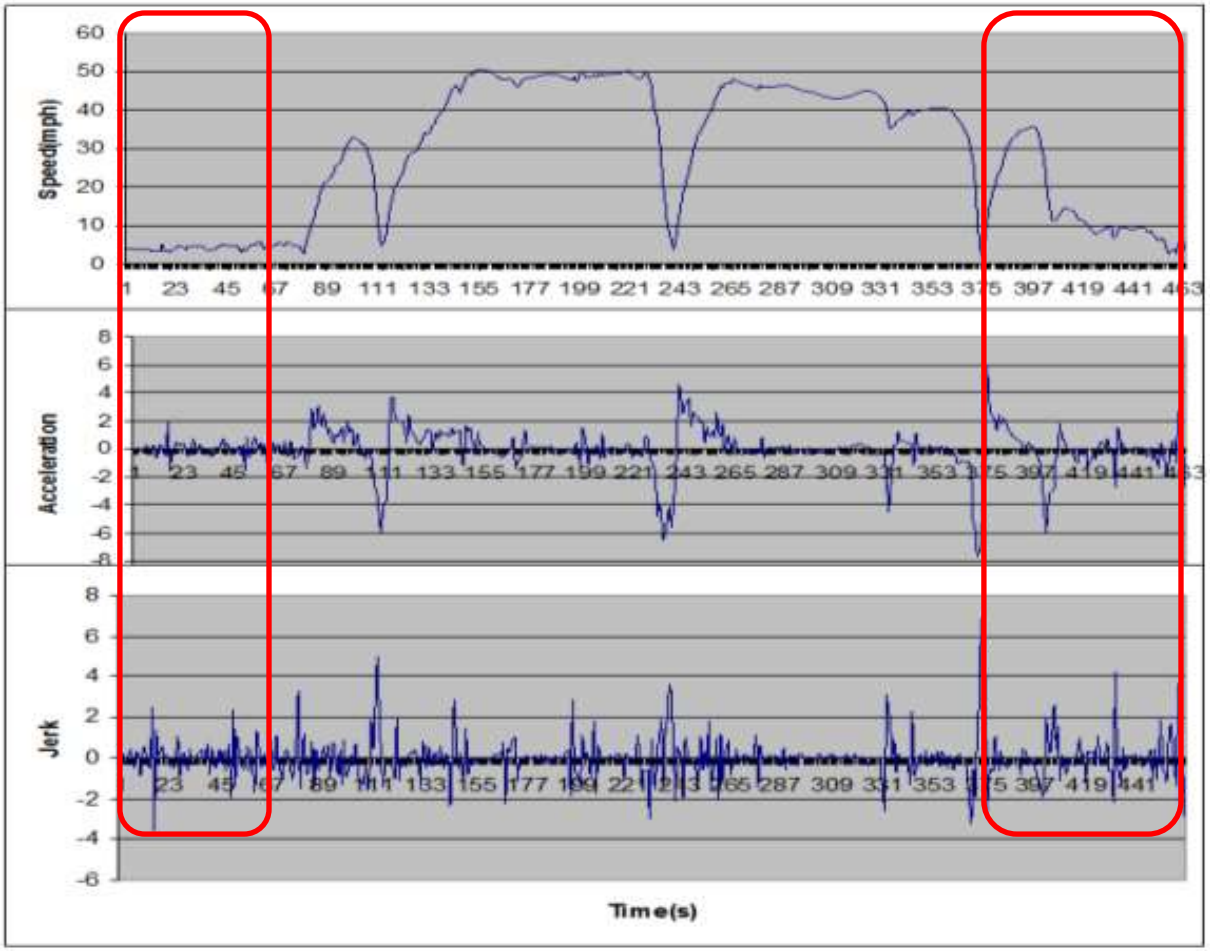
Note: * Available for GPS subsample

Conceptual framework



Methodology: Jerk to measure volatility

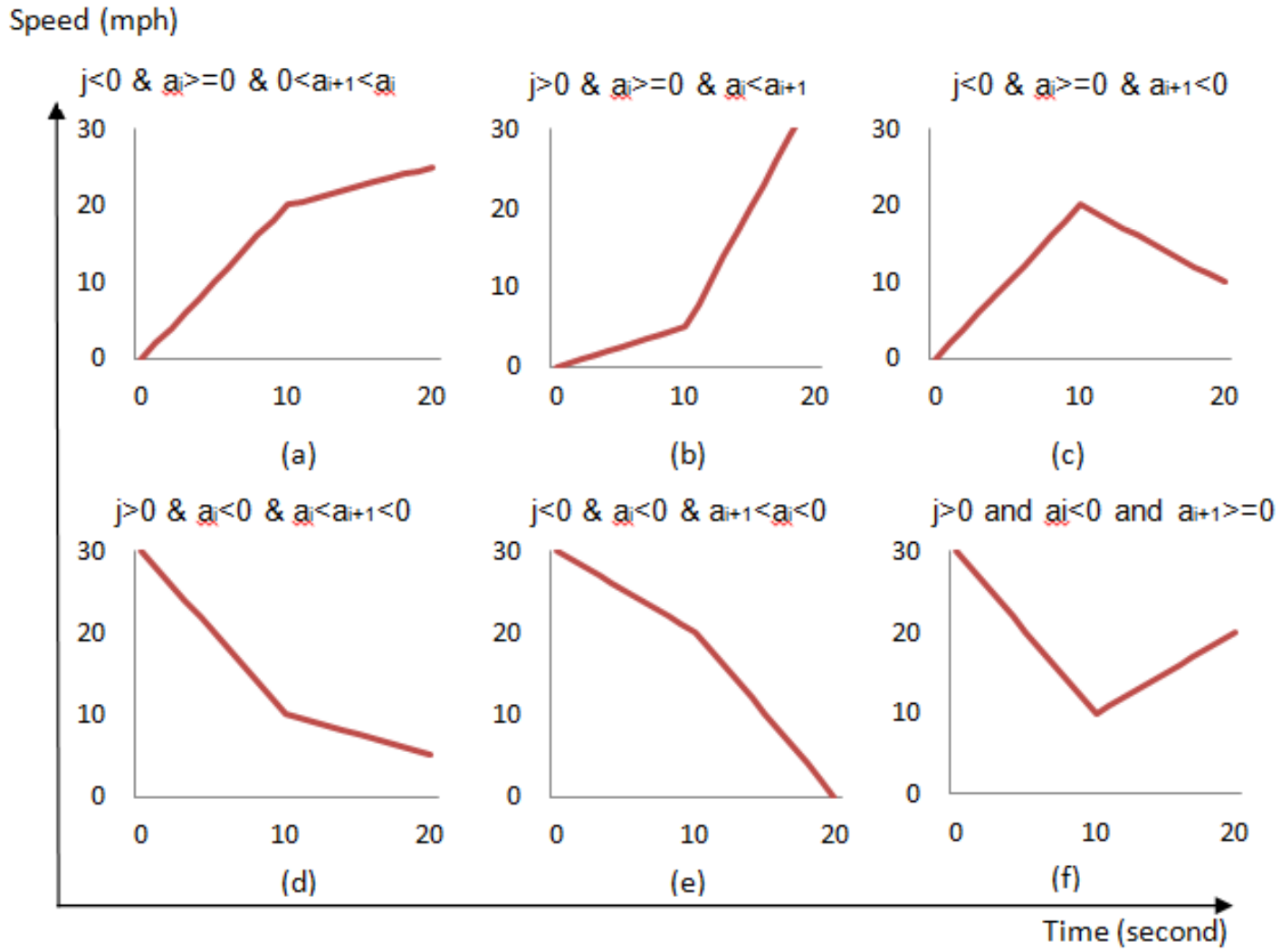
- How jerk works-amplify oscillations



$J = d(a)/d(t)$
$= d^2(v)/d(t)^2$
$= d^3(d)/d(t)^3$

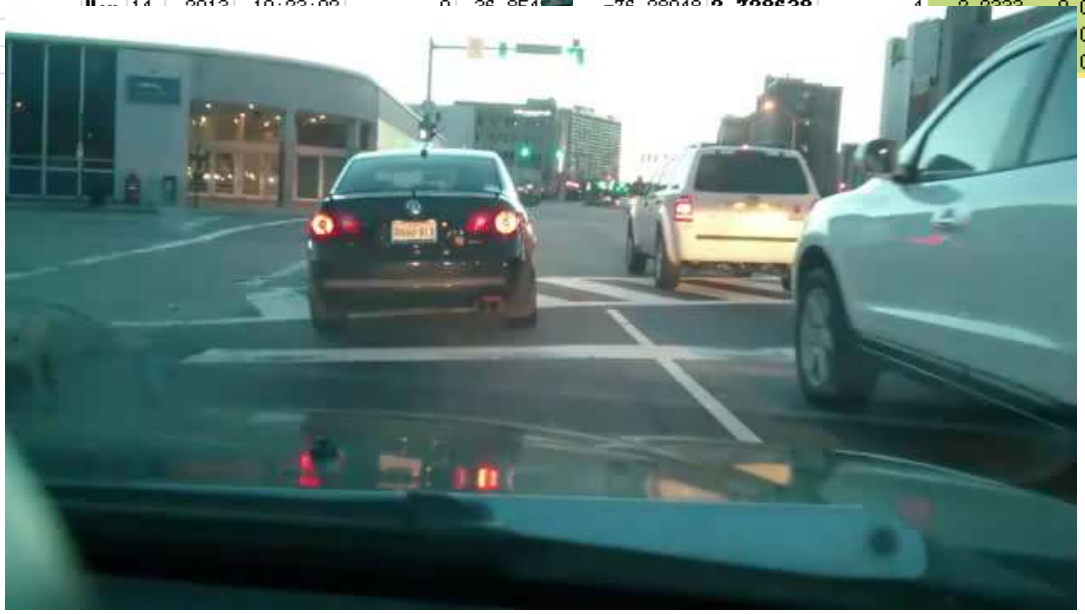
J -jerk
a-acceleration
v-velocity
d-distance

Methodology: Vehicle jerking decisions



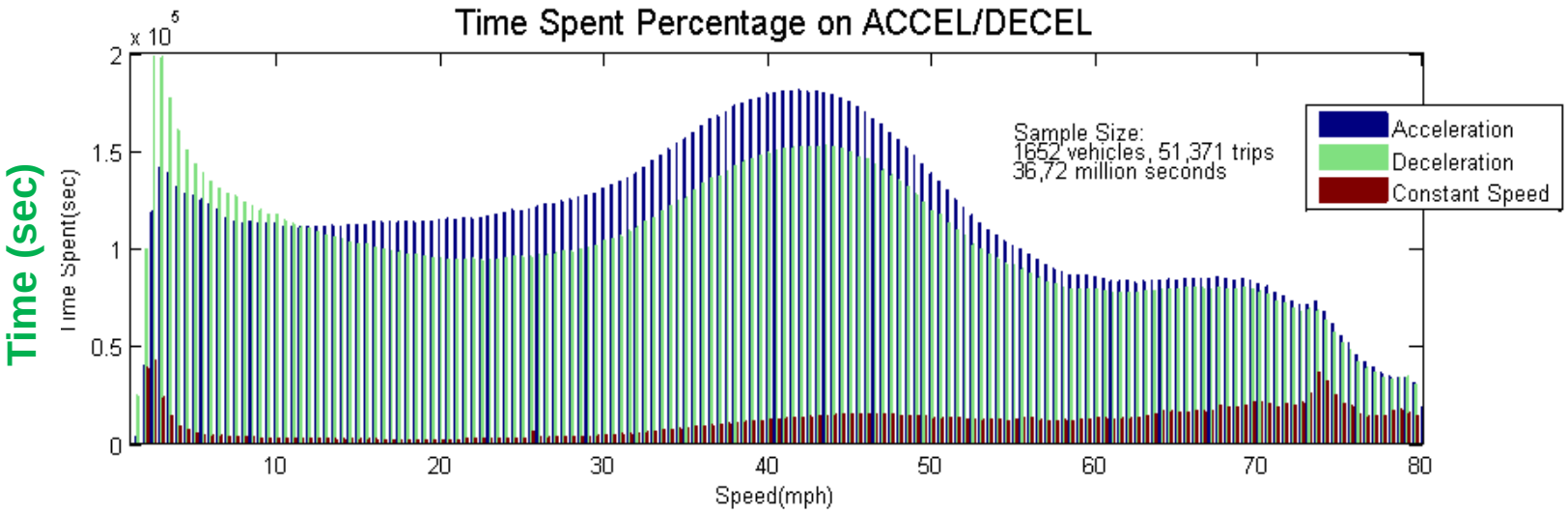
Note: j=jerk; a_i=acceleration at time i; a_{i+1}=acceleration at time i+1

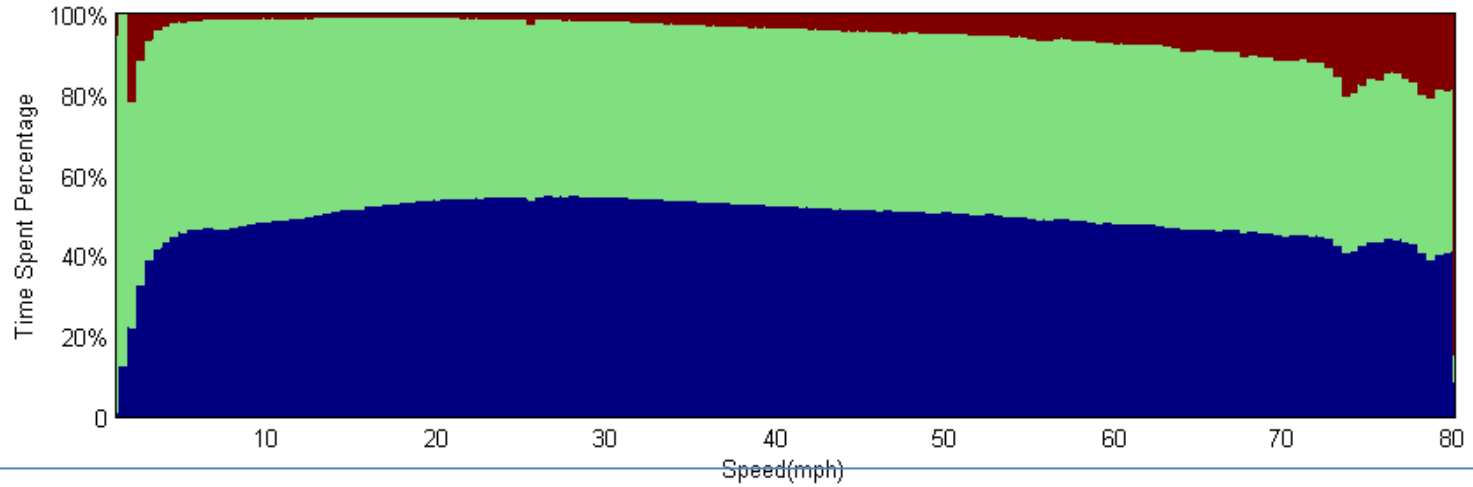
	SPEED (mph)	Acc (mph/s)	jerk (mph/s2)	volatile	MONTH	DAY	YEAR	TIME	Slope (%)	LATITUDE	LONGITUDE	VSP (kW/ton)	Modo VSP	CO_2 (g/s)	CO (g/s)	NOX (g/s)	HC (g/s)	Fuel (l/s)	Fuel (gll/km
2	0				Mar	14,	2013	19:22:41	0	36.85427	-76.28715	**0**	3	1.1354	0.0033	0.0003	0.0004	0.00042	0.000105
3	0.625	0.625			Mar	14,	2013	19:22:42	0	36.85427	-76.28715	**0.12155**	3	1.1354	0.0033	0.0003	0.0004	0.00042	0.000105
4	2.5	1.875	1.25		Mar	14,	2013	19:22:43	0	36.85427	-76.28718	**1.165599**	4	2.2333	0.0083	0.0012	0.0004	0.00082	0.000207
5	2.5	0	-1.875	1	Mar	14,	2013	19:22:44	0	36.85427	-76.28718	**0.147081**	3	1.1354	0.0033	0.0003	0.0004	0.00042	0.000105
6	8.75	6.25	6.25	1	Mar	14,	2013	19:22:45	0	36.85428	-76.28724	**12.41381**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
7	13.125	4.375	-1.875		Mar	14,	2013	19:22:46	0	36.85428	-76.28731	**13.3068**	8	4.635	0.0292	0.0042	0.001	0.00171	0.00043
8	16.25	3.125	-1.25		Mar	14,	2013	19:22:47	0	36.8543	-76.28748	**12.10105**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
9	16.25	0	-3.125	1	Mar	14,	2013	19:22:48	0	36.8543	-76.28748	**1.067101**	4	2.2333	0.0083	0.0012	0.0004	0.00082	0.000207
10	19.375	3.125	3.125	1	Mar	14,	2013	19:22:49	0	36.85431	-76.28769	**14.48537**	8	4.635	0.0292	0.0042	0.001	0.00171	0.00043
11	20	0.625	-2.5		Mar	14,	2013	19:22:50	0	36.85431	-76.28779	**4.101487**	5	2.9199	0.011	0.0017	0.0005	0.00108	0.000271
12	21.875	1.875	1.25		Mar	14,	2013	19:22:51	0	36.85432	-76.2879	**10.4729**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
13	21.875	0	-1.875		Mar	14,	2013	19:22:52	0	36.85432	-76.2879	**1.560859**	4	2.2333	0.0083	0.0012	0.0004	0.00082	0.000207
14	24.375	2.5	2.5	1	Mar	14,	2013	19:22:53	0	36.85433	-76.28802	**15.05471**	8	4.635	0.0292	0.0042	0.001	0.00171	0.00043
15	24.375	0	-2.5	1	Mar	14,	2013	19:22:54	0	36.85433	-76.28802	**1.813966**	4	2.2333	0.0083	0.0012	0.0004	0.00082	0.000207
16	28.125	3.75	3.75	1	Mar	14,	2013	19:22:55	0	36.85436	-76.28832	**25.15651**	11	6.5348	0.1138	0.0076	0.0021	0.00241	0.000606
17	29.375	1.25	-2.5	1	Mar	14,	2013	19:22:56	0	36.85436	-76.28856	**10.37377**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
18	30	0.625	-0.625		Mar	14,	2013	19:22:57	0	36.85436	-76.28871	**6.549926**	5	2.9199	0.011	0.0017	0.0005	0.00108	0.000271
19	29.375	-0.625	-1.25		Mar	14,	2013	19:22:58	0	36.85439	-76.28886	**-1.59383**	2	1.458	0.0039	0.0006	0.0003	0.00054	0.000135
20	30.625	1.25	1.875		Mar	14,	2013	19:22:59	0	36.8544	-76.289	**10.8761**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
21	31.875	1.25	0		Mar	14,	2013	19:23:00	0	36.85438	-76.28918	**11.38605**	7	4.1075	0.02	0.0031	0.0008	0.00152	0.000381
22	31.875	0	-1.25		Mar	14,	2013	19:23:01	0	36.85438	-76.28932	**2.728638**	4	2.2333	0.0083	0.0012	0.0004	0.00082	0.000207
23	31.875	0	0												0083	0.0012	0.0004	0.00082	0.000207
24	31.875	0	0												0083	0.0012	0.0004	0.00082	0.000207
25	31.875	0	0												0083	0.0012	0.0004	0.00082	0.000207



7% - idling & speed<5 mph
47% -acceleration
41% -deceleration
5% -maintaining speed

Volatility: REGIONAL LEVEL

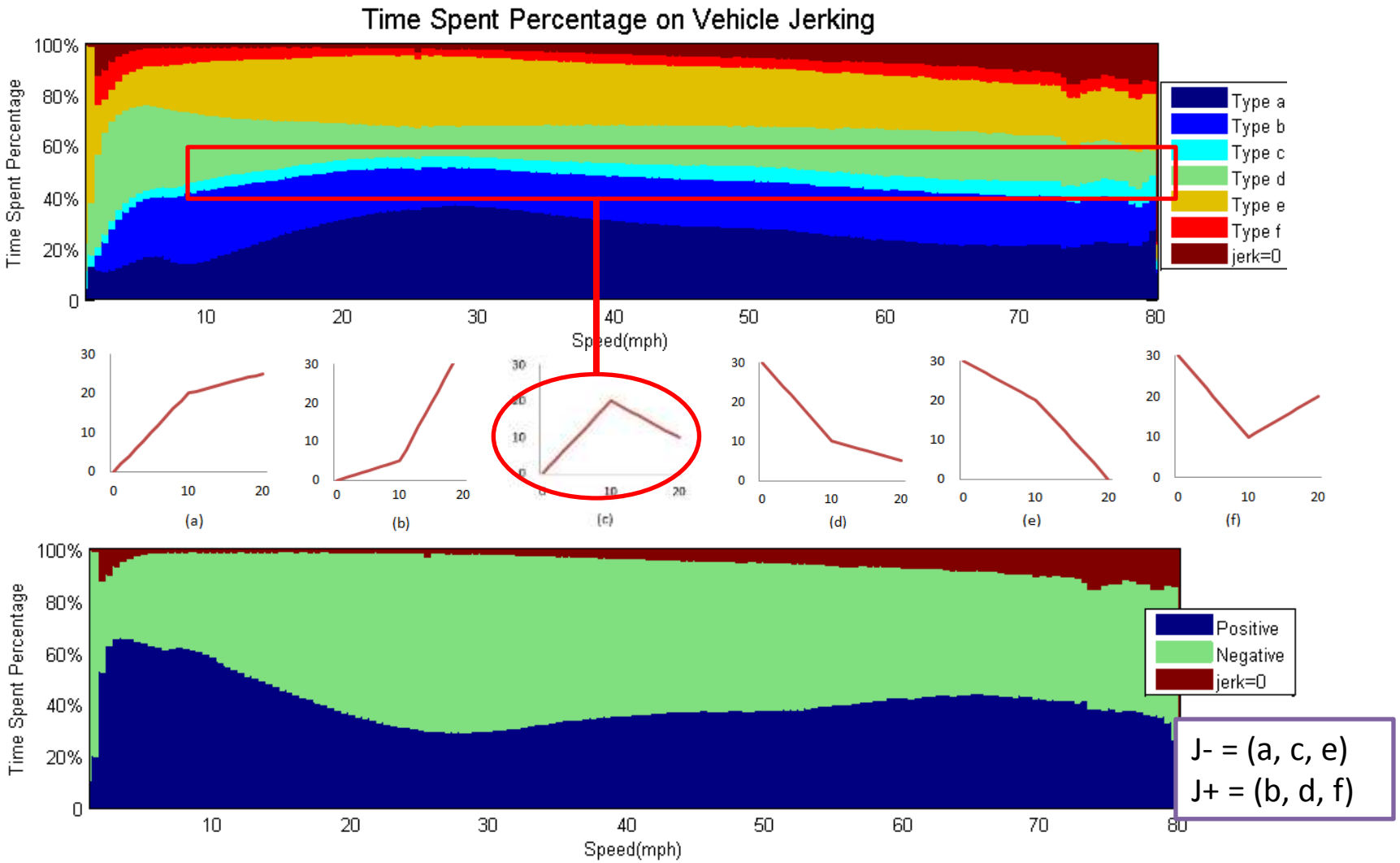




Separate out for: congested/uncongested & road type

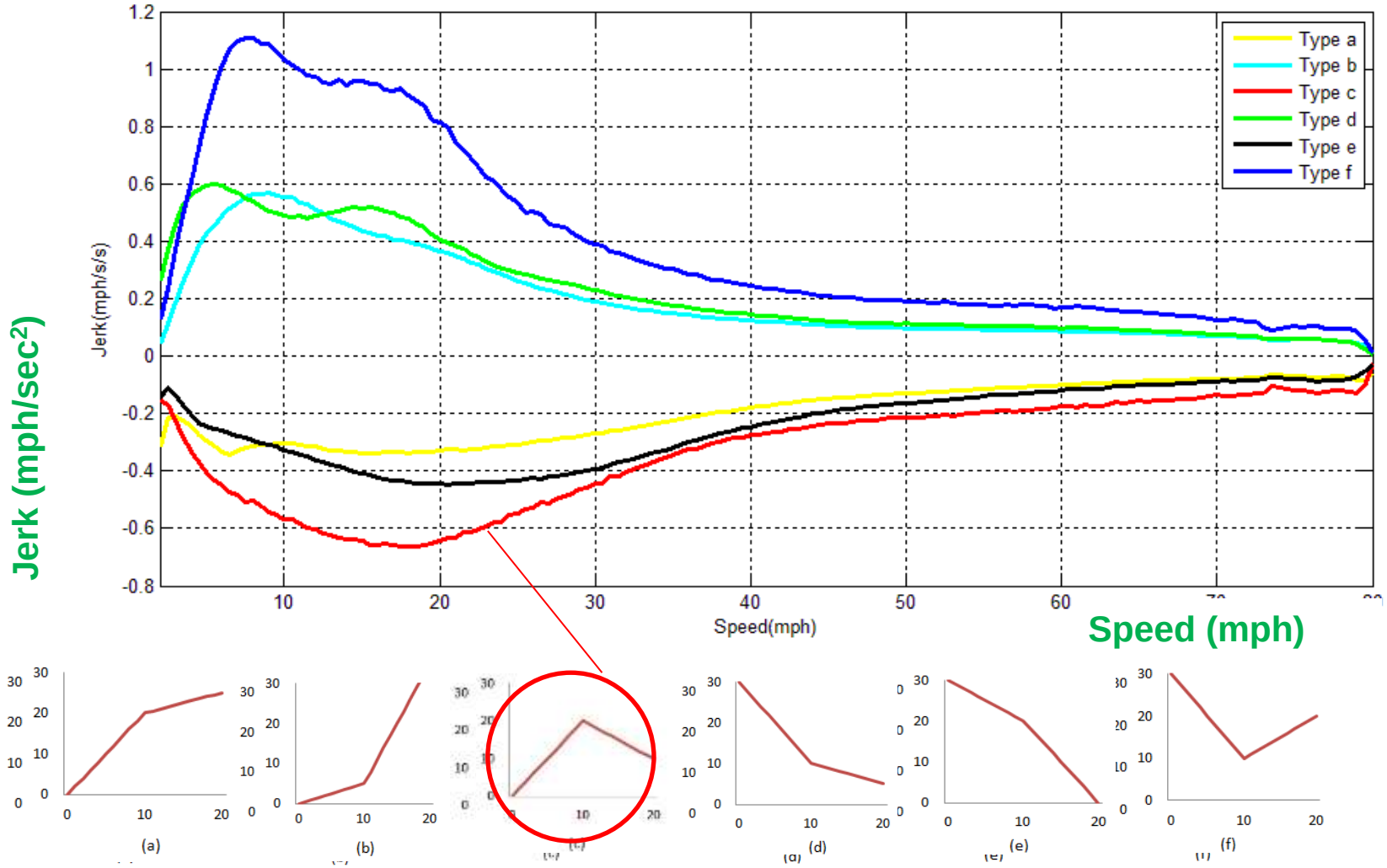
Volatility Profile: REGIONAL LEVEL

Negative jerk compared with positive jerk (53.79% vs. 40.83%).



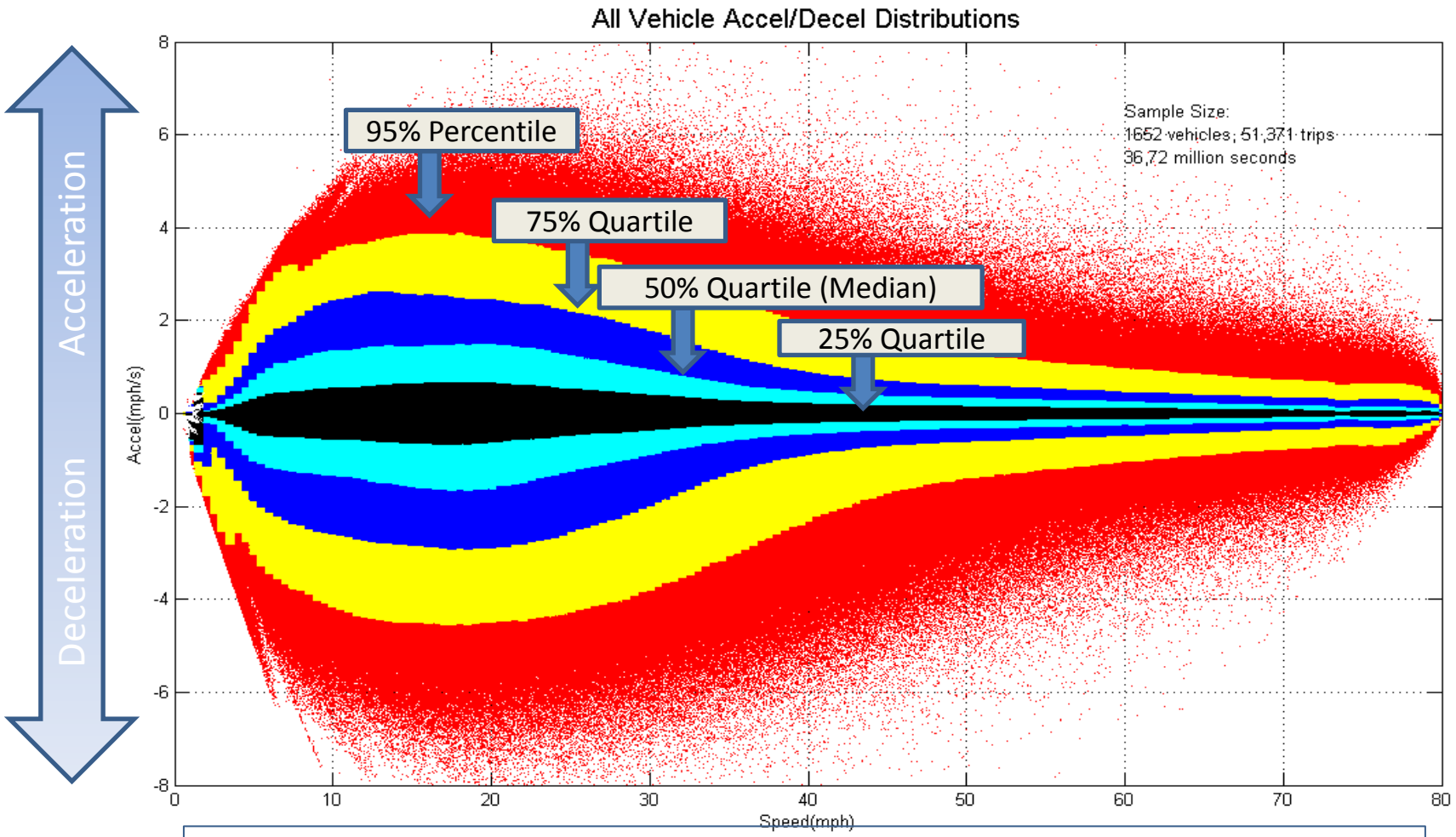
Sample Size: 36,715,308 secon

Volatility Profile: REGIONAL LEVEL
Speed vs. Vehicular jerk



Sample Size: 36,715,308 seconds

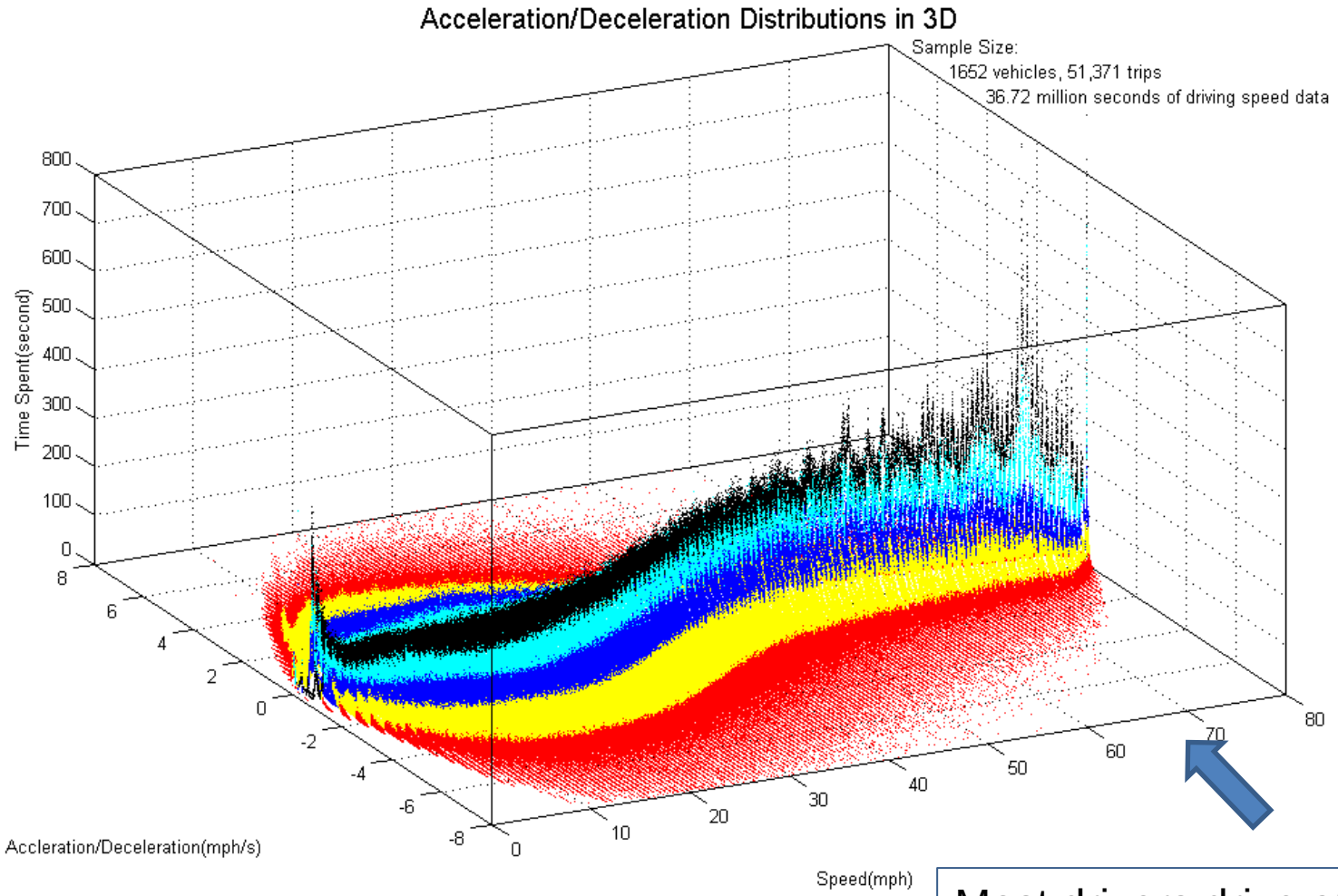
Volatility Profile: REGIONAL LEVEL ACCEL/DECEL-Bands



At lower speeds, acceleration magnitude is less than deceleration.

Sample Size: 36,715,308 sec

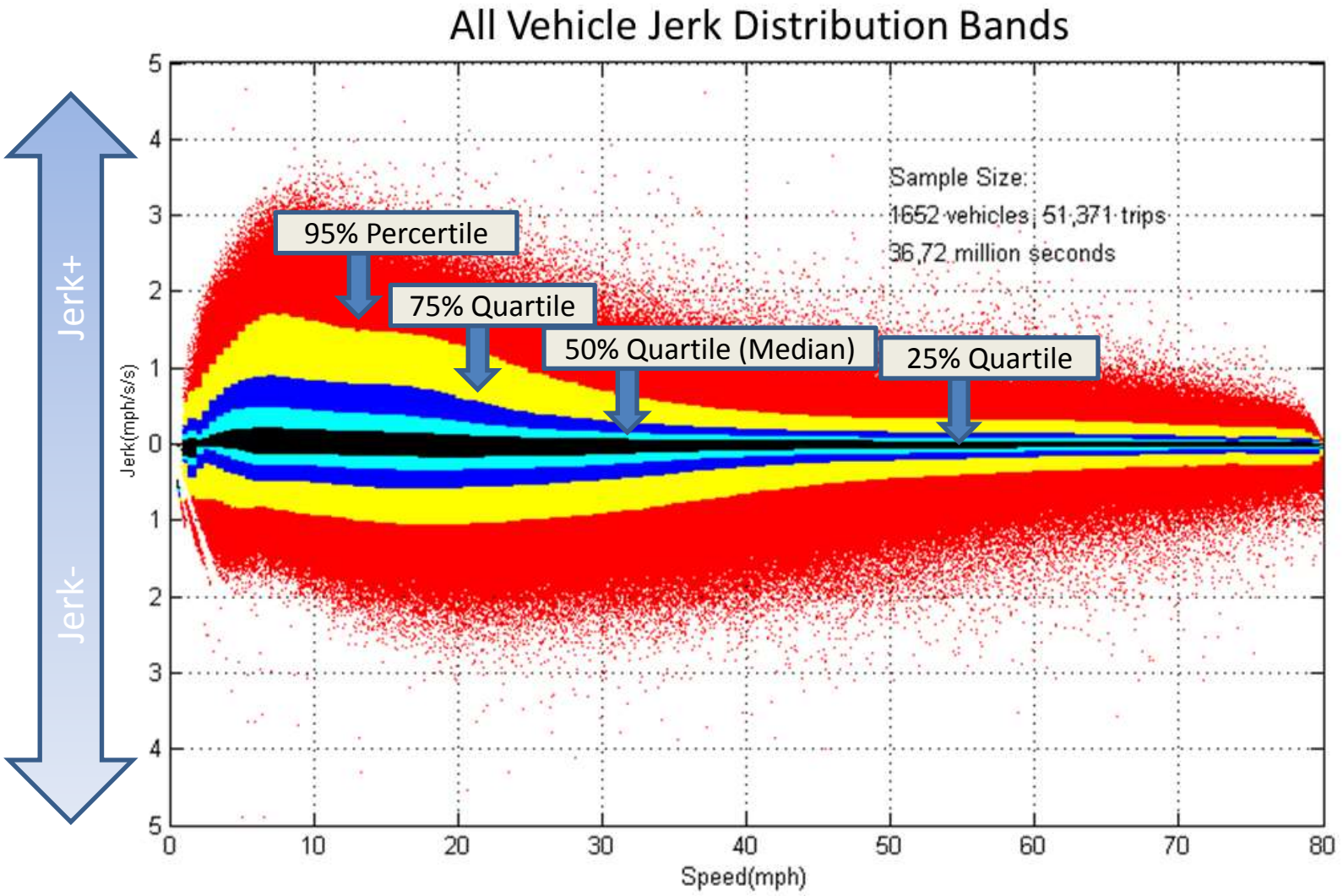
Volatility Profile: REGIONAL LEVEL ACCEL/DECEL-Bands in 3D



Most drivers drive at around 70 mph-their interstate speed

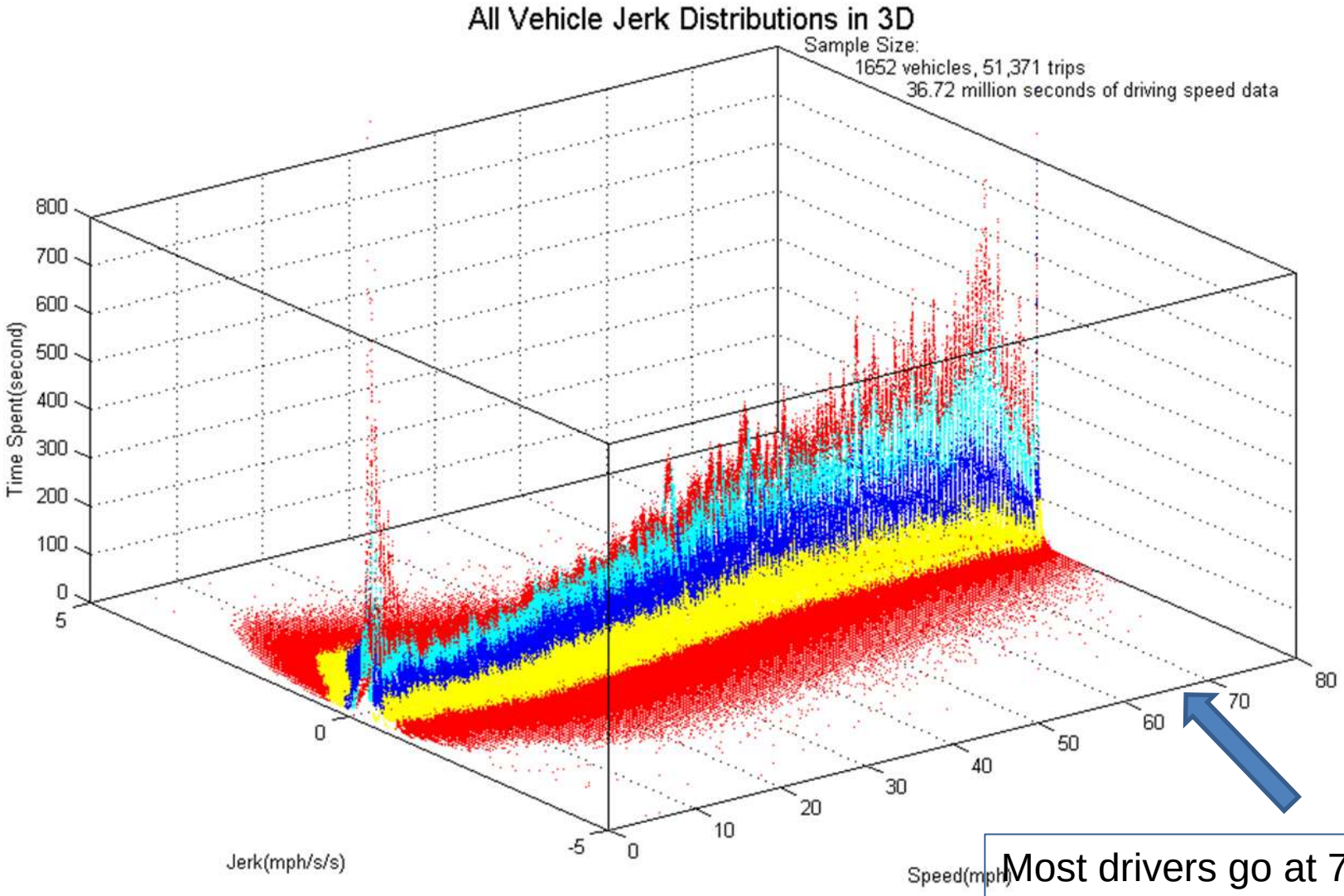
Sample Size: 36,715,308 sec

Volatility Profile: REGIONAL LEVEL Jerk+/Jerk- Bands



Sample Size: 36,715,308 seconds

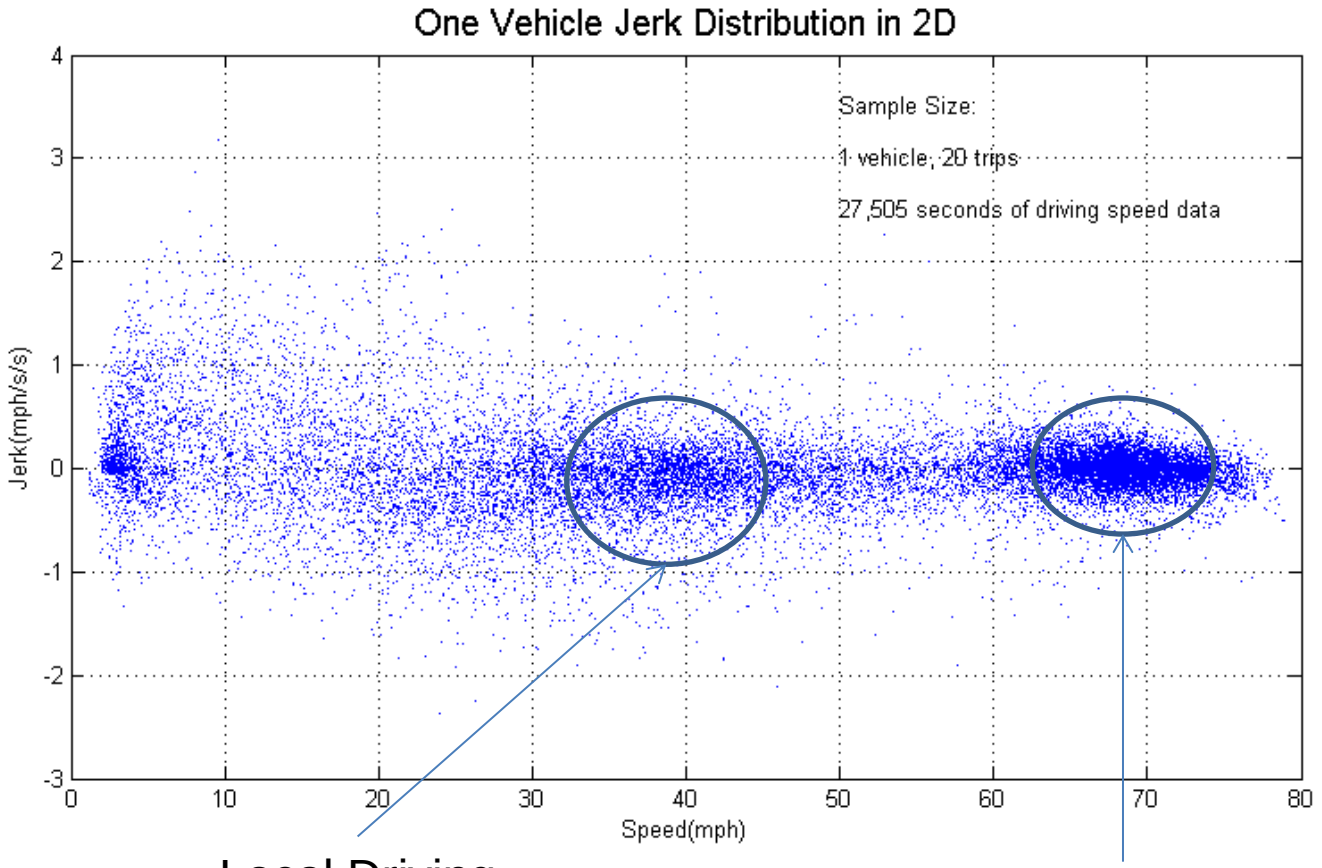
Volatility Profile: REGIONAL LEVEL Jerk Distribution



Most drivers go at 70 mph on interstates

Sample Size: 36,715,308 seconds

Volatility Profile: Individual Driver



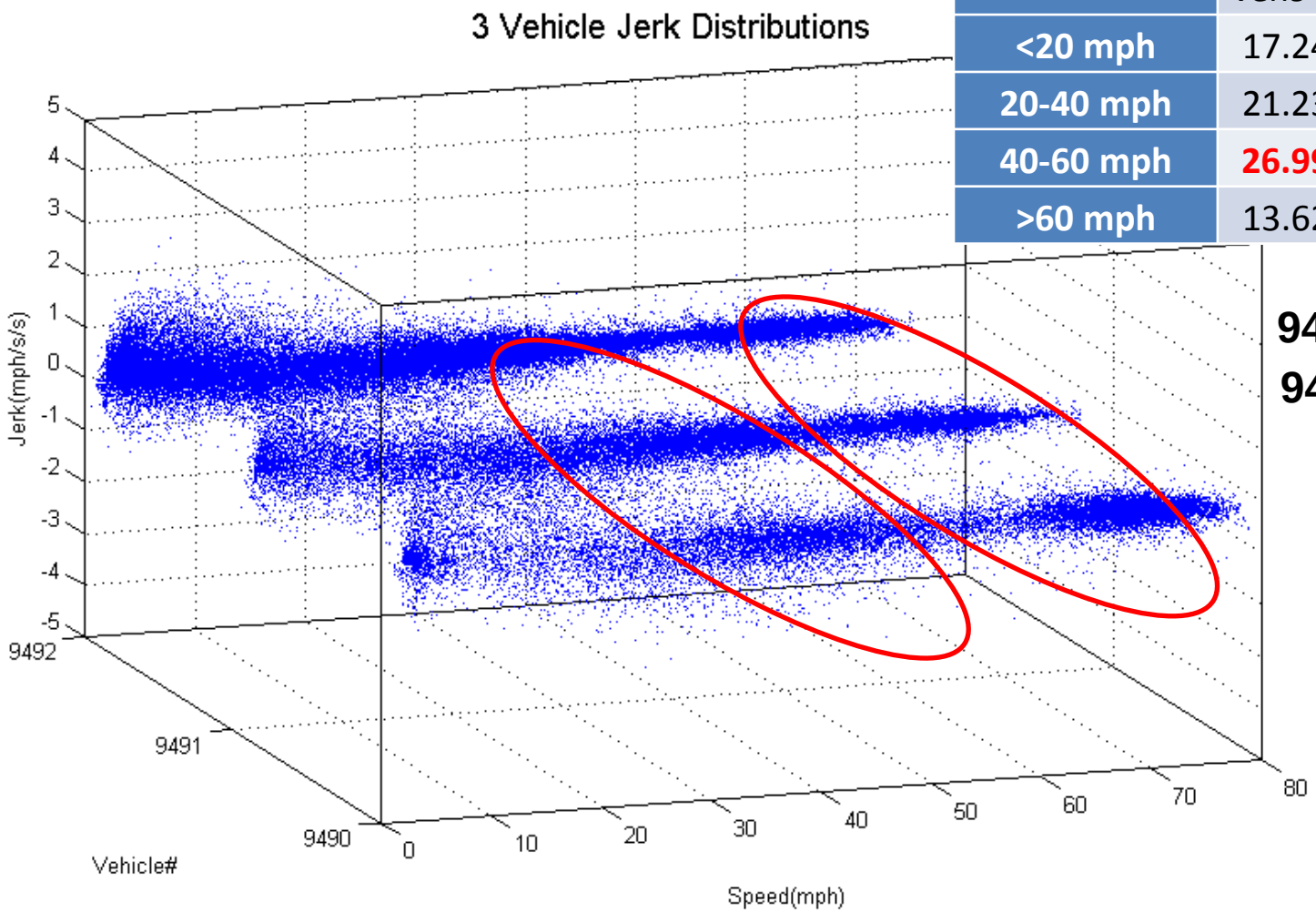
Local Driving

Interstate Driving
5-10 mph over posted speed limit

Sample Size: 27,505 seconds

Volatility Profile: Compare Drivers

Volatility score in different speed ranges			
Speed Range	veh9490	veh9491	veh9492
<20 mph	17.24%	12.60%	8.47%
20-40 mph	21.23%	12.92%	6.61%
40-60 mph	**26.99%**	15.02%	7.50%
>60 mph	13.62%	12.63%	9.39%



9490: high volatility

9492: less volatility

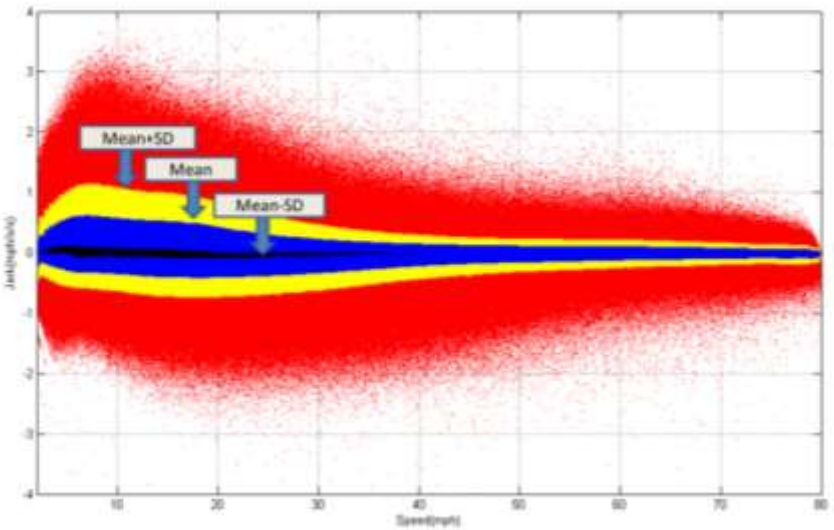
Volatility profile: Trip Level Volatility Score for each trip

- For each second of the trip, tag volatile second when ***Acceleration/Jerk is out of the band range***

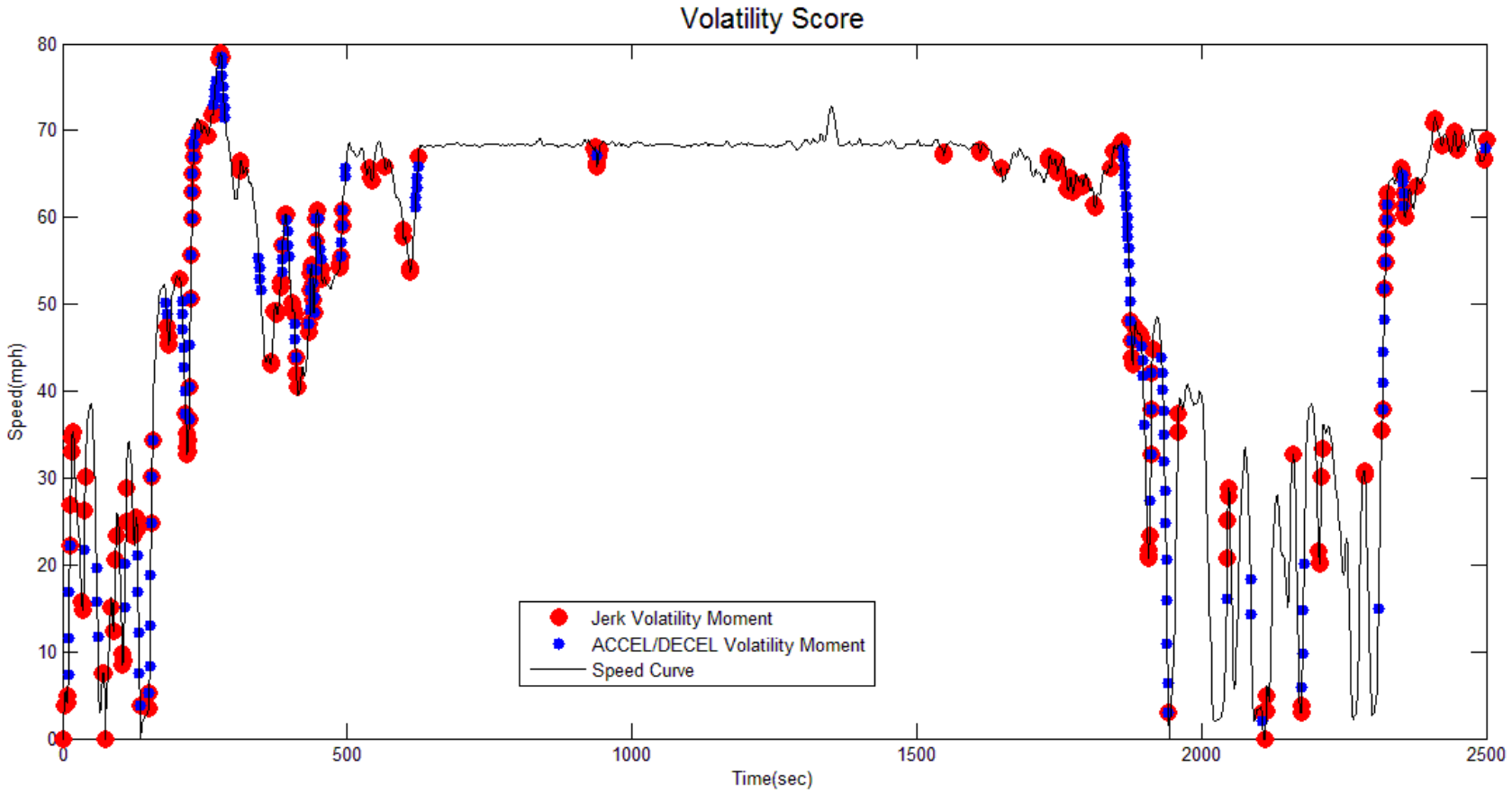
Red Area

- For each trip, calculate % of time tagged as "volatile" seconds

Volatility Score



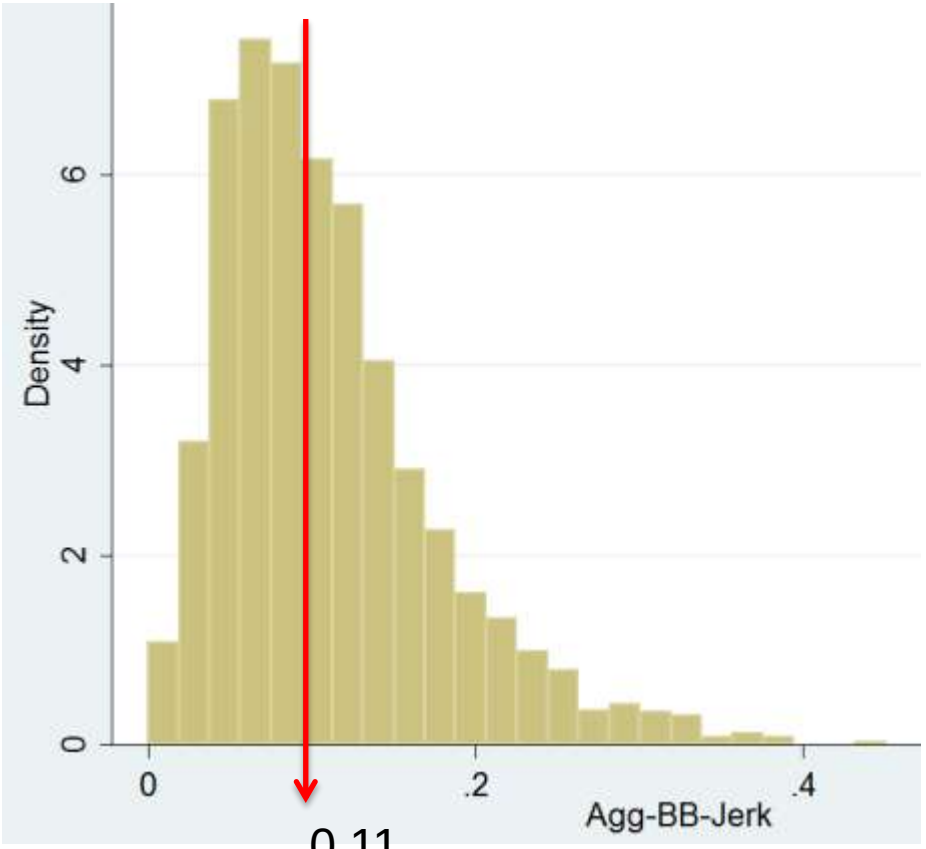
Volatility Score: Decision points



Jerk better captures critical decision points
volatility score - 8.6% using jerk bands
- 6.1% using acceleration bands

Volatility score: subsample

- Sample: Pick one weekday for each person
  - 543 households
  - 843 drivers
  - 857 vehicles
  - 3962 trips



Results: Descriptive Stats & ANOVA

Variable List	Level	COMMUTE TRIPS					NON-COMMUTE TRIPS				
		(% in sample)	Volatility Score		ANOVA P-value	ANOVA F-test	(% in sample)	Volatility Score		ANOVA P-value	ANOVA F-test
			Mean	SD				Mean	SD		
Person Variable (N=507 for commute, N=722 for non-commute)	Gender	Male (43%)	10.59	6.54	base	0.035	(55%)	9.81	6.79	base	0.000
		Female (57%)	11.35	6.59	0.035		(45%)	11.35	7.21	0.000	
	Age	16-24yrs (7.5%)	14.23	6.81	base	0.000	(6.0%)	11.82	6.62	base	0.002
		25-34yrs (11.9%)	12.03	6.51	0.007		(8.3%)	11.31	7.72	0.480	
		35-44yrs (27.4%)	11.83	7.13	0.001		(20.1%)	11.11	7.01	0.260	
		45-54yrs (31.9%)	10.24	6.36	0.000		(30.3%)	10.62	7.02	0.049	
		55-64yrs(16.4%)	9.70	5.51	0.000		(22.8%)	10.46	7.32	0.029	
		>65yrs (5%)	8.69	5.01	0.000		(12.5%)	9.41	6.36	0.000	
Vehicle Type (N=507 for commute, N=736 for non-commute)	Auto-Sedan	(44%)	11.6	6.66	base	0.000	(42%)	11.4	7.58	base	0.000
	Two Seated	(4%)	13.7	8.60	0.022		(3%)	12.59	6.56	0.125	
	Van	(9%)	9.84	5.91	0.914		(12%)	10.97	6.31	0.000	
	RV	(0.2%)	6.91	4.90	0.151		(0.1%)	11.16	6.14	0.953	
	SUV	(28%)	10.38	6.41	0.002		(28%)	10.06	6.51	0.000	
	Station Wagon	(2%)	13.61	7.40	0.0122		(2%)	17.07	9.31	0.000	
	Pickup	(13%)	10.47	5.58	0.000		(12%)	9.93	5.83	0.000	
Vehicle Fuel Type	Gasoline	(96%)	11.01	6.46	base	0.000	(97%)	10.65	7.09	base	0.146
	Diesel	(2%)	9.91	5.60	0.390		(1%)	4.5	4.57	0.062	
	Hybrid	(2%)	15	10.57	0.003		(1%)	12.34	7.58	0.226	
	Flex Fuel	(0.5%)	11.69	3.97	0.000		(1%)	12.13	5.73	0.350	
Trip Variable (N=1369 for commute, N=2702 for non-commute)	AM Rush	(41%)	11.21	6.69	0.299	0.755	(26%)	10.99	7.16	0.083	0.292
	Lunch Rush	(6%)	10.78	5.78	0.956		(7%)	10.3	6.99	0.868	
	PM Rush	(29%)	11.03	6.37	0.550		(29%)	10.77	7.14	0.257	
	Non Rush	(24%)	9.74	6.82	Base		(37%)	10.39	6.94	Base	
	Distance	0-15mile (78.1%)	11.75	6.92	Base	0.000	(88.4%)	11.05	7.24	Base	0.000
		15-30mile(15.3%)	8.91	4.58	0.000		(8.3%)	8.05	4.95	0.000	
		30-45mile(5.4%)	7.73	3.50	0.000		(2.4%)	7.09	3.33	0.000	
		>45mile(1.2%)	5.59	1.34	0.001		(0.8%)	5.18	3.83	0.000	

Average Volatility Score: **11%** for both commute and non-commute trips

Simple OLS model

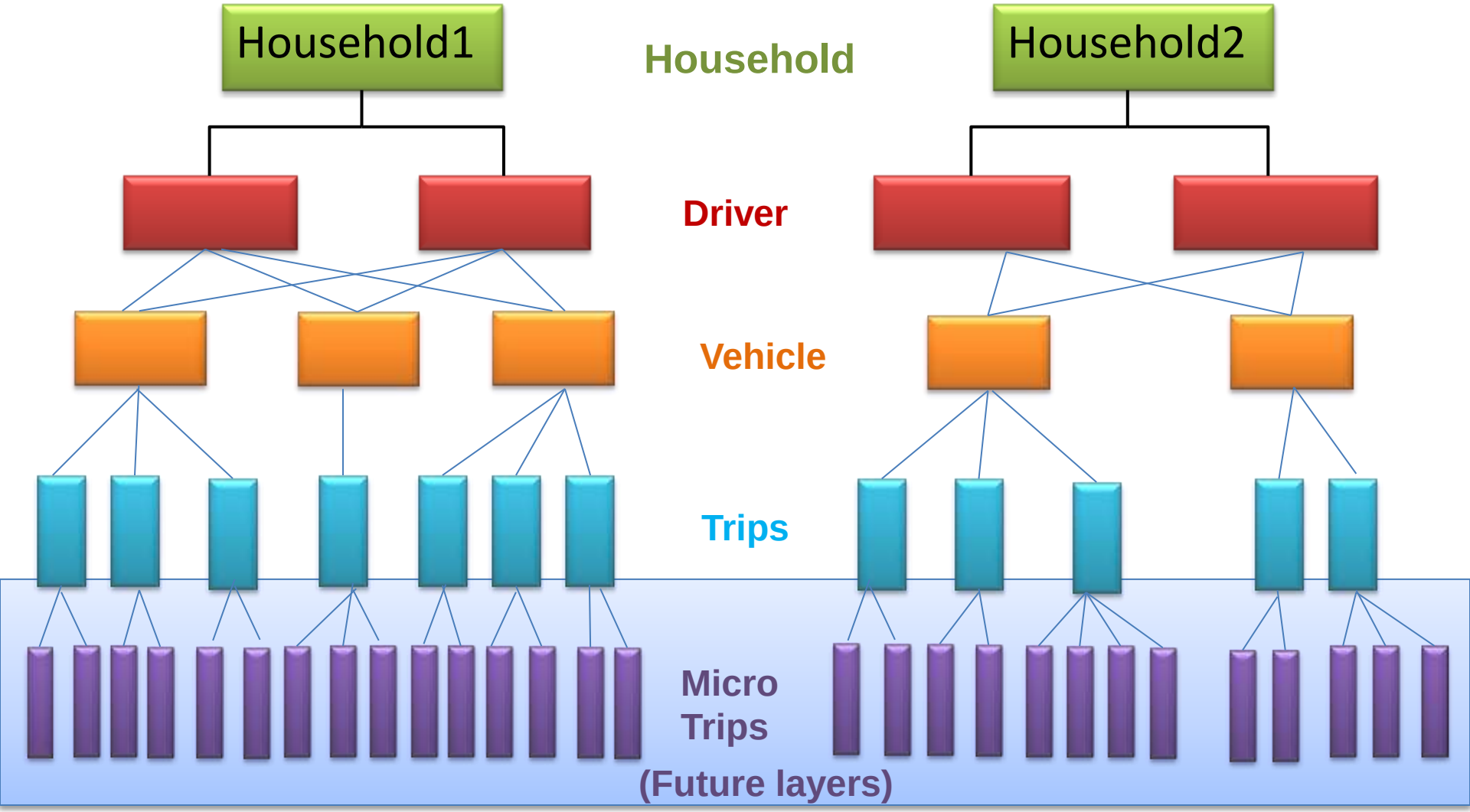
Variable List		Coefficient	P-Value
Person Variable	Gender: Female	0.747	0.000
	Age: 25-34yrs	-0.634	0.119
	Age: 35-44yrs	-0.657	0.058
	Age: 45-54yrs	-1.399	0.000
	Age: 55-64yrs	-2.018	0.000
	Age: >65yrs	-2.880	0.000
Vehicle Type	Two Seated	1.419	0.025
	Van	-1.518	0.000
	RV	-3.478	0.155
	SUV	-1.241	0.000
	Station Wagon	4.266	0.000
	Pickup	-1.946	0.000
Vehicle Fuel Type	Diesel	-0.234	0.403
	Hybrid	2.290	0.057
	Flex Fuel	-0.765	0.650
Trip Distance	Trip Distance	-0.127	0.000
Constant		13.291	0.000
Number of obs = 3962, Prob > F = 0.000, R-squared = 0.086			

- **Samples in this model are not independent**
  - **Same drivers make multiple trips**
  - **Members of same household not independent**

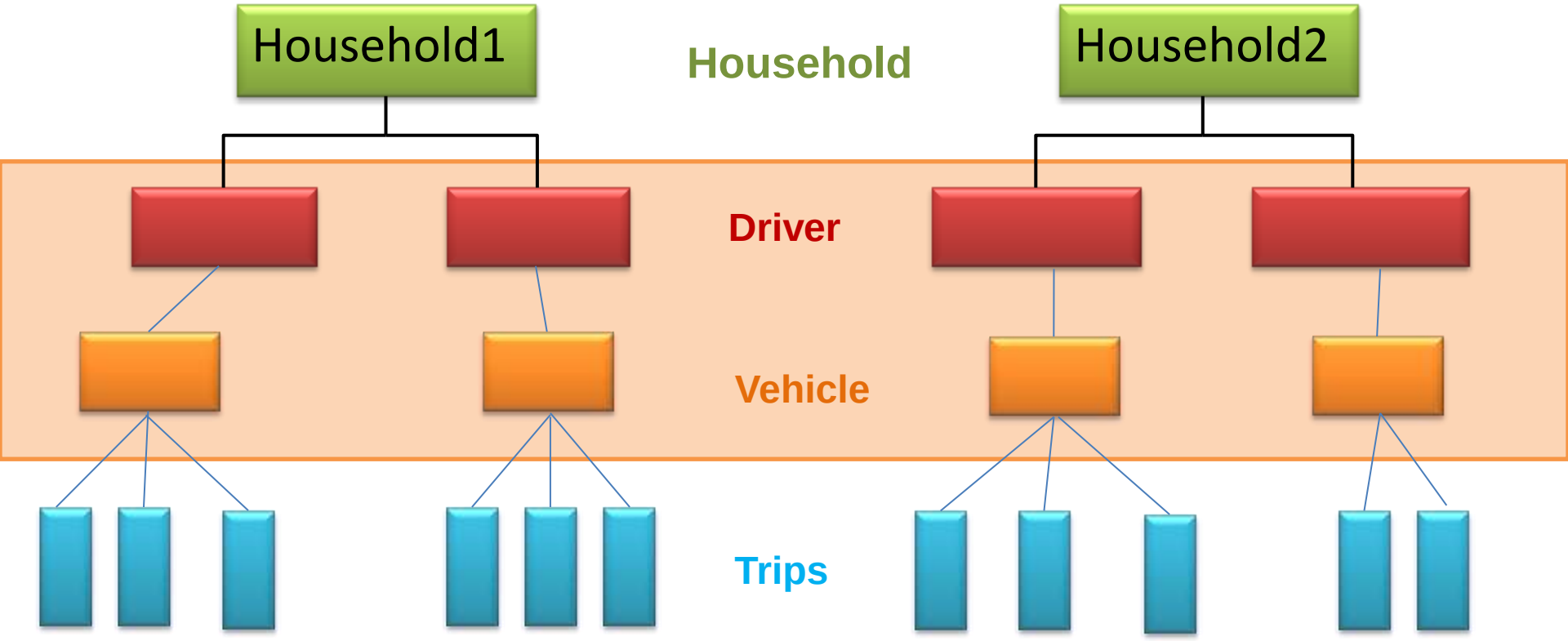
$V = \beta' X + e$

Hierarchical Structure

Too Complicated?



Simplified Hierarchical structure



Test 2 Layers - constant only model

Drivers differ in average volatility scores → inter-person differences

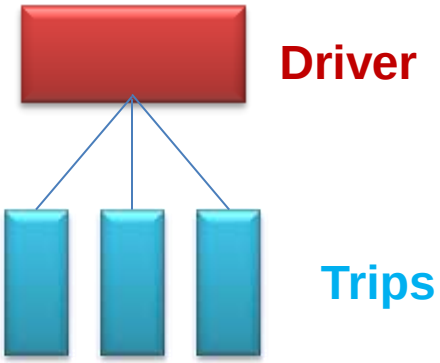
Inter-person variance nearly the same as inter-trip variance

```
Mixed-effects ML regression                     Number of obs      =      3962
Group variable: jointper                        Number of groups   =       843

                                                Obs per group: min =         1
                                                               avg =       4.7
                                                               max =        17

                                                Wald chi2(0)       =         .
Log likelihood =   5630.645                     Prob > chi2        =         .
```

AggBBJerk	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]
μ00 _cons	.1102476	.0018157	60.72	0.000	.1066889 .1138063

Random-effects Parameters		Estimate	Std. Err.	[95% Conf. Interval]
jointper: uoj	ity var(_cons)	.0021067	.0001354	.0018574 .0023904
rij	var(Residual)	.002474	.0000625	.0023545 .0026004

LR test vs. linear regression: chibar2(01) = 1162.31 Prob >= chibar2 = 0.0000



Volatility Fixed Inter-trip

$V_{ij} = \beta_{0j} + r_{ij}$

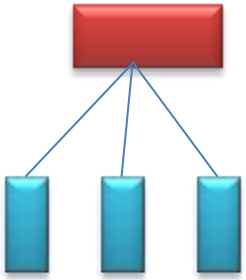
$\beta_{0j} = \mu_{00} + u_{0j}$ Inter-person

i-trip, j-driver Grand mean

OLS model problematic

2 Layers model – add person level variables

```
Mixed-effects ML regression                     Number of obs      =      3962
Group variable: jointper                        Number of groups   =       843

                                                Obs per group: min =
                                                               avg =         4
                                                               max =

                                                Wald chi2(2)       =     34.
Log likelihood =  5647.7375                     Prob > chi2        =    0.00
```



$V_{ij} = \beta_{0j} + r_{ij}$

$\beta_{0j} = \mu_{00} + \mu_{01}$ Age+ μ_{00} Gender + u_{0j}

i-trip, j-driver

AggBBJerk	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	-.0007087	.0001349	-5.26	0.000	-.000973	-.0004444
gender	.0080125	.0035979	2.23	0.026	.0009607	.0150643
_cons	.1393063	.0070721	19.70	0.000	.1254453	.1531673

μ01 μ02 μ00

Two fixed effects added

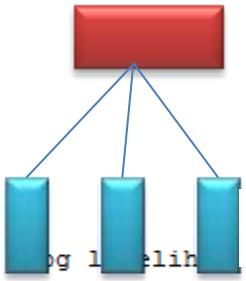
Random-effects Parameters	Estimate	Std. Err.	[95% Conf.	Interval]
jointper: Identity				
u_{0j} var(_cons)	.0020035	.0001299	.0017644	.0022751
r_{ij} var(Residual)	.0024724	.0000624	.0023529	.0025978

LR test vs. linear regression: chibar2(01) = 1114.48 Prob >= chibar2 = 0.0000

Dropped by 5%: Age & gender explain person-level variance; More variables needed to reduce unexplained var.

2 Layers model – add trip level variable

Cov (negative) sig. → evidence that association of volatility & trip distance is related to average volatility score of driver




```
Mixed-effects ML regression                     Number of obs      =      3962
Group variable: jointper                        Number of groups   =       843

                                                Obs per group: min =         1
                                                               avg =       4.7
                                                               max =        17

                                                Wald chi2(1)       =    227.25
log likelihood =                                Prob > chi2        =    0.0000
```

AggBBJerk	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]
distance	-.0014633	.0000971	-15.07	0.000	-.0016535 -.001273
_cons	.1215054	.0022111	54.95	0.000	.1171718 .1258391

μ10

μ00

Trip level variable added

Random-effects Parameters	Estimate	Std. Err.	[95% Conf. Interval]
jointper: Unstructured			
var(distance)	1.82e-06	3.08e-07	1.31e-06 2.54e-06
var(_cons)	.0029732	.0001994	.002607 .0033908
cov(distance,_cons)	-.0000736	8.03e-06	-.0000893 -.0000579
var(Residual)	.0022507	.0000567	.0021422 .0023646

u1j

u0j

rij

```
LR test vs. linear regression:       chi2(3) =  1324.80   Prob > chi2 = 0.0000

Note: LR test is conservative and provided only for reference.
```

$V_{ij} = \beta_{0j} + \beta_{1j}\ \text{Distance} + r_{ij}$

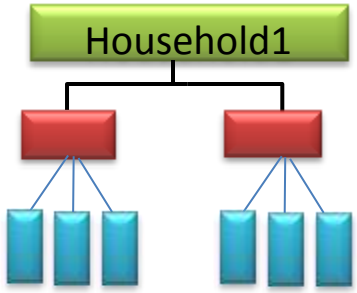
$\beta_{0j} = \mu_{00} + u_{0j}$

$\beta_{1j} = \mu_{10} + u_{1j}$

i-trip, j-driver

Dropped 8%: Distance explains trip-level variance

Test 3 layers- Constant only model



Households differ in their average volatility score;

Drivers differ in their average volatility within HH;

More Variance among different trips

3962

Group Variable	No. of Groups	Observations per Group Minimum	Average	Maximum
sampno	543	1	7.3	28
jointper	843	1	4.7	17

Log likelihood = 5643.2585

Wald chi2(0) = .

Prob > chi2 = .

AggBBJerk	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
μ _cons	.109926	.0019834	55.42	0.000	.1060386	.1138134

Random-effects Parameters		Estimate	Std. Err.	[95% Conf.	Interval]
sampno: Ide					
uk	var(_cons)	.0007775	.0001598	.0005197	.0011631
jointper: I	ty				
uik	var(_cons)	.0013223	.0001581	.001046	.0016
rijk	var(Residual)	.0024765	.0000626	.0023567	.0026

LR test vs. linear regression: chi2(2) = 1187.53 Prob > chi2 = 0.0000

$V_{ijk} = \beta + r_{ijk}$ (Inter-trip)

$\beta = \mu + u_k + u_{ik}$

Grand mean; Inter-HH; Inter-person

i-trip, j-driver k-household

OLS model problematic

Implications: Volatility is useful…

- Regional level:
  - how people drive→ traffic operations
  - 7% idling, 47% acceleration, 41% deceleration, 5% constant speed
- Individual level:
  - how each person compares with driving practices of sample → identify volatile drivers
- Trip level:
  - how a driver performs on a particular trip→ design intelligent driver feedback systems

Conclusions: All about Volatility

- What is Volatility?
  - It is a score for each trip
  - % of time driver jerks vehicle during trip
- How to properly measure volatility?
  - Using a regional jerk profile (Mean +/- SD)
- What is the level of volatility in discrete driving decisions?
  - On average, 11% of the time (based on 36 million seconds)

Conclusions

- What are the correlates of volatile instantaneous driving decisions?

  -Females↑, younger people↑, people driving station wagon or 2-seat sports car↑ people driving SUV and pickup↓

  - Shorter trip↑

  - Rush hour does not associate with volatility

Conclusions

- Simple hierarchical model:
  - Quantifies inter-person differences
  - Quantifies inter-trip differences exist
  - Association of trip level variables (e.g., trip length) with volatility may be related to a person's past behavior and attributes
- On-going research
  - To find variables that better explain relationships

Contributions

Fundamental in nature

- Driver's volatile instantaneous decisions: Analyzing large-scale GPS data
- Generate **Volatility Score** for **each trip**
- Understand typical driving practices in a metropolitan area
  - Time used to ACCEL/DECEL
  - Variance in ACCEL/DECEL/Jerk
  - Relationships: Speeds vs. ACCEL/DECEL/Jerk

Limitations & future work

- Limitations
  - Some variables not available to researchers, e.g., geo-codes, type of roads, congestion
  - Accuracy of GPS data (constrained to 7-14 ft.)

- Future work
  - Modeling volatility (hierarchical models)
  - Explore role of technology, environment & land use
  - Comparative studies in different regions/states