Using Crowdsourced Vehicle Braking Data to Identify Roadway Hazards

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Abstract

Modern vehicles know more about the road conditions than transportation agencies. Enhanced vehicle data that provides information on "close calls" such as hard braking events or road conditions during winter such as wheel slips and traction control will be critical for improving safety and traffic operations. This research applied conflict analyses techniques to process approximately 1.5 million hard braking events that occurred in the state of Indiana over a period of one week in August 2019. The study looked at work zones, signalized intersections, interchanges and entry/exit ramps. Qualitative spatial frequency analysis of hard-braking events on the interstate demonstrated the ability to quickly identify temporary and long-term construction zones that warrant further investigation to improve geometry and advance warning signs. The study concludes by recommending the frequency of hard-braking events across different interstate routes to identify roadway locations that have abnormally high numbers of "close calls" for further engineering assessment.

Keywords:

Braking, conflict analysis, vehicle dynamics

Background

Probe speed data has enabled agencies to assess roadway conditions on their facilities with ever-greater temporal and spatial fidelity, and have assisted in making data-driven operational decisions (*1–8*). Conventional highway speed data is collected using Bluetooth sensors, crowdsourced GPS telematics, smartphones, and cellular-connected personal vehicles. The data and tools have impacted the industry tremendously with operational insight for managing both recurring and non-recurring congestion, workzones, inclement weather conditions, and traffic signal timing. Each year in the US alone, there are over 33,000 motor vehicle fatalities (*9*), and in workzones one fatality occurs for every four billion VMT (*10*). Workzones account for about 10% of all congestion and about 24% of unexpected expressway delays (*10*). During the winter season, about 440,000 persons are injured in weather-related crashes per year using a 10-year average with an annual cost of $22 to $51 billion (*11*). As more sophisticated equipment is added to consumer vehicles – both in terms of connectivity and sensing – the quality of the data will enable agencies to manage their roads with more insights than previously.

Data Source

Recently, enhanced vehicle data from the automotive industry have been made available for researchers. Hard-braking data collected from anonymized consumer vehicles where a deceleration of greater than 0.26g can now be retrieved in scale. The dataset contains global coordinates, time stamp, and a hard-braking event that occurred. For instance, **Figure 1** shows 1.5 million hard-braking events over a 1-week period in August 2019 within the state of Indiana, with each red dot signifying a hard-braking event. Details for major urban areas and interstate routes can be seen from the overview. For a small urban area of 230,000 residents in and around Lafayette, IN, approximately 23,000 events were recorded over the same one-week period.
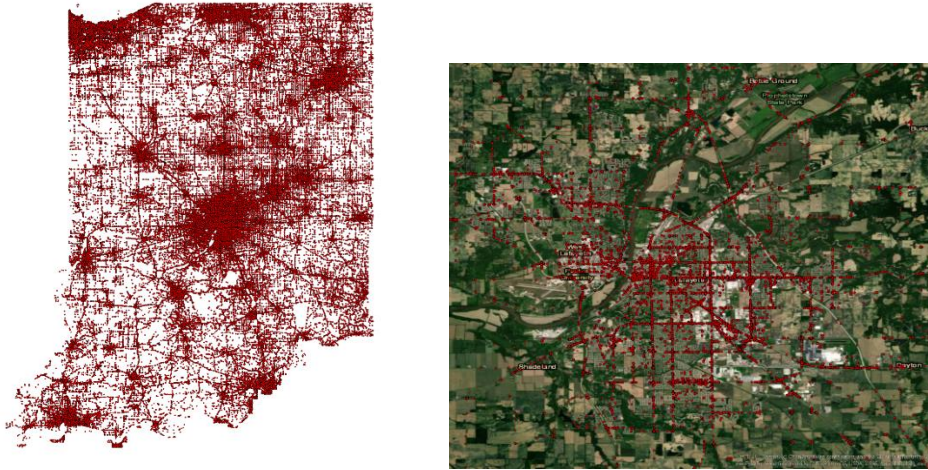

Figure 1. One week of hard-braking events in Indiana and a local city.

Applying Conflict Analysis Techniques for Hard-Braking Events

Two use cases have been identified for the hard-braking data: 1) on limited-access, high-speed roadways, and 2) suburban signalized corridors. In the first scenario, typical driving behaviour on expressways that are uncongested would not normally expect any type of hard-braking. However, situations such as workzones, maintenance of traffic, wildlife crossings, debris, crashes, weather events, merge dynamics, and congestion would cause drivers to hit their brakes and thus be reflected in the data. In the second scenario, vehicles are anticipated to brake in advance of a traffic signal when a red light is expected, or if there are residual queues. Any hard-braking events would signify arrivals on red for the more aggressive drivers, or opportunities for mitigating potential dilemma zone issues. Using this type of data fallows within the broad area of "conflict analysis" that is often used to rank safety related projects (*12*).

Limited-access roadways

Typical driving behaviour on limited-access roadways and expressways do not expect any braking behaviour. However, as seen in **Figure 2**, there are a number of hard-braking events approaching a workzone (callout i) on an expressway, with braking events extending back one mile or more (callout ii). Queued vehicles in and advance of workzones are not uncommon depending on time-of-day, construction activity, and volumes. The hard-braking data shows in detail the more severe decelerations and locations of where

the decelerations have occurred. As opposed to slow speeds in a queue, the change in speed just before a queue is a critical factor for safety, in some cases near 23-times more hazardous than normal conditions (*13*). **Figure 3** is a time-space heat map of the same workzone over a two-day period of when the hard-braking data was collected, created using conventional probe data. The pink hues signify speeds below 15 mph. From the figure, it can be seen that at least six queues have formed just before mile marker 218 (callouts i through vi) The hard-braking information can help agencies and maintenance-of-traffic personnel to strategically place signs and warnings, station public safety, and other queue mitigation solutions to improve driver response to impending slowed traffic.
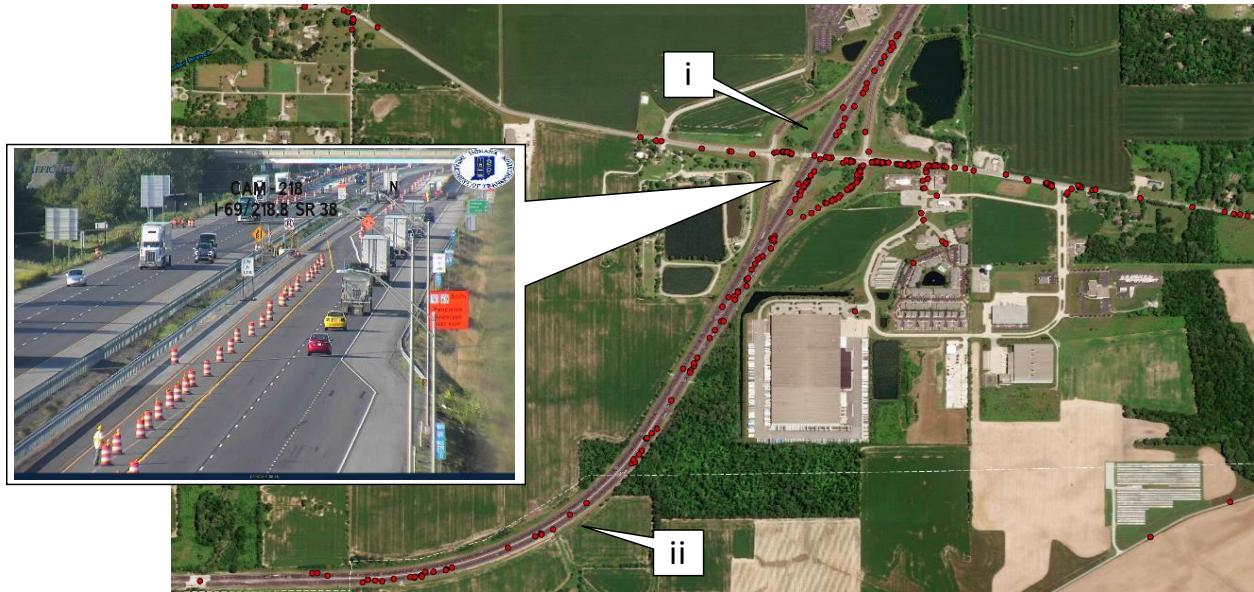

Figure 2. One week of hard braking events on Interstate 69 at a workzone area, mile marker 219 adjacent to location with a work zone lane shift.
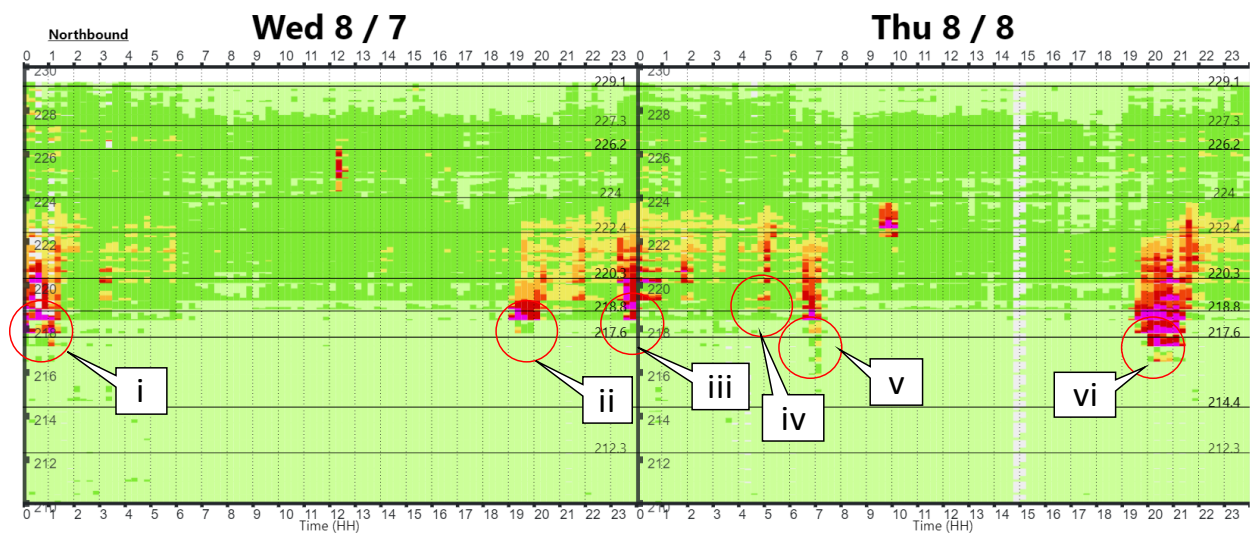

Figure 3. Spatial-temporal heat map of identified locations of back-of-queue.

Signalized corridors

Vehicle hard-braking data can also be leveraged to assess signalized arterial performance. **Figure 4** shows

two signalized interchanges (a conventional diamond interchange and a single-point urban interchange) overlaid with hard-braking events. Callouts i-vi show hard-braking events associated with the ramp traffic signals, mostly clustering 200 to 300 feet before the stopbar. There are fewer hard-brakes going through the intersection which many vehicles are arriving on green with few queues. There are also no hard-braking events on the expressway due to mostly uncongested conditions in this area. Similarly, callouts vii and viii show hard-braking events at a high-volume intersection as vehicles exit the off ramp coming from the interstate.

However, of particular note are the hard-braking events that occur on the interstate (callout ix). These are of particular concern because they indicate significant queueing where drivers must slow down dramatically and/or stop that increases the risk of a back-of-queue or "rear-end" collision.
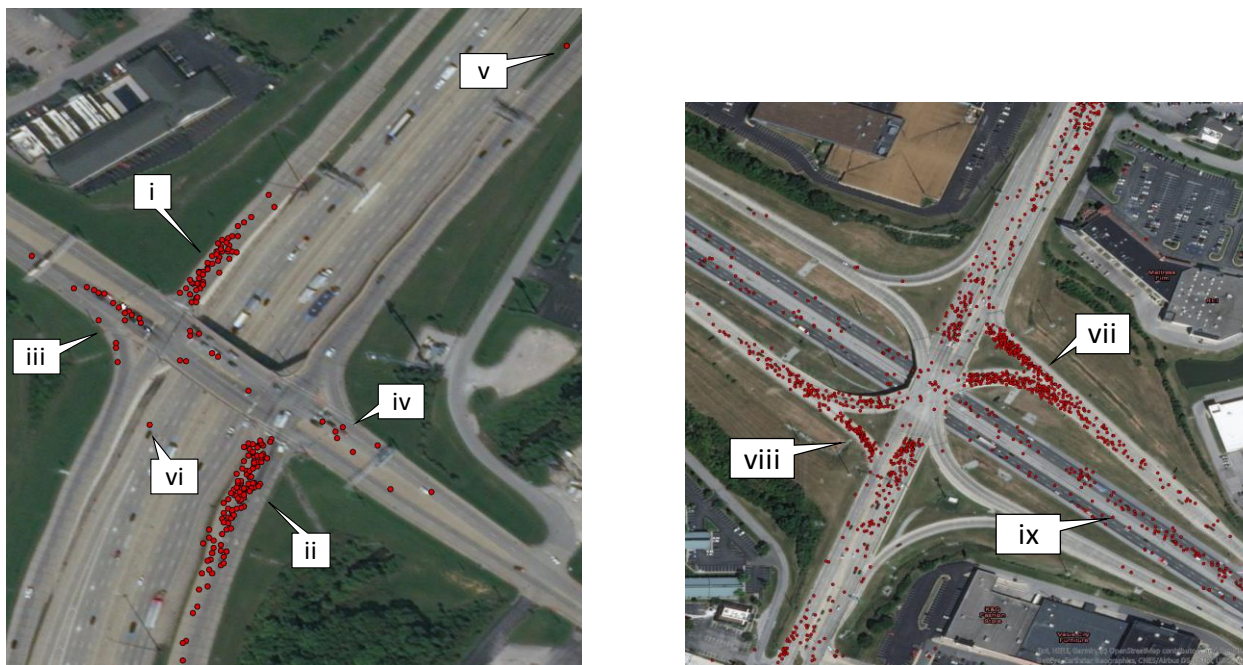

Figure 4. Hard-braking at signalized interchanges.

Figure 5 shows a green profile diagram (*14*) overlaid with hard-braking events approaching a signalized intersection with an accompanying Purdue Coordination Diagram (PCD) (*15*). The X-axis indicates the seconds in a coordinated cycle over a certain time-of-day where green probabilities were experienced for that approach. The primary Y-axis indicates the probability that the signal was green for that approach at the specific time-in-cycle. Unlike conventional green profile diagrams, **Figure 5** also has a secondary Y-axis that indicates the setback from the stopbar of where a hard-barking event has occurred. The hard-braking events are plotted as dots (colorized by speed range) along that axis for a specific time-in-cycle. Callout i shows a hard-braking that occurred within the green period at slower speeds (between 15 to 24 mph) approaching the back of a stopped queue from about 380 feet back from the stopbar. Callouts ii and iii show vehicles stopping from a higher rate of speed (25 to 34 mph, and 35 to 44 mph respectively) closer to the stop bar between 240 to 280 feet. Callout ii may have occurred around the time of the onset of yellow where

the driver was confronted with a potential dilemma zone scenario, around cycle second 60. The column of hard-braking further into the red period, between cycle second 80 and 90, and much closer to the stop bar around 80 to 100 feet, may indicate either very aggressive stopping behaviour from late-arriving platoons that are clipped, as indicated on the PCD in callout iv, or potentially clock offset issue between the vehicle data and the traffic signal data (callout v). This presents an opportunity for further investigation.
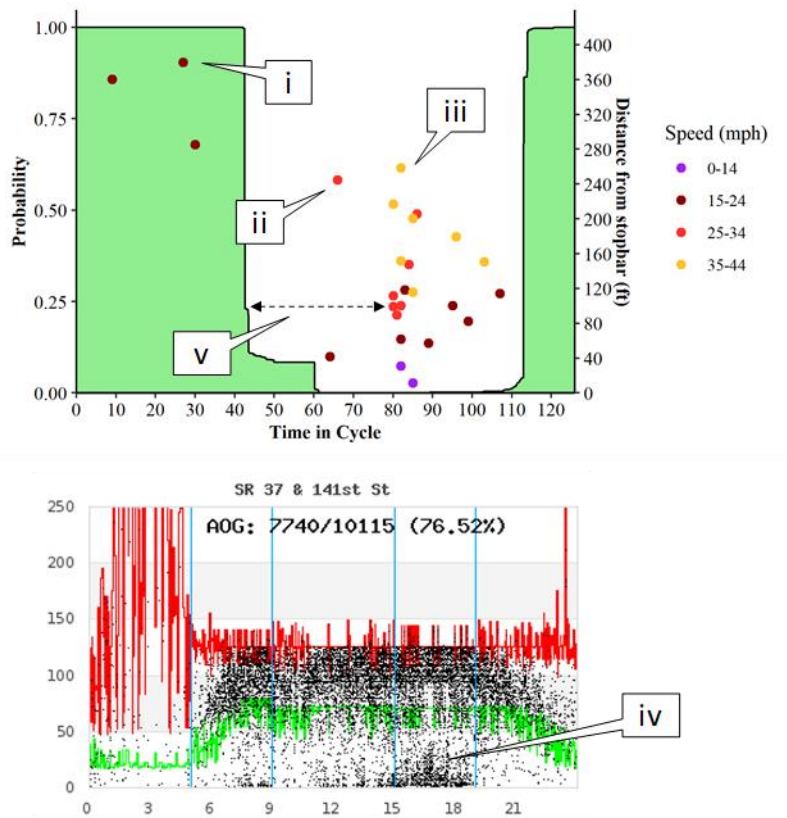

Figure 5. Arrival-on-green assessment using hard-braking and traffic signal phase data.

State-wide Assessment

Data penetration

To assess how much hard-braking occurs on a state-wide basis and how much of the data is available to practitioners, a sorted data availability diagram can be used, such as the one presented in **Figure 6**. In the graph, three different expressway routes are analysed based on the percentage of minutes that had at least one hard-braking event, and the coverage in miles over each of the routes. This is analysed over a one-week period. The three routes have inherently different traffic characteristics: I-465 is 53 miles in length and is characteristically urban with typical recurring congestion patterns; I-65 is 262 miles in length and is a major corridor for interstate travel connecting three major urban areas; I-74 is 170 miles in length and is a relatively low-volume corridor. These interstates have the following ADT ranges over their duration

- I-465, 34,000 to 95,000
- I-65, 22,000 to 78,000
- I-74, 7,400 to 24,000

I-465 had at least one hard-braking event captured for 10 out of every 100 minutes of the entire week (callout i), where I-65 had about 8 (callout ii) and I-74 had less than 4 (callout iii). For congested periods where the hard-braking was spread out over a wider area on each route, for instance at 2 miles the number of minutes with events covering this length is 4 out of 100 minutes on I-465 (callout iv), 3 out of 100 minutes on I-65 (callout v), and just above 1 out of 100 minutes on I-74 (callout vi). At 20 miles, all three routes drop to below 1 minute for every 100 minutes (callout vii). The further right on the graph indicates the rarer occurrences where a greater part of the network was affected. As penetration of connected vehicles increase, these curves will shift upwards significantly.
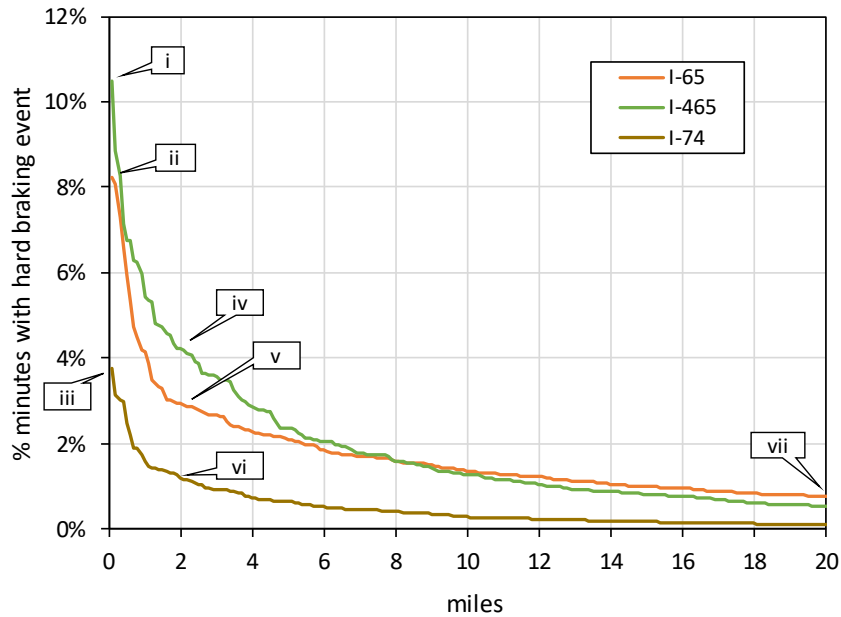

Figure 6. Miles of interstate with hard-braking events.

Statewide workzone analysis

The hard-braking data can be mapped spatially for an expressway from state line to state line with workzone areas identified. **Figure 7** shows a 255 mile section of I-65 in both directions between Chicago area (left-hand side, callout i) and Louisville metro (right-hand side) with spikes of hard-braking events along the entire route. Four workzones are identified along the route (callouts i-vi) where callout iii is a workzone in the metro Indianapolis area. The red spikes indicate large number of occurrences of hard-braking activity, especially at boundaries entering the workzone from each direction, as can be seen in callout iv.
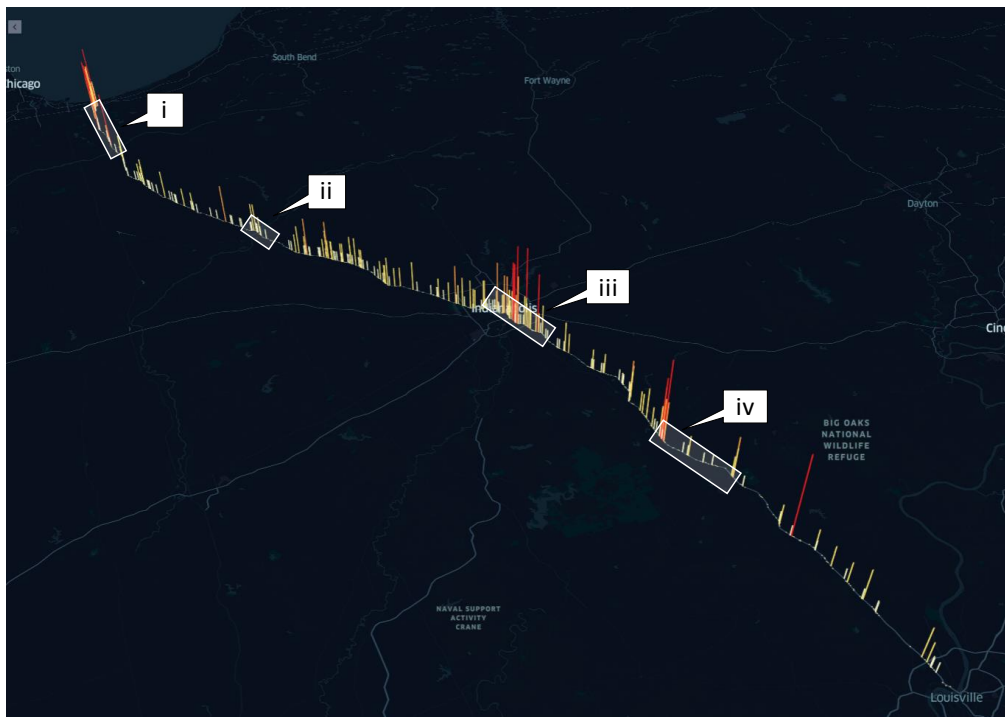
Figure 7. Hard-braking events along Interstate 65 in Indiana over one week.

Conclusions and Future Research

Qualitative spatial frequency analysis of hard braking events on signalized corridors demonstrate that dilemma zone type conditions can be identified by hard braking events. This is particularly important as historical methods used by traffic engineers often identified dilemma zone problems by looking for pavement skid marks. Similarly, interstate work zone operational and safety problems have often been identified by crash reports that have a substantial lag time before they are available in online databases. This study demonstrates the ability to quickly identify temporary and long-term construction zones that warrant further investigation to improve geometry and advance warning signs. Future research will focus on real-time integration of hard-braking events with high-resolution traffic signal data (**Figure 5**) on a regional and state-wide basis and correlate with crash frequency. Similar work will be performed for freeway segments, normalizing for traffic volume.

Acknowledgements

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