Carbin App: A crowdsourced approach for monitoring quality of roads and their environmental impact

Jacob Roxon

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2019 Arizona Pavements/Materials Conference

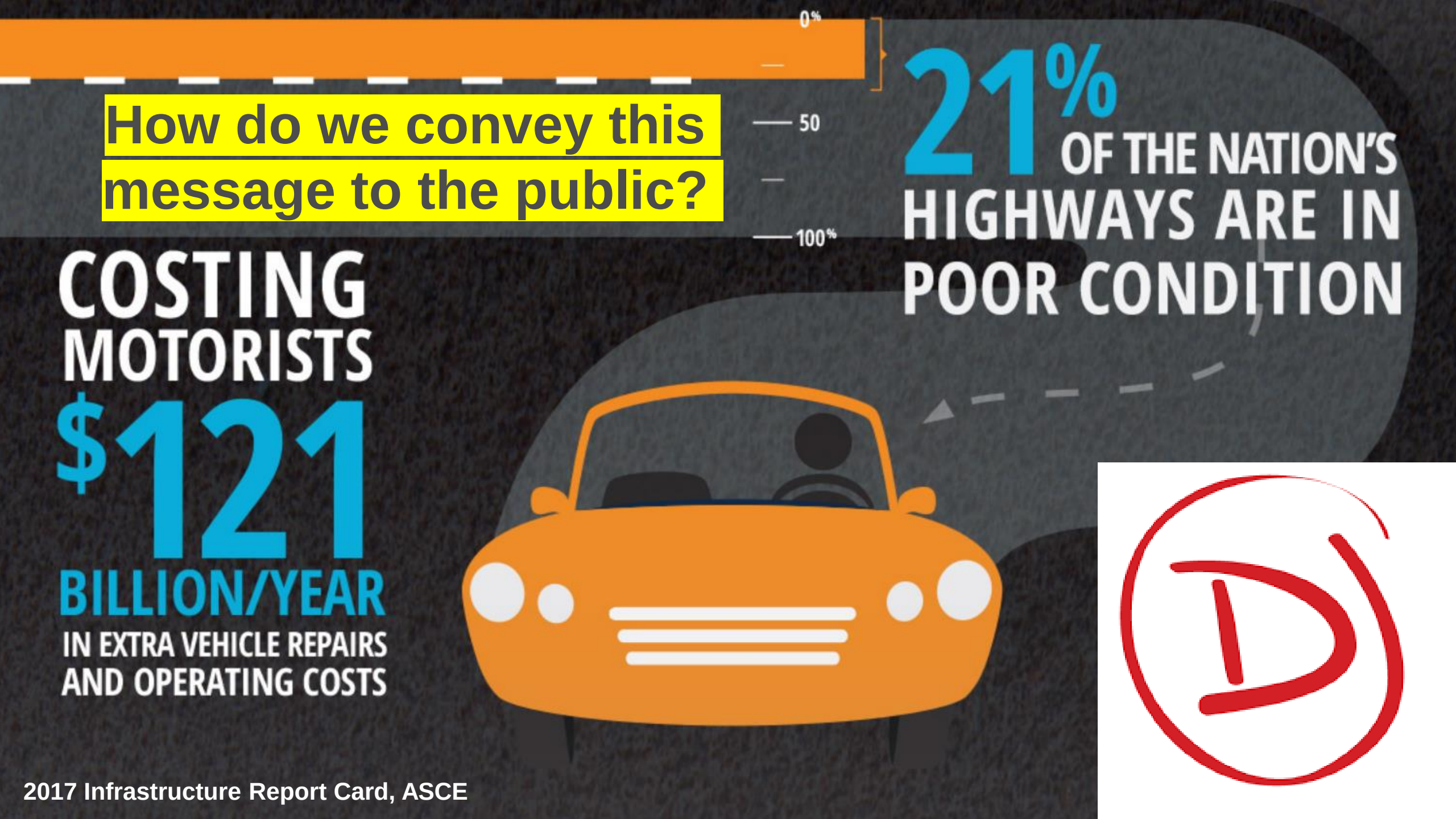
1)Safety

2)Traffic

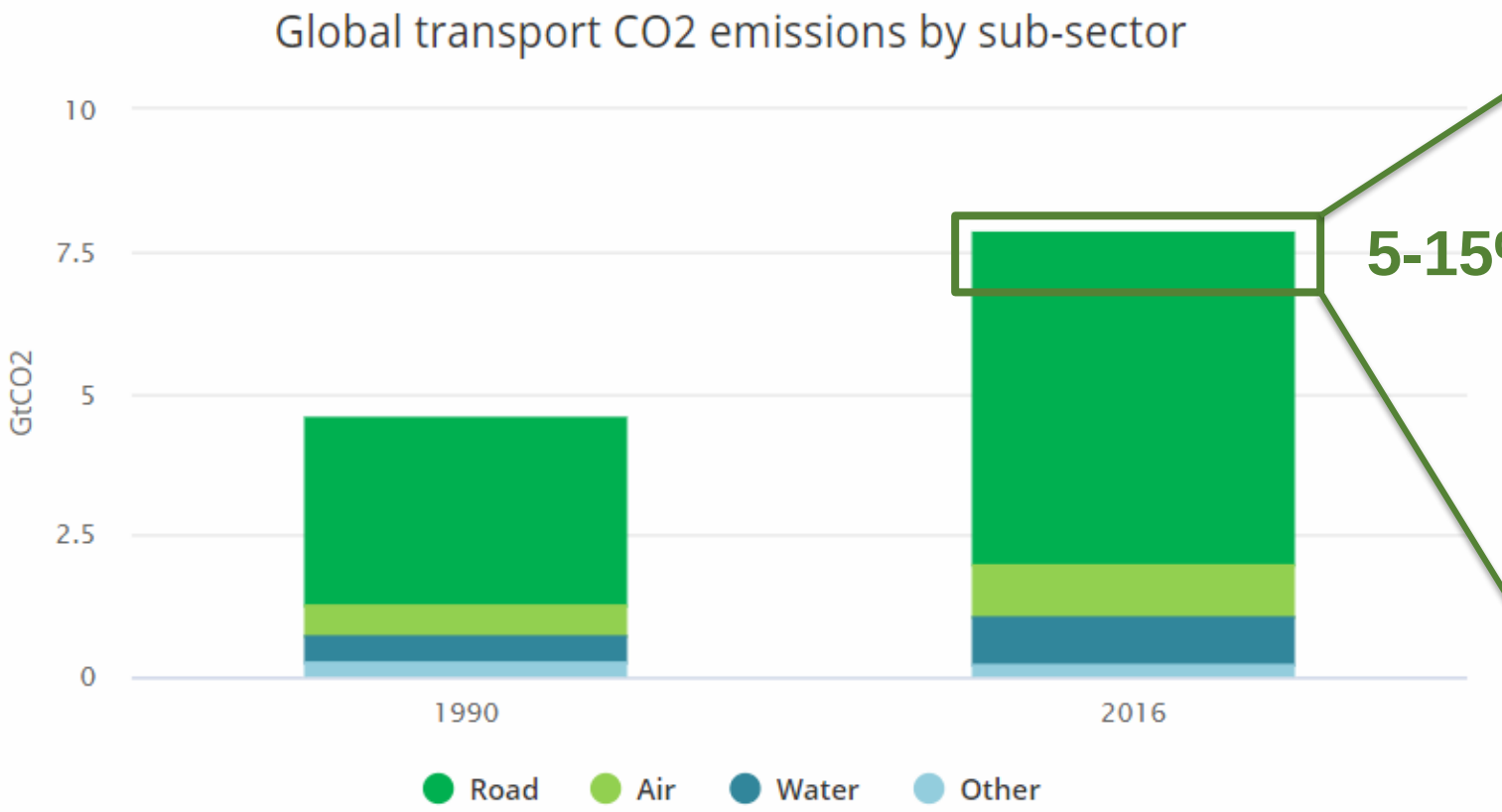
3)Comfort of driving

4)Fuel Consumption

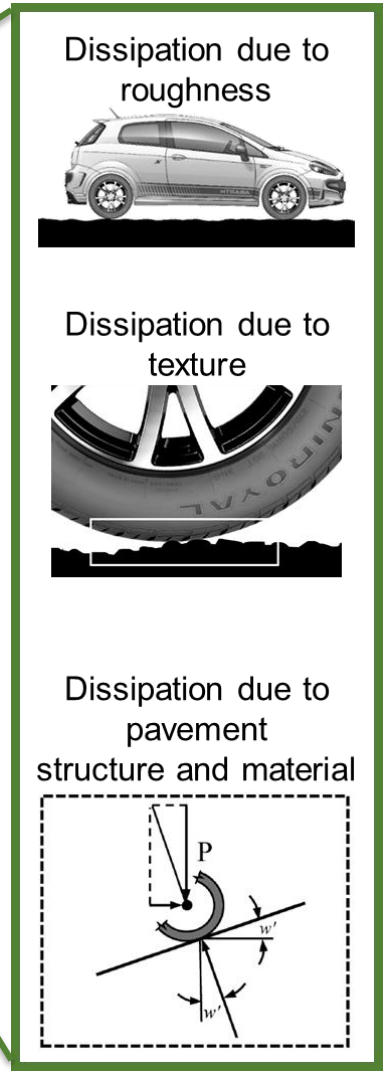
5)Quality of Air


How do we convey this message to the public?
0%
50
100%
21% OF THE NATION'S HIGHWAYS ARE IN POOR CONDITION
COSTING MOTORISTS
$121
BILLION/YEAR
IN EXTRA VEHICLE REPAIRS AND OPERATING COSTS
D
2017 Infrastructure Report Card, ASCE

Quality of roads affects fuel economy and GHG emissions.



5-15%



How do we convey this message to the public?

Additional Challenge: How do we monitor performance of roads while addressing CLIMATE CHANGE?

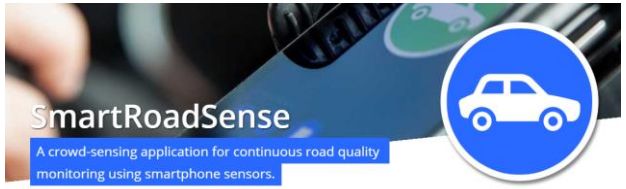
> 1,000,000,000 vehicles

> 50,000,000 miles of roads

Current approaches only measure the current state of infrastructure (i.e. IRI) without ability to predict the future, not to mention GHG…

Laser/camera systems aren't scalable ($100-300 per lane mile)

Crowdsourced apps not designed to be crowdsourced.



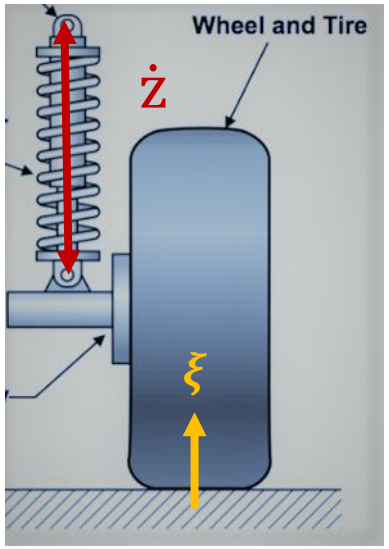
Aimed towards a technical user

IRI … Universal Ride Quality Measure

Car Body (mass) Attaches Here

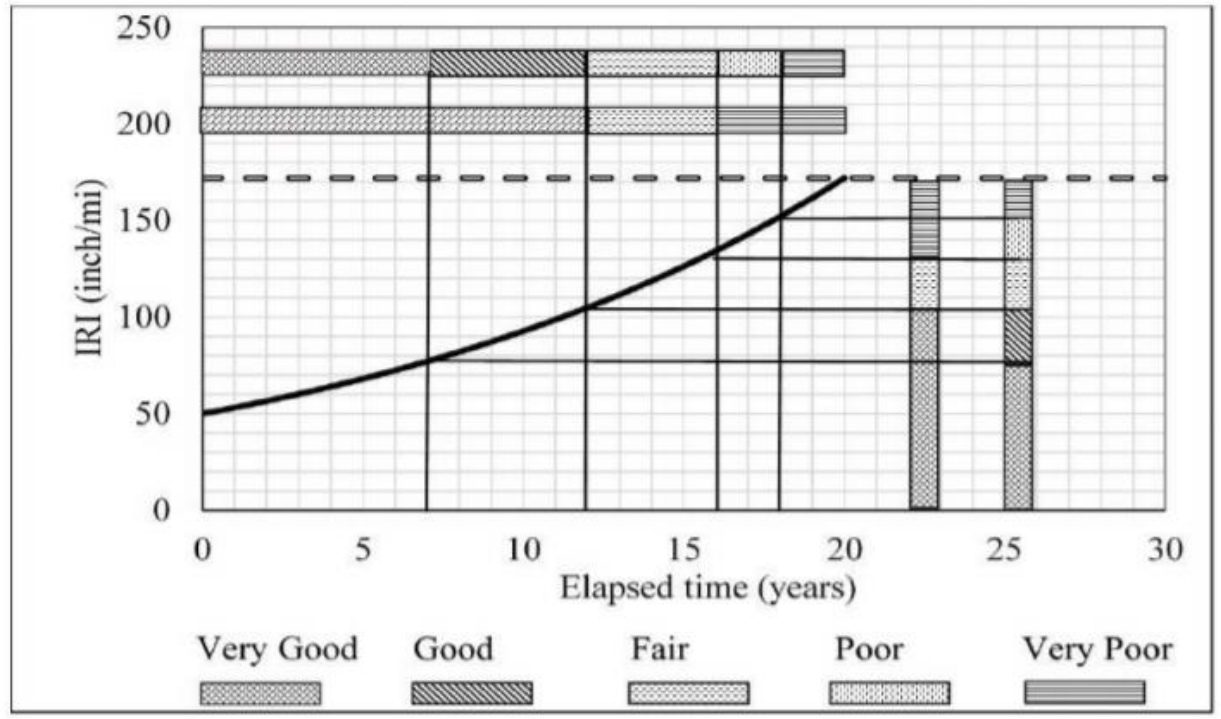
Suspension System:
Spring
Damper

Hub Assembly



$$\text{IRI} = \frac{1}{LV_0}\int |\dot{z}|_{\text{GC}}\ dt$$

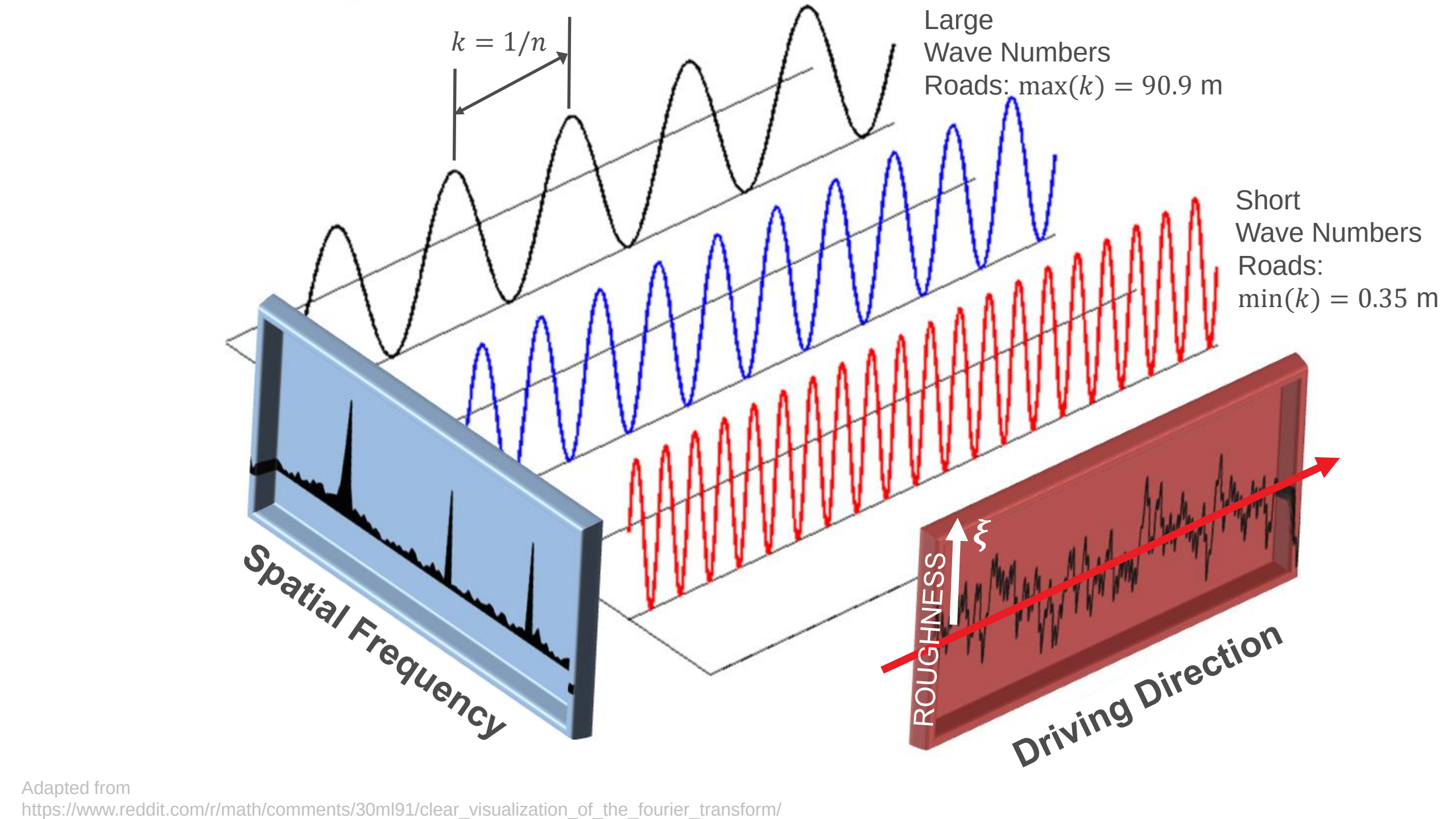
Figure 1. RFP condition states (CSs) for three- and five-level scales.



1 inch/mi = 0.01588 m/km.

Longitudinal Roughness, ξ, causes vibrations.
Suspension Motion, ż, is response of vehicle to roughness induced vibrations

FHWA Publication No.: FHWA-HRT-16-046 https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/16046/16046.pdf



Adapted from
https://www.reddit.com/r/math/comments/30ml91/clear_visualization_of_the_fourier_transform/

IRI and Excess Fuel Consumption

$$\Omega = 2\pi n$$

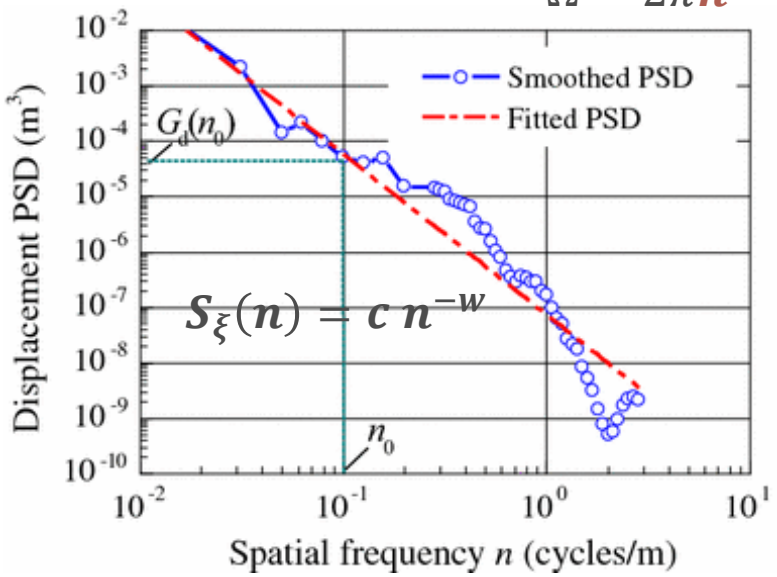
- Measurement of Suspension Motion of a specific vehicle (Golden Car), at a fixed reference speed ($V_0 = 80$ kmh), over a distance L:

$$\mathrm{IRI} = \frac{1}{LV_0}\int |\dot{z}|_{\mathrm{GC}}\ dt = \frac{1}{V_0}\mathrm{E}[|\dot{z}|_{\mathrm{GC}}]_L$$

$$\mathrm{IRI} = \kappa\sqrt{\int_0^{\infty} \Omega^2 \quad |H_z|^2_{\mathrm{GC}} \qquad \boldsymbol{S_\xi}(\Omega) \quad d\Omega}$$

KNOWN REFERENCE "GOLDEN CAR" PROPERTIES

MEASURED ROUGHNESS POWER SPECTRAL DENSITY (PSD)



ISO 8608 :$\Omega \in [0.069 \ldots 17.77]$ (rad/m)
Wavenumbers: $k = 1/n = [0.35 - 90.9]$ m

EXCESS FUEL CONSUMPTION = ENERGY DISSIPATION IN SUSPENSION, TIRES…

$$\mathrm{E}[\delta\mathcal{E}] = \frac{1}{V}C_S\mathrm{E}[\dot{\boldsymbol{z}}^2] \times \mathbf{CAL} = 4\pi\frac{\zeta f_s}{V}m_s\mathrm{E}[\dot{\boldsymbol{z}}^2] \times \mathbf{CAL}$$

CAL = (1/34.2) ltr/MJ (Gasoline)
= (1/15) kg CO2/MJ

V … YOUR Speed
f_s … YOUR Vehicle's Resonant Frequency
ζ … YOUR Suspension Damping
m_s … YOUR Vehicle mass

$$\mathrm{E}[\dot{\boldsymbol{z}}^2] = V^2\int_0^{\infty} \Omega^2 \quad |H_z|^2_{\substack{\mathrm{Your}\\ \mathrm{Car}}} \quad \boldsymbol{S_\xi}(\Omega)_{\substack{\mathrm{Measured}\\ \mathrm{PSD}}}\ d\Omega$$

* Sayers M.W., Karamihas S.M., (1998) The Little Book of Profiling, U. Mich. http://www.umtri.umich.edu/content/LittleBook98R.pdf
** Loprencipe, G. & Zoccali, P. J. Mod. Transport. (2017) 25: 24. https://doi.org/10.1007/s40534-017-0122-1
*** A Louhghalam, M Tootkaboni, FJ Ulm (2015), JEM-ASCE, https://doi.org/10.1061/(ASCE)EM.1943-7889.0000944
**** A Louhghalam, M Tootkaboni, T Igusa, FJ Ulm (2019), JAM-ASME, https://doi:.org/10.1115/1.4041500

APPROACH TYPE	Smartphone Acceleration Measurement	Road Roughness PSD	Smartphone Acceleration PSD	Vehicle Properties	IRI / Road classifier	Environm. IMPACT	SAMPLE References
AD HOC ENGINEERING	X	NO	NO	NO (rigid vehicle)	YES (integration of acceleration)	NO	Originate from Pothole – Bump Approaches (many) Applied to IRI by e.g. Islam et al. (2014)
CORRELATION APPROACH e.g. RMS – IRI (ev. Speed) Fuzzy Logic)	X	NO	NO	NO	YES (CORRELATIONS NOT TRANSFERABLE)	NO	**US 9108640 B2** Douangphachanh & Oneyama (2014) Hanson et al. (2014) Kumar et al. (2016) Sadjadi (2017) Zeng & Park (2018) …
RANDOM VIBRATION THEORY	X	YES (50%) (but low-pass filter w=2); Speed-dependent pole.	YES	NO (considers GOLDEN CAR properties)	YES (50%) (determines rough-ness index, not IRI)	NO	**Alessandroni et al. (2017) & TEAM** http://www.smartroadsense.it/

APPROACH TYPE	Smartphone Acceleration Measurement	Road Roughness PSD	Smartphone Acceleration PSD	Vehicle Properties	IRI / Road classifier	Environm. IMPACT	SAMPLE References
CARBIN	**X**	**YES (STOCHASTIC PROCESS)**	**YES (RANDOM VIBRATION THEORY)**	**YES (PROBABILISTIC INVERSE ANALYSIS)**	**YES (RANDOM VIBRATION THEORY)**	**YES (THERMO-DYNAMICS)**	**Patent FILED**
AD HOC ENGINEERING	X	NO	NO	NO (rigid vehicle)	YES (integration of acceleration)	NO	Originate from Pothole – Bump Approaches (many) Applied to IRI by e.g. Islam et al. (2014)
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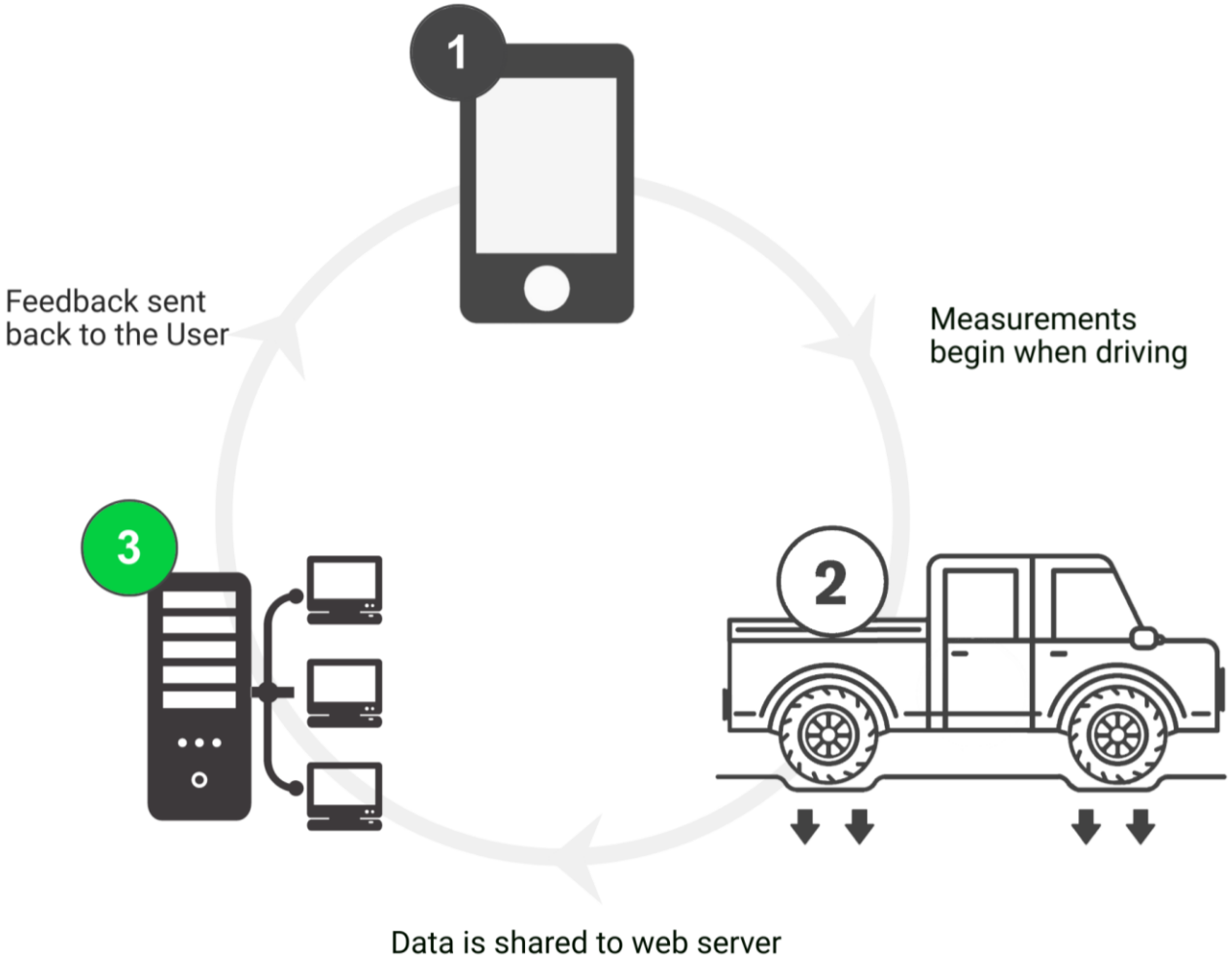
Carbin is VERY EASY TO USE and offers more than just road quality data.



Record data: Mount the phone in a stable position and click start

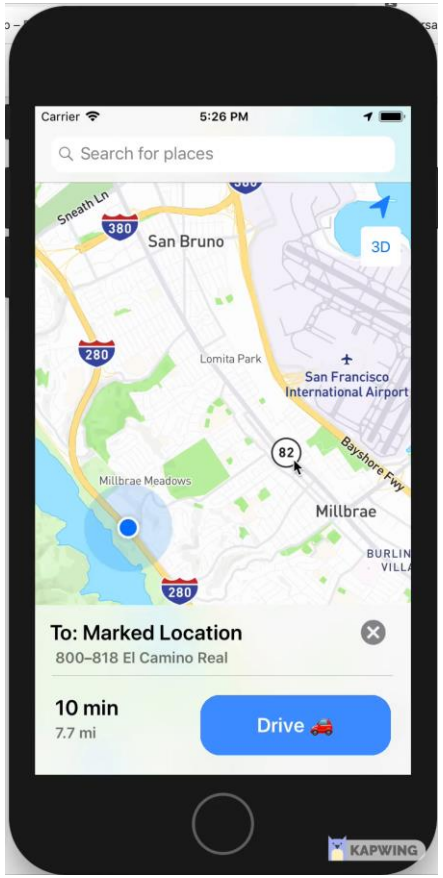
2 inputs: X,Y,Z acceleration (100Hz) and **GPS coordinates (1Hz)** are sent to the server

Results: Anonymous data gets analyzed in real time and shared with the user.

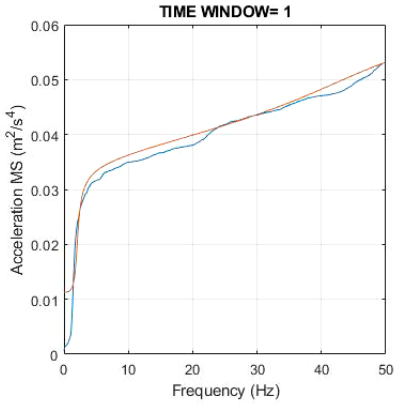
15Mb of data per hour / Wi-Fi compatibility

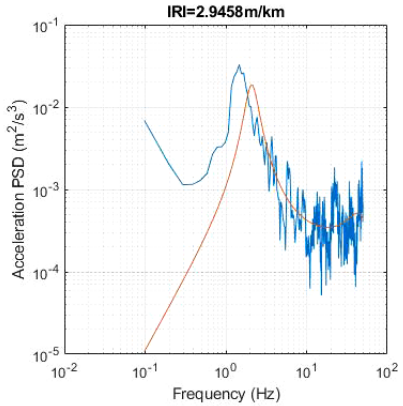
Analysis begins once the user starts driving

Crowdsourced Measurements: GPS, Accelerations (100Hz)



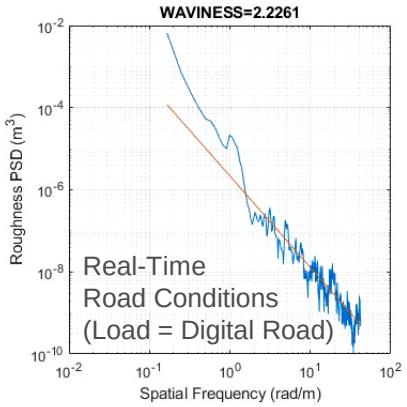
Real-Time Analysis (Amazon Server)

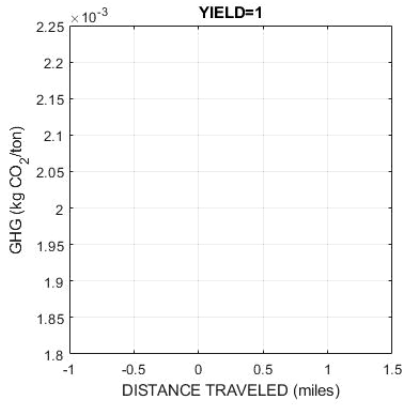




Random Vibration Theory
+ Bayesian Statistics
(Vibration Response)

Feedback (road, env. Footprint, eco-routing, Vehicle maintenanc, etc.)





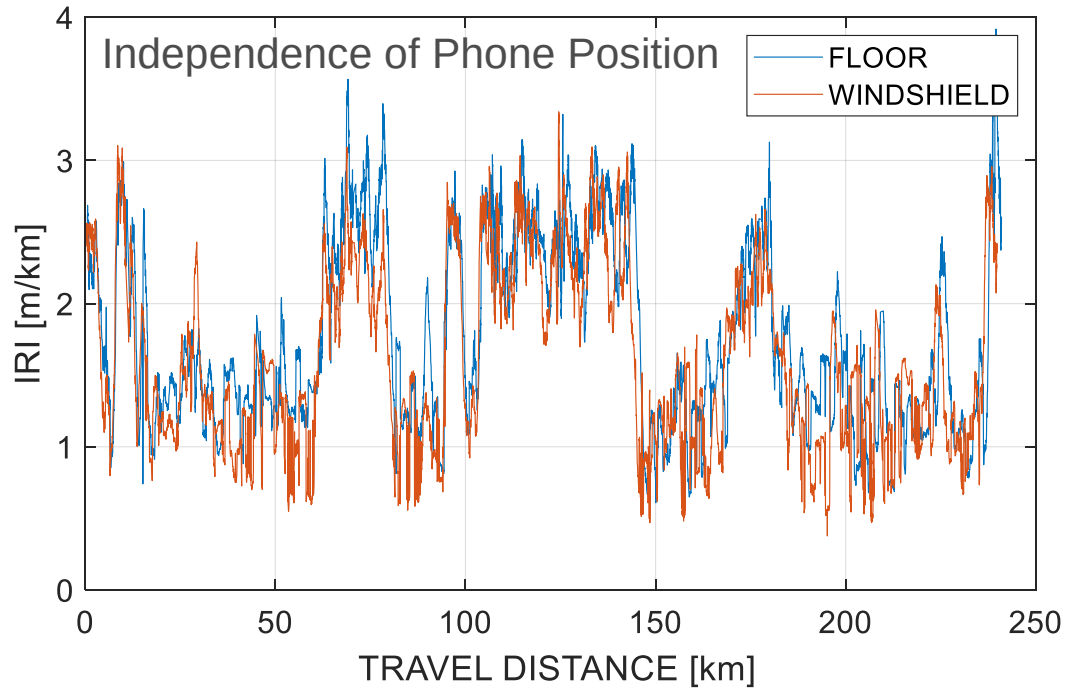
Fluctuation-Dissipation Theorem
(2nd Law of Thermodynamics)
[Excess fuel]

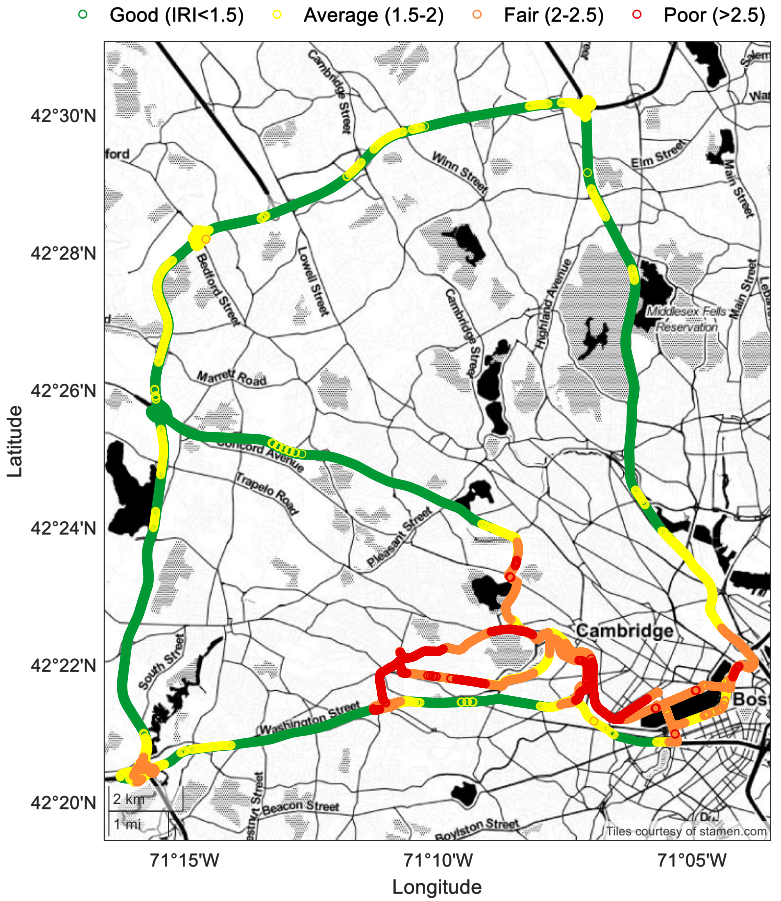
Real-Time Access to: Load Cycles And Vehicle Properties (tires, suspension,…)

CARBIN App avail. AppStore (IOS), GooglePlay (Android)

Phone can be placed anywhere* (IRI comparison)

***must be in a stable position**

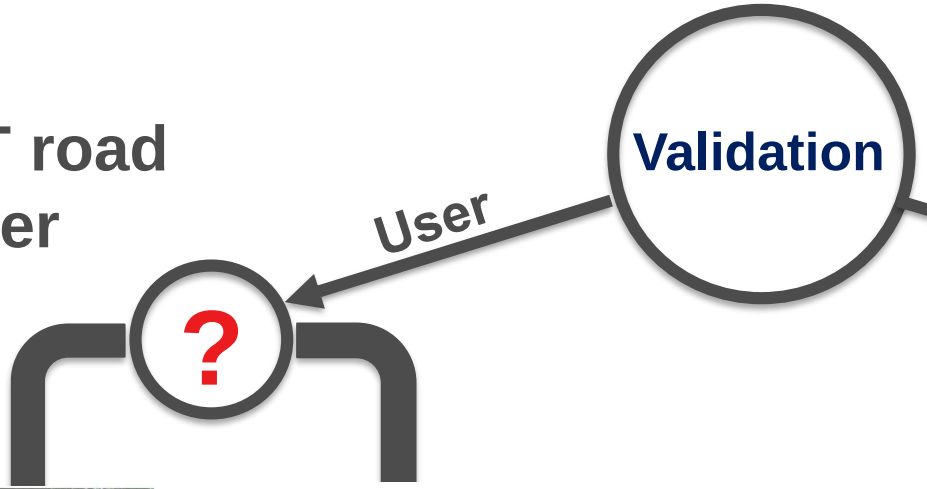




→ **But there is a need for multiple measurements for high accuracy due to different quality of phone sensors**

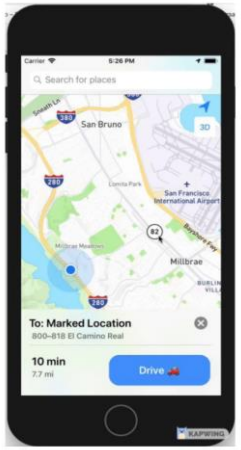
Validating phone obtained IRI results

DYNATEST road laser profiler

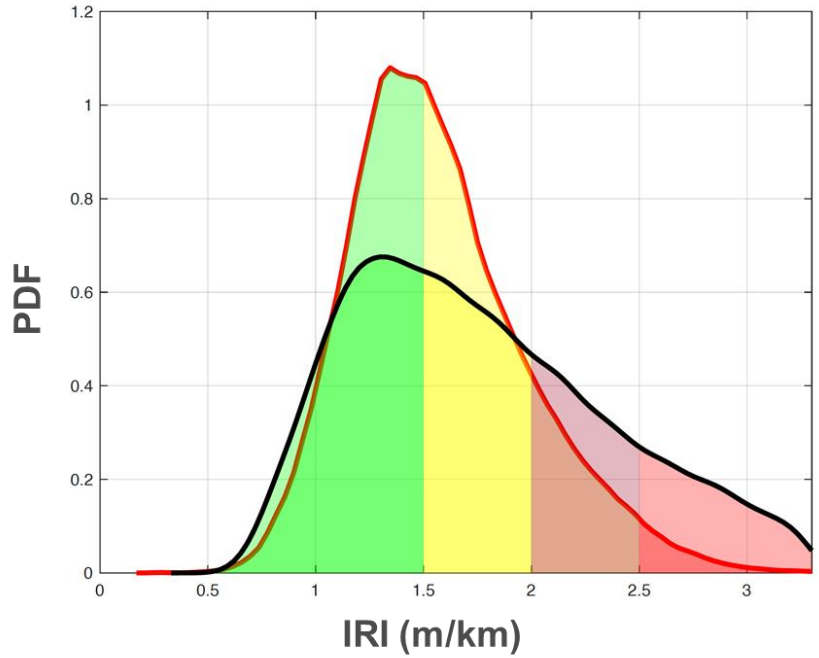


State of California

Laser Measurement for 50 miles



Carbin

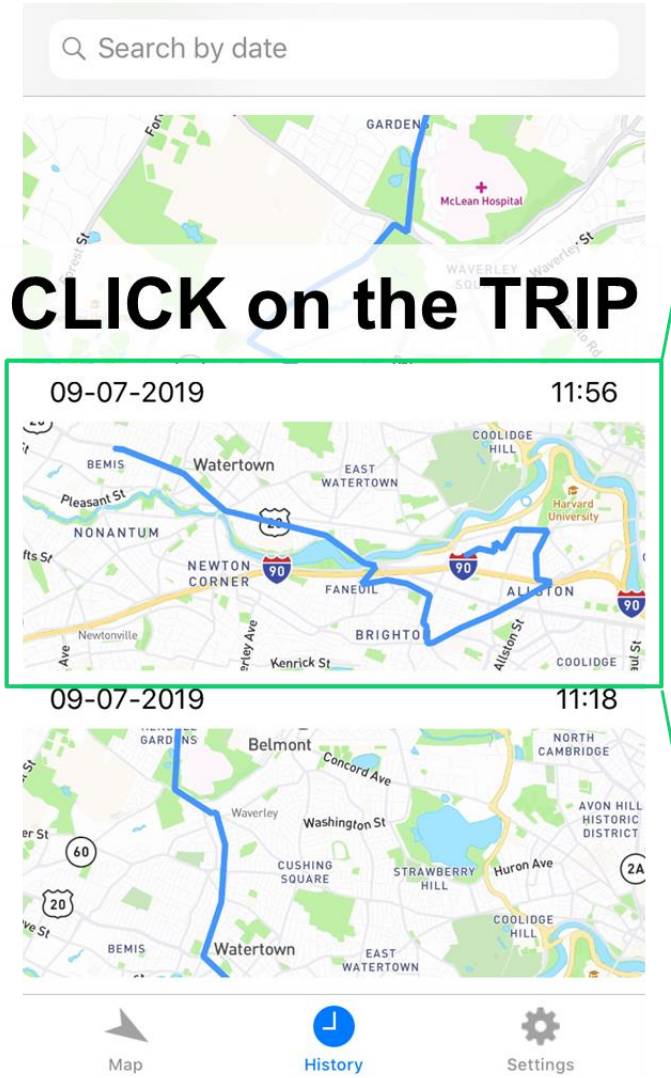


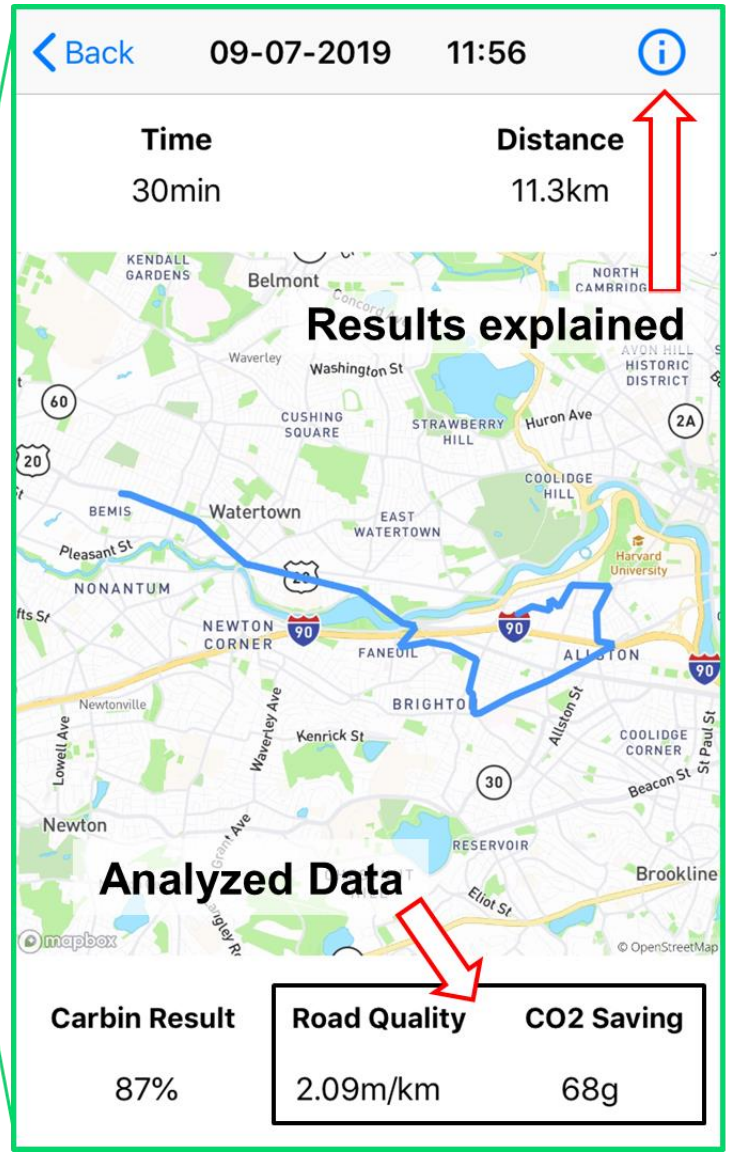
2013 DOT

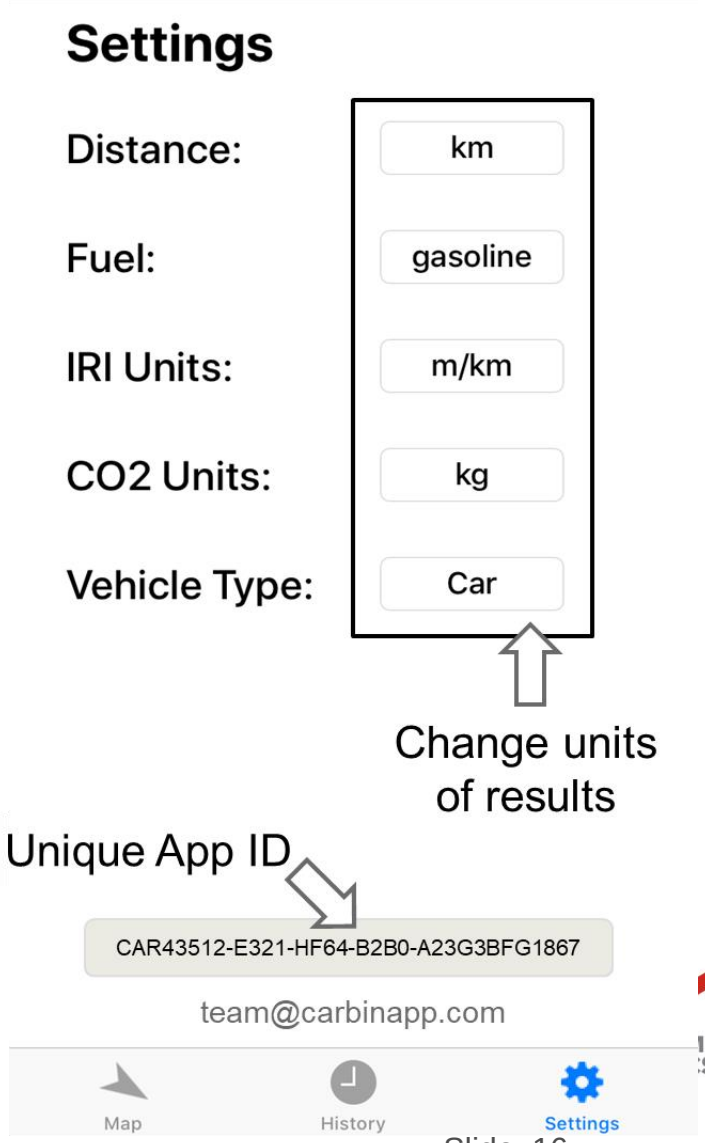
2019 Carbin

(expected completion: Winter 2019)

Get immediate feedback upon completing the trip

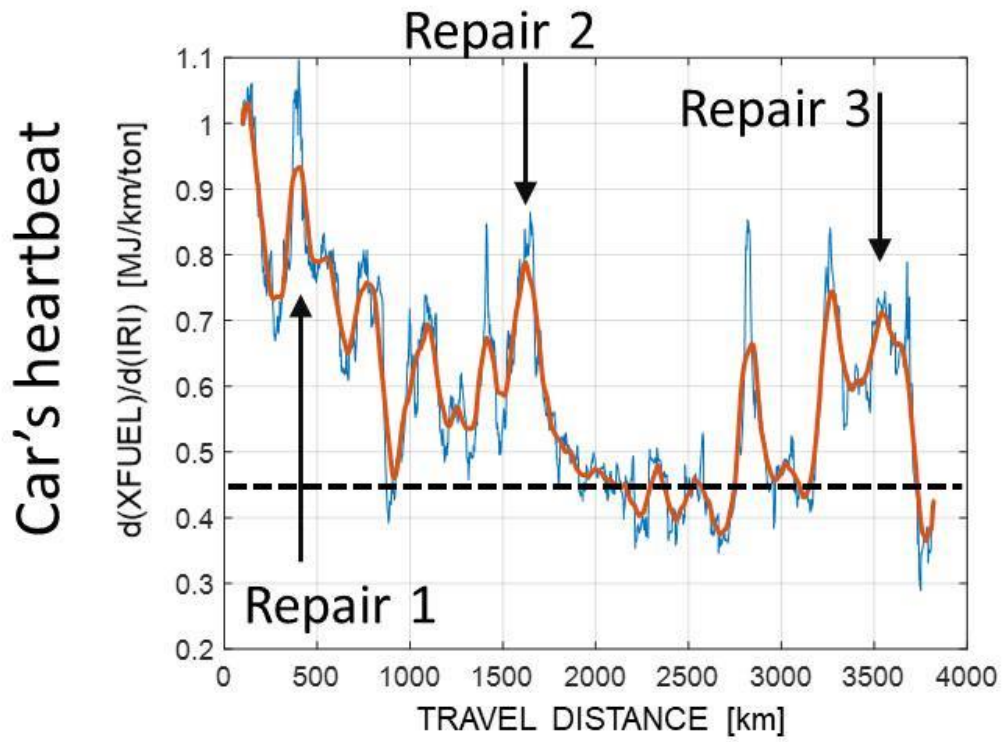






With 500+ miles Carbin can identify issues with suspension

Heartbeat of the suspension system



Repair 1: Wheel Alignment

Repair 2: Punctured tire repair

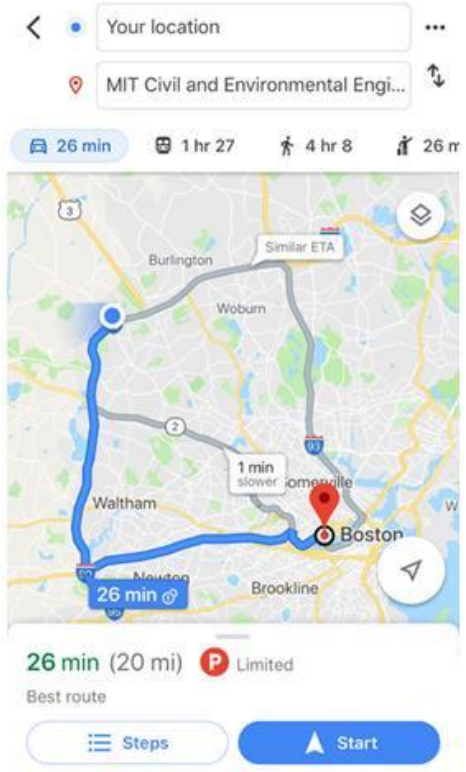
Repair 3: Front Axle Bearing Replacement

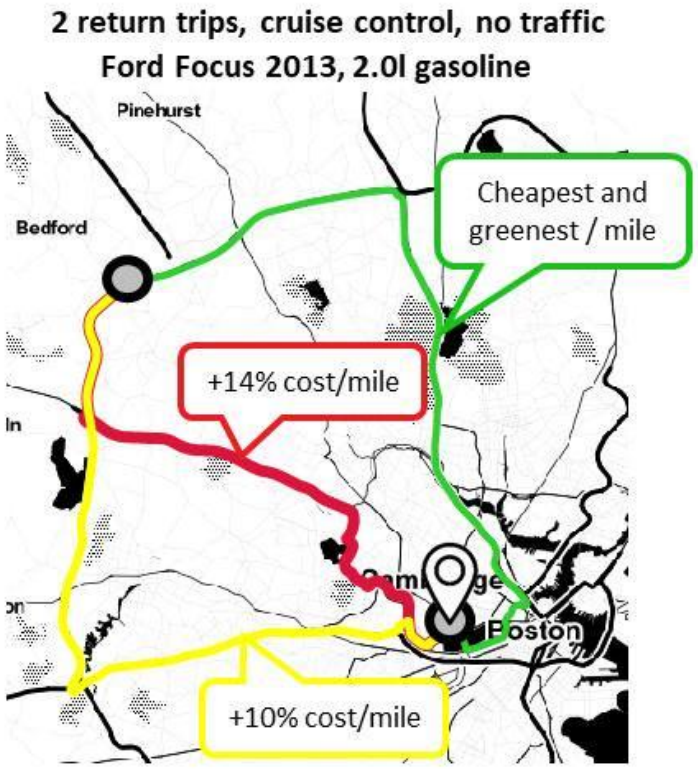
-------- Baseline Performance

Not available to the user yet

In the future Carbin will be able to offer eco-routes

Eco-routing





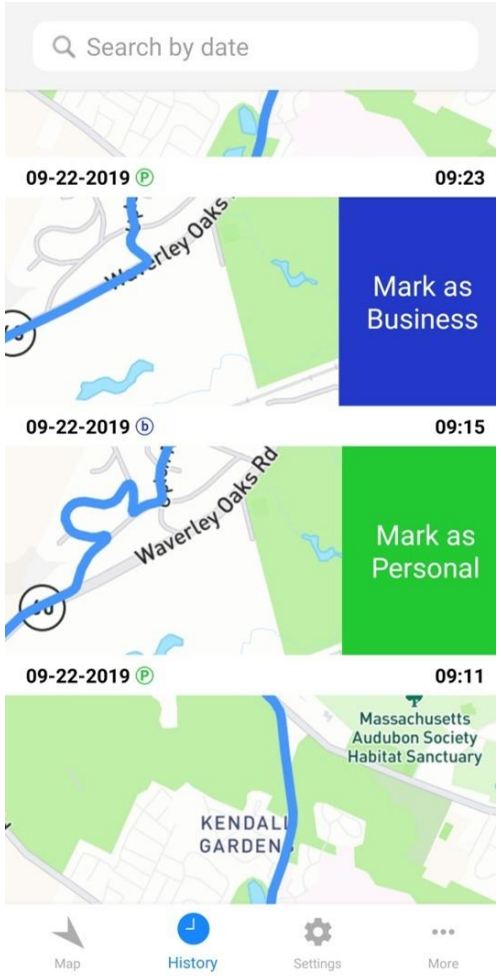
Avg. Results

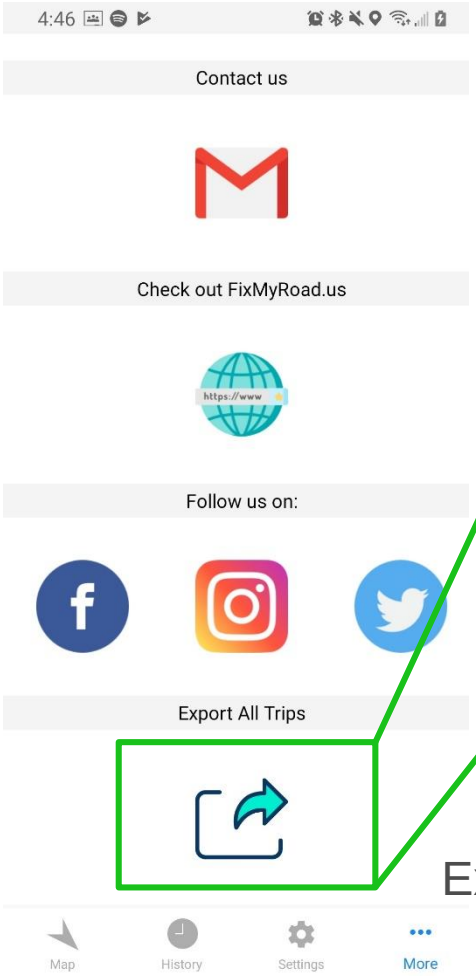
Trip	1	2	3
IRI (m/km)	1.10	1.21	1.28
MPG	43	39.1	37.8
L/100km	5.47	6.02	6.22
Fuel Cost ($/mile)	0.066	0.073	0.076
Fuel Cost ($/km)	0.041	0.046	0.048
Fuel Cost & Emissions increase	0%	**+10%**	**+14%**

* Fuel cost: $2.85/gallon ($0.75/L)

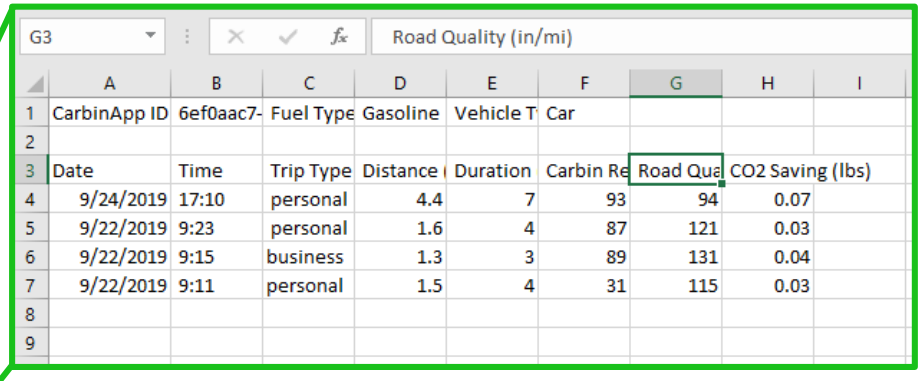
Lexington, MA → MIT, Cambridge MA

Other benefits of the app





Direct access to updates and support through social media, website and email



	A	B	C	D	E	F	G	H	I
1	CarbinApp ID	6ef0aac7-	Fuel Type	Gasoline	Vehicle T	Car			
2									
3	Date	Time	Trip Type	Distance	Duration	Carbin Re	Road Qua	CO2 Saving (lbs)	
4	9/24/2019	17:10	personal	4.4	7	93	94	0.07	
5	9/22/2019	9:23	personal	1.6	4	87	121	0.03	
6	9/22/2019	9:15	business	1.3	3	89	131	0.04	
7	9/22/2019	9:11	personal	1.5	4	31	115	0.03	
8									
9									

Export by email or store in a .csv format

Universal metric, real-time impact

www.fixmyroad.us

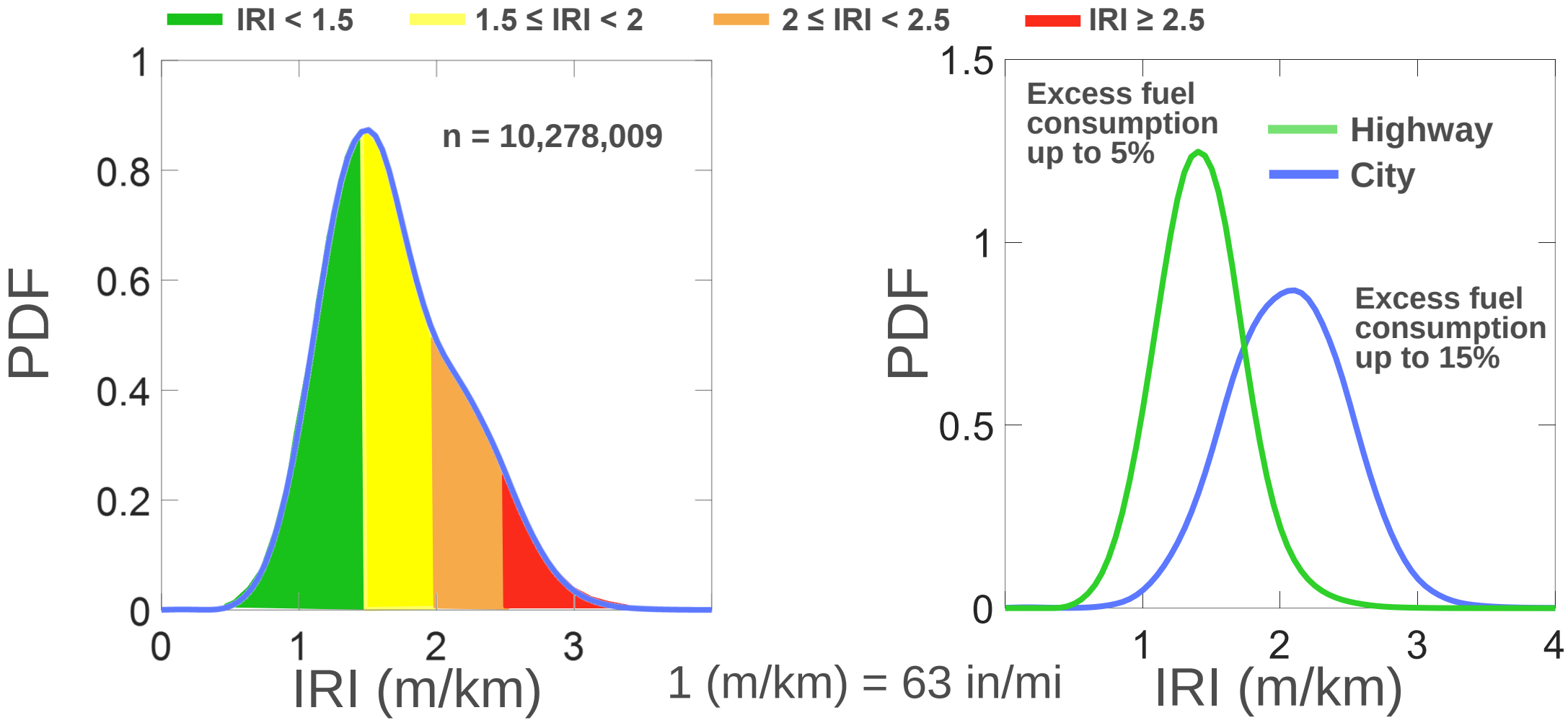
March 2019

October 2019

6-months & 350 active users (friends & family)

Increasing IRI database with hourly updates for all classes of roads

FWHA limits



1 (m/km) = 63 in/mi

→ What would the impact be with 10k or 100k users?

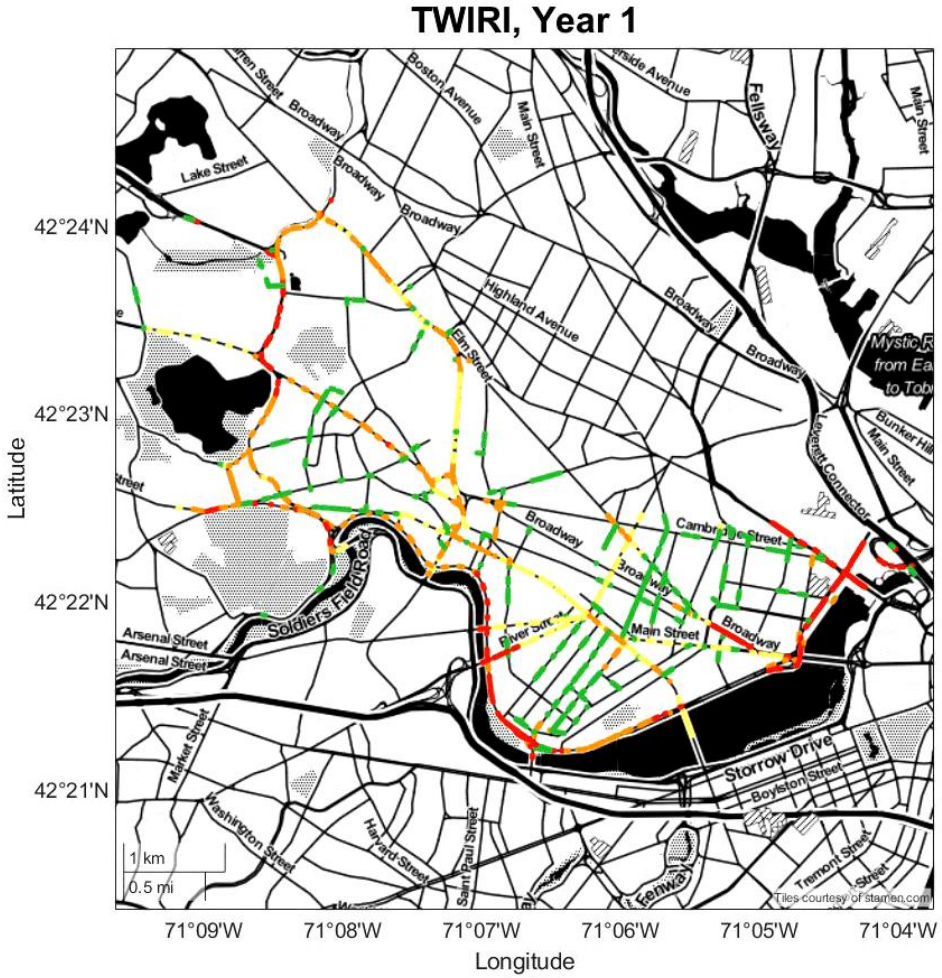

Quality of Roads
Environmental Impact
Road Roughness
Search
ENVIRONMENTAL IMPACT → CO2 Tax / Climate Change
www.fixmyroad.us/results
With environmental impact of their state roads CALTRANS was able to increase their funding by 12%
FAIR: >55t and <130t /km/year in CO2 savings*
POOR: >130t /km/year in CO2 savings* ~6,000 trees
*when compared to top 5% of roads
Good
Average
Fair
Poor

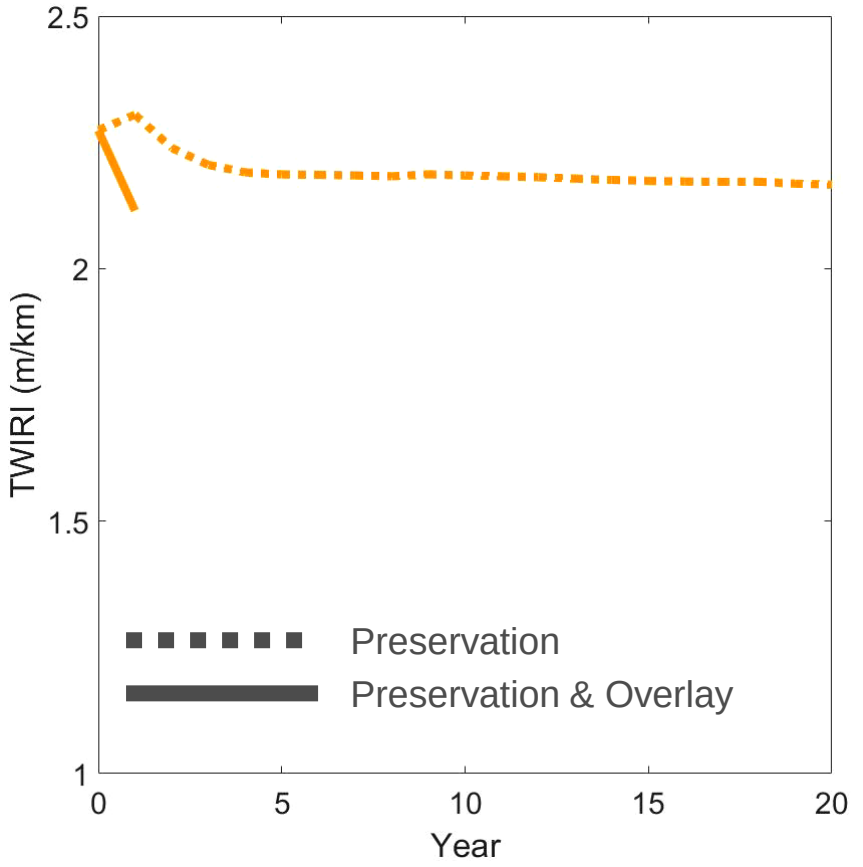
What can we do with this type of data?

Cambridge MA
(example of a well-maintained dirt road system):

Maximizing road quality, while minimizing CO2 driving emissions with a fixed budget

Incorporating long-term treatment actions improves pavement network conditions and reduces GHG emissions



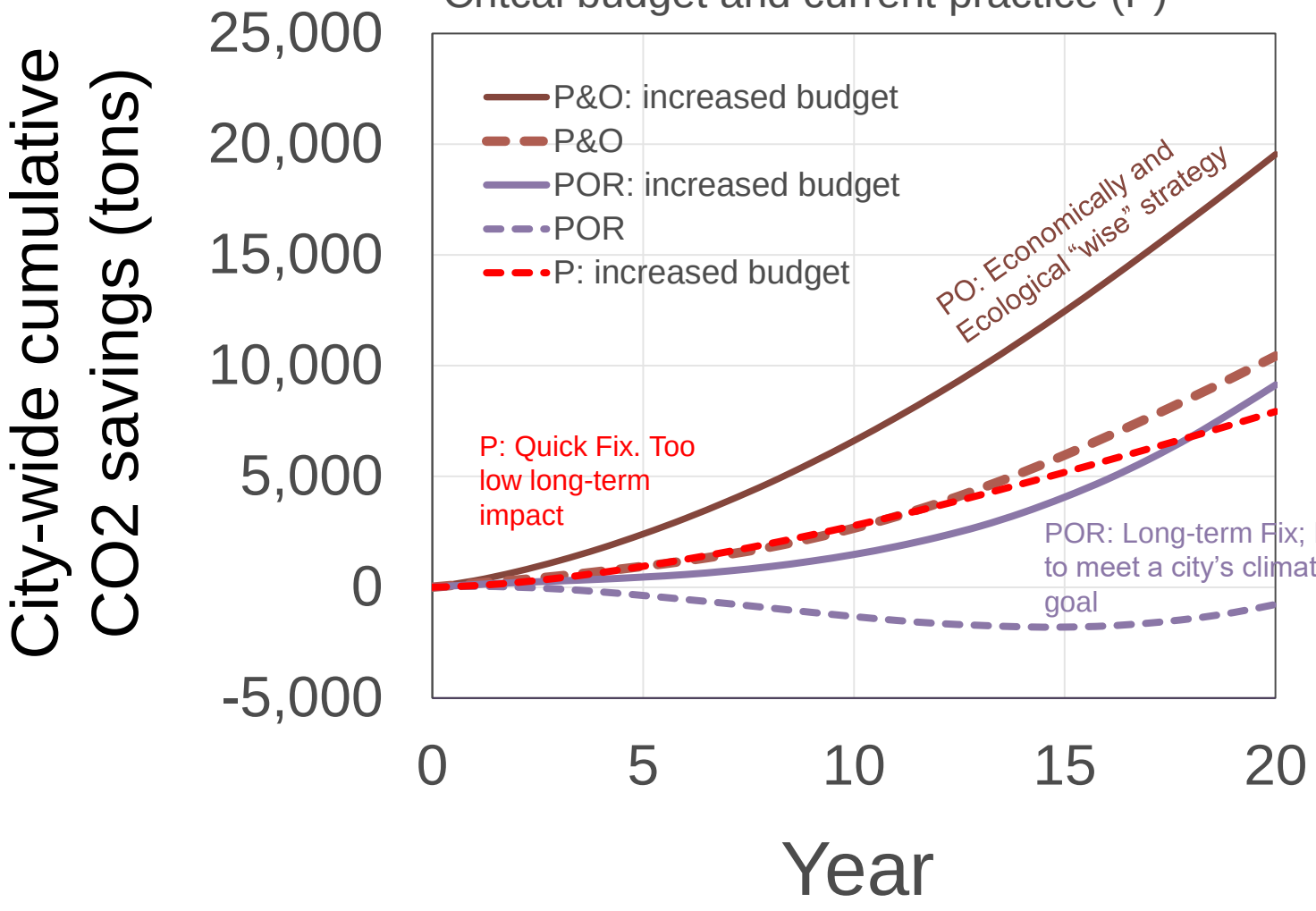


TWIRI < 1.5 | 1.5 ≤ TWIRI < 2 | 2 ≤ TWIRI < 2.5 | TWIRI ≥ 2.5

Sustainable asset management

Reference case:

Critcal budget and current practice (P)



How can Cambridge MA get the maximum GHG emission reduction through the right choice of road maintenance actions?

1. Preservation (P) (current practice)
2. Preservation+Overlay (P&O)
3. Preservation+Overlay+Reconstruction (POR)

Levers for GHG reduction at city scale: budget, type of maintenance action, choice of materials…

NEXT STEPS

May 2020

Carbin APP:

1. Fidelity Program: “COLLECT MILES WITH CARBIN and GET REWARDS”
2. Push Notification: daily and weekly updates
3. Background Automatic Recording: no need to press start → just mount the phone
4. SDK model to be used as part of any app

Analysis

1. Predicting accurate AADT values for different vehicle classes
2. Temperature with pavement deflection modeling
3. **Monitoring roads with identification of pavement types:**
   Asphalt vs. Concrete → which one is “better” in the short / long run

Available on the App Store

Get it on Google play

CSHub

MIT CONCRETE SUSTAINABILITY HUB

Thank you

HELP US GET 1 million miles

www.fixmyroad.us/takeaction

@CarbinApp

facebook.com/carbinapp

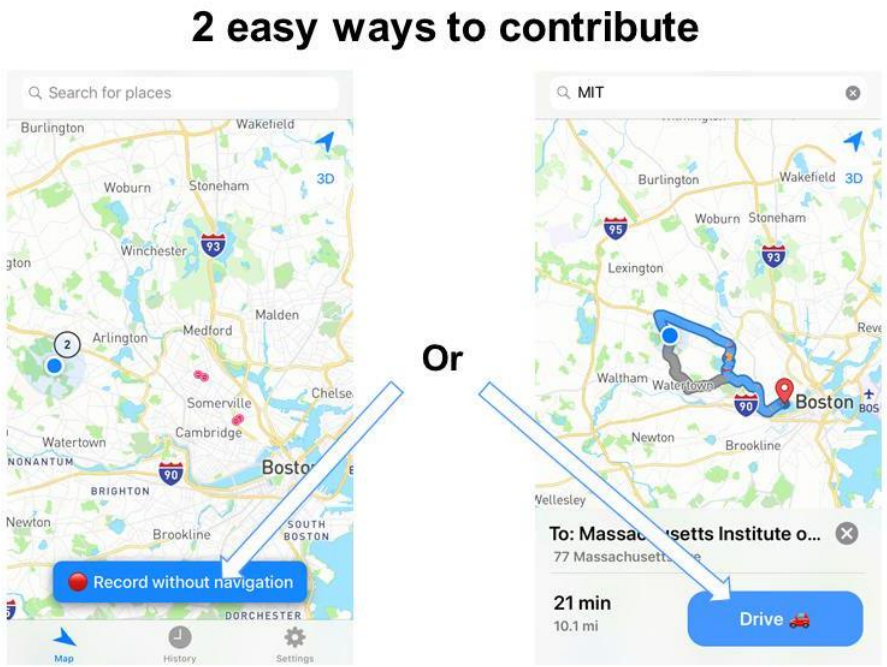
@carbinapp

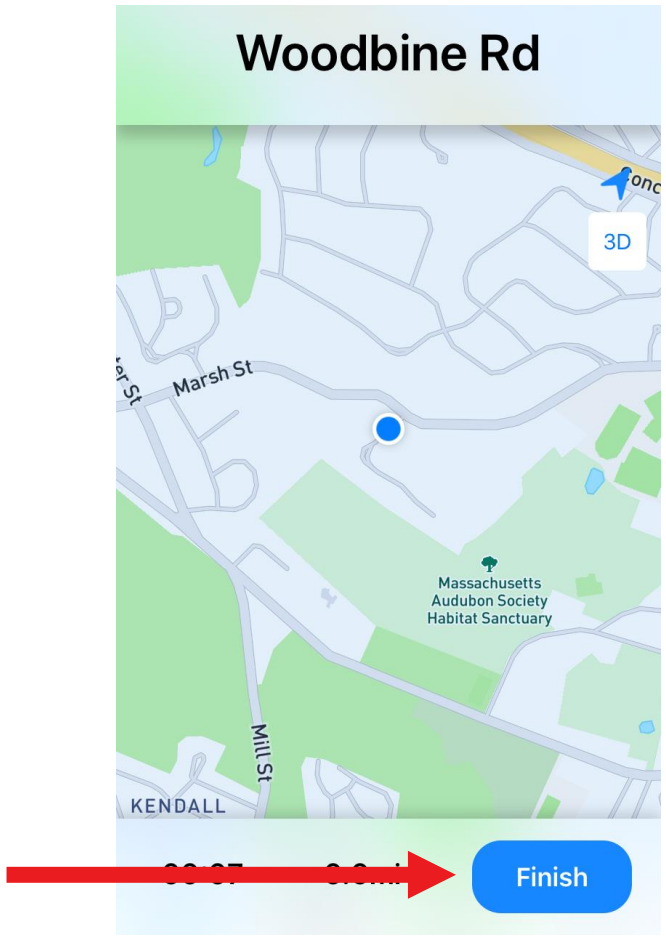
EXTRA SLIDES

To participate get Carbin and start collecting data

ANDROID: Google play store → search for Carbin

iPhone: App Store → search for Carbin





Press “Finish: to see your results when recording without navigation. In navigation mode just click “x”

2 OUT OF 5 MILES OF THE NATION'S INTERSTATES ARE **CONGESTED**

6.9 BILLION HOURS DELAYED IN TRAFFIC

42 HOURS PER DRIVER

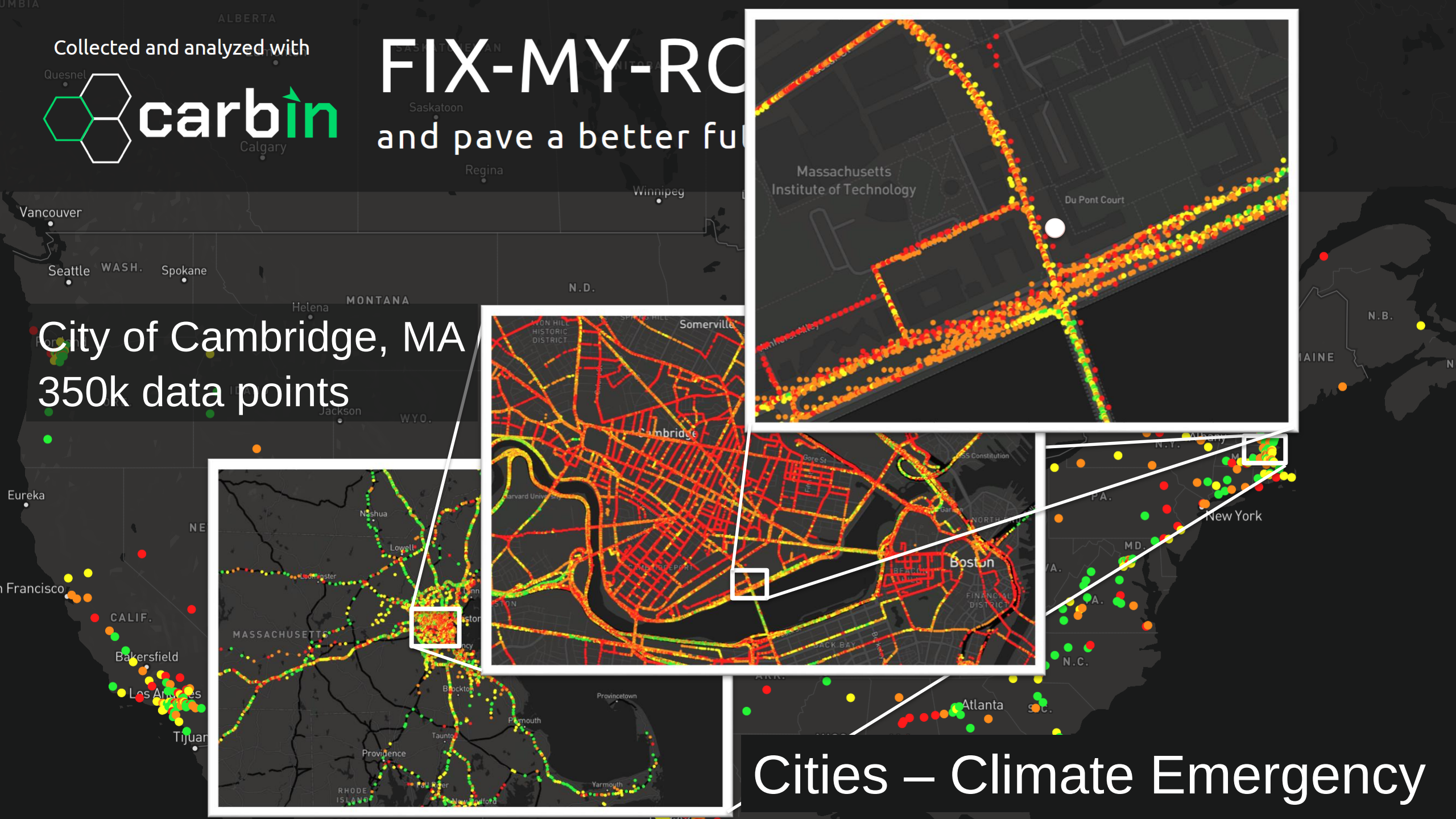
2017 Infrastructure Report Card, ASCE

Collected and analyzed with

carbin

FIX-MY-RO

and pave a better fu



City of Cambridge, MA

350k data points

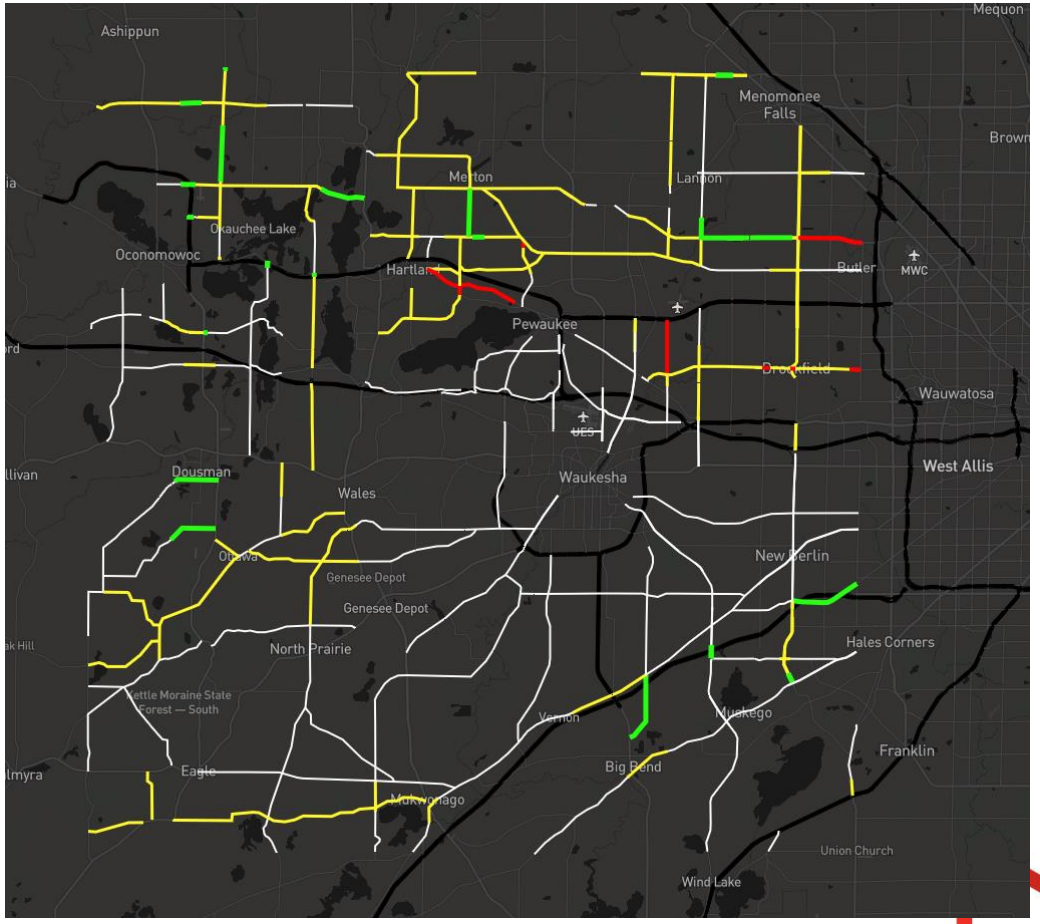
Cities – Climate Emergency

Application of Carbin: PCI vs IRI + mapping

Waukesha County, WI

	Branch ID	Section ID	From	To	Section Rank	Surface Type	Section Length, ft	Predicted PCI
2	CTH FT	FT01A	85 ft. ecl Delafield Rd	PC 620 ft. W wcl CTH J	S	AC	4,359	42
3	CTH K	K09A	85 fts. E CL CTH Y	PC at Brookfield City Lim	P	AC	2,877	84
4	CTH K	K09D	384 ft. W CL Shasta Rd	331 ft. E CL Shasta Rd.	P	AC	715	88
5	CTH K	K09E	331 ft. E CL Shasta Rd.	CL Marcy Rd.	P	AC	1,243	88
6	CTH K	K11C	1286 ft E CL CTH YY	479 ft. W CL Lily Rd	P	AC	3,044	57
7	CTH M	M03E	348 ft. E Brookfield Rd. R-A	892 ft. E CL Le Chateau Dr.	P	AC	3,398	38
8	CTH M	M03H	358 ft. E CL Brook Springs Dr.	718 ft E CL Glen Cove Ln.	P	AC	3,250	15
9	CTH VV	VV07AEB	466 ft. E CL CTH Y	728 ft. W CL Clover Ln	P	AC	4,195	81
10	CTH VV	VV07BEB	728 ft. W CL Clover Ln	600 ft. W CL Marcy Rd	P	AC	2,713	80
11	CTH Y	Y09A	62 ft. N ncl CTH K	213 ft. S scl CTH VV	P	AC	4,297	3
12	CTH YY	YY01BNB	400 ft. scl CTH VV	CL Mill Rd.	P	AC	5,766	60
13	CTH YY	YY01BSB	400 ft. scl CTH VV	CL Mill Rd.	P	AC	5,766	56
14	CTH K	K11FEB	72 ft. W CL 132nd St.	CL 124th St.	P	APC	2,873	70
15	CTH K	K11FWB	72 ft. W CL 132nd St.	CL 124th St.	P	APC	2,873	69
16	CTH Y	Y07F	446 ft N CL Larkspur Dr	CL Gebhardt Rd.	P	APC	3,254	46
17	CTH Y	Y08A	CL Gebhardt Rd.	443 ft. S CL Round About North Ave	P	APC	1,896	41
18	CTH F	F02ANB	CL I-94	125 ft. S CL Westwood Dr.	P	PCC	984	90
19	CTH F	F02ASB	CL I-94	125 ft. S CL Westwood Dr.	P	PCC	984	90
20	CTH F	F04CNB	479 ft. N CL Mitchell Ln.	655 ft. S scl Main St.	P	PCC	3,729	65
21	CTH F	F04CSB	479 ft N CL Mitchell Ln.	655 ft. scl Main St.	P	PCC	3,729	62
22	CTH F	F04HNB	CL CTH V South Portion	CL CTH V Noth Portion Round About	P	PCC	2,709	75
23	CTH F	F04HSB	CL CTH V South Portion	CL CTH V North Portion Round About	P	PCC	2,709	76
24	CTH M	M04HEB	187 ft. E CL Fair Heaven Blvd	wcl 124th Street	P	PCC	1,056	27
25	CTH M	M04HWB	187 ft. E CL Fair Heaven Rd.	wcl 124th Street	P	PCC	1,056	26

Carbin IRI map



OUTCOME → Using Carbin for annual road quality measurements