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?

21% of the nation's highways are in poor condition.

Costing motorists $121 billion/year in extra vehicle repairs and operating costs.

2017 Infrastructure Report Card, ASCE
Quality of roads affects fuel economy and GHG emissions.

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
INTERNATIONAL ROUGHNESS INDEX

IRI … Universal Ride Quality Measure

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

Longitudinal Roughness, \( \xi \), causes vibrations.
Suspension Motion, \( \dot{z} \), is response of vehicle to roughness induced vibrations.
Large Wave Numbers Roads: $\max(k) = 90.9 \text{ m}$

Short Wave Numbers Roads: $\min(k) = 0.35 \text{ m}$

$k = 1/n$
IRI and Excess Fuel Consumption

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

$$IRI = \frac{1}{L_{V_0}} \int |\ddot{z}|_{GC} \ dt = \frac{1}{V_0} E[|\ddot{z}|_{GC}]L$$

$$IRI = \kappa \int_0^{\infty} \Omega^2 \frac{|H_z|_{GC}^2}{S_\xi(\Omega)} \ d\Omega$$

**EXCESS FUEL CONSUMPTION = ENERGY DISSIPATION IN SUSPENSION, TIRES…**

$$E[\delta E] = \frac{1}{V} C_S E[\dot{z}^2] \times CAL = 4\pi \frac{\xi f_s}{V} m_s E[\dot{z}^2] \times CAL$$

$$CAL = \frac{1}{(34.2)} \ \text{ltr/MJ (Gasoline)}$$

$$\text{} = \frac{1}{(15)} \ \text{kg CO2/MJ}$$

$V$ ... YOUR Speed

$f_s$ ... YOUR Vehicle’s Resonant Frequency

$\xi$ ... YOUR Suspension Damping

$m_s$ ... YOUR Vehicle mass

Wavenumbers: $k = 1/n = [0.35 - 90.9]$ m

ISO 8608: $\Omega \in [0.069 ... 17.77]$ (rad/m)
<table>
<thead>
<tr>
<th>APPROACH TYPE</th>
<th>Smartphone Acceleration Measurement</th>
<th>Road Roughness PSD</th>
<th>Smartphone Acceleration PSD</th>
<th>Vehicle Properties</th>
<th>IRI / Road classifier</th>
<th>Environm. IMPACT</th>
<th>SAMPLE References</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD HOC ENGINEERING</td>
<td>X</td>
<td>NO</td>
<td>NO</td>
<td>NO (rigid vehicle)</td>
<td>YES (integration of acceleration)</td>
<td>NO</td>
<td>Originate from Pothole – Bump Approaches (many) Applied to IRI by e.g. Islam et al. (2014)</td>
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<tr>
<td>CORRELATION APPROACH</td>
<td>X</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES (CORRELATIONS NOT TRANSFERABLE)</td>
<td>NO</td>
<td>US 9108640 B2</td>
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<td>e.g. RMS – IRI</td>
<td></td>
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<td></td>
<td></td>
<td>Douangphachanh &amp; Onyama (2014)</td>
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<td>(ev. Speed)</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>Hanson et al. (2014)</td>
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<td>Fuzzy Logic</td>
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<td>Kumar et al. (2016)</td>
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<td>Sadjadi (2017)</td>
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<td>Zeng &amp; Park (2018)</td>
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<tr>
<td>RANDOM VIBRATION THEORY</td>
<td>X</td>
<td>YES (50%)</td>
<td>YES (considers GOLDEN CAR properties)</td>
<td>YES (50%) (determines roughness index, not IRI)</td>
<td>NO</td>
<td></td>
<td>Alessandroni et al. (2017) &amp; TEAM <a href="http://www.smartroadSense.it/">http://www.smartroadSense.it/</a></td>
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<tr>
<td>CARBIN</td>
<td>X</td>
<td>YES (STOCHASTIC PROCESS)</td>
<td>YES (RANDOM VIBRATION THEORY)</td>
<td>YES (PROBABILISTIC INVERSE ANALYSIS)</td>
<td>YES (RANDOM VIBRATION THEORY)</td>
<td>YES (THERMO-DYNAMICS)</td>
<td>Patent FILED</td>
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<td>RANDOM VIBRATION THEORY</td>
<td>X</td>
<td>YES (50%) (but low-pass filter w=2): Speed-dependent pole.</td>
<td>YES</td>
<td>NO (considers GOLDEN CAR properties)</td>
<td>YES (50%) (determines roughness index, not IRI)</td>
<td>NO</td>
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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)

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

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

Validation

User

Network

State of California

Laser Measurement for 50 miles

Carbin

(expected completion: Winter 2019)

PDF

IRI (m/km)

2013 DOT
2019 Carbin

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.
Other benefits of the app

- Direct access to updates and support through social media, website and email
- Export by email or store in a .csv format
Universal metric, real-time impact

www.fixmyroad.us
6-months & 350 active users (friends & family)
Increasing IRI database with hourly updates for all classes of roads

FWHA limits

Increasing IRI database with hourly updates for all classes of roads

FWHA limits

What would the impact be with 10k or 100k users?
ENVIROMENTAL 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
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.
Sustainable asset management

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

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

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

May 2020
HELP US GET 1 million miles
www.fixmyroad.us/takeaction

@CarbinApp
facebook.com/carbinapp
@carbinapp

Thank you
To participate get Carbin and start collecting data

**ANDROID:** Google play store → search for Carbin
**iPhone:** App Store → search for Carbin

2 easy ways to contribute

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.
City of Cambridge, MA
350k data points
Application of Carbin: PCI vs IRI + mapping

Waukesha County, WI

OUTCOME ➔ Using Carbin for annual road quality measurements