Real-Time Probe Data Dashboards for Interstate Performance Monitoring During Winter Weather and Incidents

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REAL-TIME PROBE DATA DASHBOARD FOR INTERSTATE PERFORMANCE MONITORING DURING WINTER WEATHER AND INCIDENTS

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ABSTRACT
The Indiana Department of Transportation (INDOT) manages over 1800 centerline miles of interstate that can be profoundly impacted by weather, crashes, and construction. Real-time performance measurement of interstate speeds is critical for successful traffic operations management. Agency managers and Traffic Management Center decision makers need situational awareness of the network and the ability to identify irregularities at a glance in order to manage resources and respond to media queries. One way to access this level of detail is crowdsourced probe vehicle data. Crowdsourced probe vehicle data can be obtained by collecting speed data from cell phones and GPS devices. In Indiana, approximately 2673 predefined interstate segments are used to generate over 3.8 million speed records per day. These data can be overwhelming without efficient procedures to reduce and aggregate both spatially and temporally. This paper introduces a spatial and temporal aggregation model and an accompanying real-time dashboard to characterize the current and past congestion history of interstate roadways. The primary high level view of the aggregated data resembles a stock ticker and is called the “Congestion Ticker.” The data archive allows for after-action review of major events such as ice storms, major crashes, and construction work zones. The utility of this application is demonstrated with two case studies: a snowstorm that covered northern and central Indiana in February 2015 and an I-70 back of queue crash in April 2015.

Keywords: Mobility, winter operations, probe data, operations dashboard
INTRODUCTION
Traffic operations engineers need to understand the current performance of the interstate system to successfully manage responses during incidents, such as snowstorms, crashes, or lane closures. Historically, ITS cameras and field reports have been used to provide this information. Crowd sourced probe vehicle data are an emerging data source that can be leveraged to assess network performance. These data are provided by a third-party vendor and consist of a minute-by-minute average speed for a predefined segment of the interstate. For the past three years, these data have been used to create plots of congestion hours and speed profiles in annual mobility reports, which are part of INDOT’s longer term performance monitoring activities (1)(2)(3). These annual reports have stimulated demand for development of real-time dashboards characterizing the current network operation. However, with 2673 speed records generated each minute for 1800 miles of interstate, or approximately 3.8 million records per day, it is critical to have a robust software system for aggregating and representing the spatial and temporal information effectively and efficiently. Indiana is not alone in this quest for operational dashboards for analyzing probe data. The I-95 Corridor Coalition’s Vehicle Probe Project (5) is very actively pursuing the development of the Regional Integrated Transportation Information System (RITIS). The CalTrans Performance Measuring System (PeMS) utilizes loop detector data to create a wide variety of performance metrics (6).

MOTIVATION FOR DASHBOARDS
Winter maintenance operations are vital to safety and mobility and also have economic benefits for society. The United States invests $2.3 billion each year keeping highways clear of snow and ice (8). However, historically there have been limited or no performance measures for an agency to monitor how effective they are in response to a winter event.

MAP-21 has motivated agencies to carefully scrutinize daily operations and identify key performance indicators in order to assess how effectively they are serving the public. The interstate performance monitoring dashboard was originally developed to aid the Indiana Department of Transportation (INDOT) in monitoring the impact of winter storms across various roads and districts in the state. The initial design goal was a dashboard of graphs displaying the number of miles of interstate that are operating below 45 mph, updated on a fifteen minute period and plotted in a stock ticker format. Two early design objectives were an intuitively simple at-a-glance dashboard that would be useful to maintenance staff and provide near real-time data updating effective for operations decision makers. An historical playback feature was added to facilitate after-action review of weather-related congestion and management. Subsequently, use of the tool was expanded to monitoring crashes, work zone-related congestion, and reoccurring congestion.

Subsequent dashboard design requirements included additional speed profiles to characterize severity, district and route sorting, and an historical archive playback feature. The dashboard and the suite of supporting drill-down graphics are coined the Congestion Ticker. Case studies will be used to illustrate the utility of the dashboard suite during a snowstorm in February 2015 and a major crash in April 2015.

METHODOLOGY & MODEL
The probe data used to create the website is obtained from a third party traffic data aggregation service that provides traffic speed data from a variety of sources, ranging from personal GPS units to fleet vehicle information, into one-minute average speeds. These speeds are available on predefined segments of road that are approximately one mile in length, shown in Figure 1a. On busy roads, data is reported for every segment every one minute. To maintain fast performance, the dashboard data model aggregates data every 15 minutes and the median speed is used to represent the entire 15-minute period.
(a) Example segment and speed data

FIGURE 1 Data collection and temporal aggregation for a west bound probe data segment near mile marker 24 on I-70 westbound

The map in Figure 1a shows data segments with a segment of I-70W highlighted with sample data. Figure 1b shows an example of the data aggregation from this segment, with the minute-by-minute speeds as diamonds and the median speed for each bin drawn as a line. These data correspond to traffic
slowing due to congestion associated with a downstream crash. Callouts i and ii show a period of extreme congestion with no probe vehicles traversing the segment with no data being reported. It is extremely rare that an interstate segment will not report at least one speed in a 15 minute period, so a 15 minute period with no data almost always implies a road closure or very extreme congestion with parked vehicles.

**Congestion Ticker Graphics**

The Congestion Ticker dashboard is built around the display of three graphs, which can be seen in Figure 2. The first graph is a stacked area graph (Figure 2, callout i) displaying the total interstate miles by agency district that are operating below 45 mph over time for the State of Indiana. The default display is a weeklong history of the interstate system’s performance. Here it can be seen that congestion on February 1st and 2nd (Figure 2, callout ii) was abnormal for the week and is attributed to a snowstorm that significantly impacted approximately 10% of the Interstate system, which will be discussed in the first case study. Figure 2, callout iii shows the same information as callout i, but colored areas are categorized by road instead of district.

**FIGURE 2 Congestion Ticker website screenshot**

The third graph (Figure 2, callout iv) is a speed profile over time using shades of green for speeds greater than 65 mph, between 55 and 64 mph, and between 45 and 54 mph, respectively. The congested periods are similarly broken into ten mile per hour bins and are represented by color shades ranging from most extreme congestion (purple, 0 to 15mph), heavy congestion (15 to 24 mph), moderate congestion (25 to 34 mph) and light congestion (35 to 44 mph) in shades of red and orange.

Along the left side the current time is shown (Figure 2, callout v), along with filtering options for specific Interstates (callout vi) and agency maintenance districts (callout vii). Users can change the threshold speed for defining congestion in the first two graphs (callout viii), which defaults to 45 mph.
There is also an option to display either the total number of miles in the column charts or as a percentage of the total interstate miles, which is useful for examining shorter routes such as the I-465 loop around metropolitan Indianapolis. The three y-axes can be locked to the same range to allow for more objective comparison across different weeks and conditions. Finally, the user can select the date range to display (Figure 2, callout ix) so that shorter or longer periods can be displayed and after-action reviews several months back can be performed.

The Congestion Ticker provides a high-level overview of congestion in the state and districts. To provide more detailed views of traffic conditions, additional tools were linked to the dashboard. One is the delta speed map, which identifies the locations with significant drops in speed between segments of roadway (9). Two other tools being used are congestion profiles and speed profiles, which are plotted by mile markers for a roadway. The congestion profiles display the number of hours operating less than 45 mph and the data can be grouped by day of week, hour of day, week, or month. The speed profile graph is colored by speed range, similar to the speed profile of the Congestion Ticker, but allows for spatial analysis along a road. Applications of the delta speed, congestion profile, and speed profile tools are explained in the following case studies.

Dashboard Use Cases
This dashboard suite of tools encompasses four items:

- Congestion Ticker
- delta speed map
- congestion profiles
- speed profiles

These tools enable decision makers at transportation agencies to make informed operational decisions using probe traffic data. Table 1 gives an overview of use cases for executive staff and traffic management center engineers from a general overview of whether there are any incidents in the system to exact times, durations, and locations of each incident. The executive use case tends to begin at the high level and drill down to finer details, while the operations engineer begins with detailed views and then zooms higher for context within the network. Table 1 includes one non-dashboard column to indicate that user knowledge also is incorporated into the view of these dashboards.
TABLE 1 Dashboard use cases, structured by typical needs and tools.

<table>
<thead>
<tr>
<th></th>
<th>Congestion Ticker</th>
<th>Delta Speed Map</th>
<th>User Knowledge</th>
<th>Congestion Profiles</th>
<th>Speed Profiles</th>
</tr>
</thead>
</table>

**Executive Staff Use Case**

1. Are there anomalies in the network? X X
2. How bad are they? X
3. How long have they been there & when did they start? X
4. What district are they in? X
5. What road? X X X
6. Where on the road (direction & milepost)? X X X
7. Why? X X X

**Traffic Management Use Case**

1. Where are my emerging traffic queues? X
2. Are they recurring or anomalies? X X
3. During incident response how are the network dynamics changing? X X
4. After action review. What lessons did we learn? What could we have done better? X X X

**TABLE 2 Dashboard spatial and temporal aggregation levels**

<table>
<thead>
<tr>
<th></th>
<th>Spatial Granularity</th>
<th>Temporal Granularity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mile Marker</td>
<td>Road</td>
</tr>
<tr>
<td>Phone calls</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Surveillance Video</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Congestion Ticker</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Delta Speed Map</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Congestion Profiles</td>
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<td></td>
</tr>
<tr>
<td>Speed Profiles</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 2 shows the use of this suite of tools in both temporal and spatial aspects. Also included are traditional phone calls and surveillance video. The probe data-based tools have some latency due to data collection and aggregation, but this latency does not preclude using them for real-time condition assessment and decision making. The delta speed and Congestion Ticker both span wide use cases temporally and spatially, while the congestion and speed profiles are best for viewing at a more specific spatial view. The usefulness of the speed data temporally can be seen as the tools are all available in both near real-time and archive modes, allowing for after-action review in great detail. The application of these tools will be discussed in the following two case studies of winter operations and a crash that closed some lanes.
CASE STUDIES
To provide context for the use of the dashboard suite, two examples of Interstate congestion in Indiana during the first half of 2015 are presented. The suite of tools are used to examine a large snowstorm in early February 2015 and an Interstate crash in April 2015.

Six Month Overview
Figure 3 shows the statewide traffic ticker for all agency maintenance districts from January 1 through June 30, 2015. A map showing the location of the districts is shown in Figure 4b. By selecting a six-month period, recurrent congestion can be identified and large peaks can be put in context of normal operation. At a glance, the typical congestion can be identified as approximately 20 to 30 miles of Interstate congested statewide (Figure 3, callout i). Six significant storm peaks stand out from the background, with the worst occurring around March 1st and the longest occurring in early February (Figure 3, callout ii). The March 1st storm had significant impact on approximately 392 miles of interstate at its peak (Figure 3, callout iii). The storm on March 5th is in contrast to the others as it mostly affected the southern part of the state, in the Seymour and Vincennes districts (Figure 3 callout iv).

Congestion rises modestly towards the end of June, coinciding with the beginning of summer vacation travel, construction and several heavy rainstorms (Figure 3, callout v). During the summer season, it is not uncommon to see 50 miles of interstate negatively impacted by roadwork. Figure 3c shows the Seymour management district in June, with weekends banded in light grey. The congestion increases each week as construction activities and traffic volumes increase in June.
(a) 2015 first quarter district congestion hours

(b) 2015 second quarter district congestion hours

(c) June 1-26, 2015, Seymour district congestion hours

FIGURE 3  Overview of Congestion, by geographic region (District)
Snow Storm, February 2015
A winter storm was selected for evaluation to show the statewide scope of the dashboard. Over February 1st and 2nd, 2015, snow fell across Indiana ranging from 0.5 inches in south central Indiana to as much as 16 inches in the northern parts of the state, shown in Figure 4a, callout i. The Fort Wayne and LaPorte districts in the north of the state, seen in Figure 4b, callout ii, were the most affected, as shown in Figure 4c, callout iii.

FIGURE 4 Statewide snow depth and congestion
Congestion due to the storm lasted for most of Sunday (February 1st) and continued into Monday (February 2nd) as snow continued to fall. The peak of the storm, as can be seen in Figure 4c, took place on February 1st at 18:45. At this peak, over 160 miles of interstate were operating at speeds less than 45 mph. For a 28-hour period between 06:00 on February 1st to 10:00 on February 2nd, at least 70 miles of interstate were congested. The vast majority of congestion reflects expectations from the snowfall map in the LaPorte and Fort Wayne districts, colored orange and black respectively in Figure 4e.
Figure 5 shows the Congestion Ticker graphs for Fort Wayne, which experienced more miles of congested conditions for a shorter duration than the LaPorte district. The district ticker in Figure 5a shows congestion spiking at noon on February 1st and dropping off eight hours later at 2000 to 27 miles, sustaining a lower level of congestion below 38 miles into the following morning. In Figure 5b, a callout shows the peak of storm congestion, 90 miles between 1845 and 1900 on February 1st.

Figure 5b also shows that a large proportion of speeds below 45mph were on I-69 N and on I-80 W. Figure 6 provides a spatial illustration of location and severity of these reduced speeds on I-69. This is called the speed profile view. Most of the congestion occurred between mile markers 285 and 357 in both directions. This tool allows for closer inspection of certain mile markers, days of week, and times of day to complement the aggregate view of the Congestion Ticker. As one can see from Figure 4, the storm impacted the northern area of the state. Figure 6 shows a similar spatial impact on I-69 with higher congestion values located on the northern portion of the interstate.
Back of Queue Crash

The previous example illustrated a regional storm that impacted multiple districts in the state. These tools can also be used for real-time monitoring and after action assessment of isolated events such as crashes and work zones.

On April 27, 2015, there was a fatal crash and a subsequent back of queue crash that left I-70 closed (11). The first crash occurred near the 22 mile marker in the westbound direction just before 6:00 PM when a vehicle lost control and rolled over.

A queue formed as a result of this collision, and forty minutes later and two miles upstream, a semi-tractor trailer crashed into the back of queue at mile marker 24 (11). Subsequently, the truck caught fire, calling for additional incident response for the secondary crash and causing further backups. The trailer fell into the ravine and the resulting fire on the bridge required closing of the Interstate. Due to the trailer debris and batteries remaining in the creek, the recovery occurred on April 28th, necessitating a closure of the left lane for two hours (16)(17).
In this particular case, emergency calls immediately alerted traffic management staff to the incident. This analysis focuses on the after-action review of the congestion associated with the crash and subsequent cleanup. When reviewing this incident, a manager or operations engineer can use the Congestion Ticker as shown in Figure 7 to identify atypical congestion in the Crawfordsville management district on April 27th and 28th. Selecting only roads in Crawfordsville for display as in Figure 7, I-70 westbound can be identified as the location of the problem. Both in real-time and in archive views, this abnormality can be linked to the crash through news sources and dispatch notes for after-action meetings.

FIGURE 7 Congestion Ticker overview for week of back of queue crash
(a) Congestion Ticker for Crawfordsville district with spatial drilldown callout

(b) Road Congestion Ticker for I-70 in Crawfordsville

(c) Back of queue crash resulting in truck fire (11)

**FIGURE 8** Congestion Ticker of queue building for back of queue crash

As can be seen in Figure 8b, the first crash takes place at 1750 on April 27th and quickly causes congestion for 2.5 mi of I-70 westbound. The second crash, pictured in Figure 8c, occurs at 1830 and causes a further backup. Comparing Figure 8b to Figure 8a, the resulting congestion for these two crashes
comprises the majority of congestion in the Crawfordsville district for the evening of April 27th, lasting 8 hours and peaking at 12.5 miles of Interstate under 45 mph. To measure both spatial and temporal congestion, the area under the curve is calculated in mile-hours, a multiplication of the length of road and duration of congestion. The crash incident resulted in 23.2 mile-hours where the interstate operated below 45 mph and 6.7 mile-hours where the interstate operated below 15 mph. The spatial data drilldown callout in Figure 8a accesses the delta speed map when clicked and will bring the user to the view shown in Figure 9.

FIGURE 9 Delta speed site for April 27, 2015 at 20:32:30

Traffic management staff reported via Twitter that all lanes on I-70 westbound were closed for three hours due to the crash with traffic diverted onto US-231. I-70 westbound opened again at 2030 (12)(13)(14)(15). Figure 9 shows the view accessed by the link in the callout of Figure 8a, providing a spatial view of the congestion on the road where the orange and red circles show when and where the back of the queue has propagated.
The other large spike of congestion in Figure 8b is associated with the cleanup that occurred on Tuesday, April 28th. The resulting lane closure occurred in the afternoon and caused additional congestion. Figure 10 shows the congestion profile (speeds less than 45mph) spatially along I-70 in both directions for the two days, with the day of the crash in blue and the day of cleanup in grey. The eastbound direction experienced nearly half an hour of speeds less than 45 mph during the day of the crash from mile marker 19 to mile marker 22 and from mile marker 32 to mile marker 36, likely caused by rubbernecking. Slowdowns in the westbound direction spanned for twenty miles the day of the crash and sixteen miles on the day of cleanup.

FIGURE 10 Congestion profile for I-70, April 27-28, 2015
Although the congestion profiles shown in Figure 10 are convenient for comparing days and hours, it does not illustrate the severity of the congestion at each mile marker. The range of speeds in a congested area can be depicted using the speed profile tool. The comparison of speed profiles in Figure 11 illustrates the severity of congestion from the cleanup effort. Both incidents caused congestion back to the 40 mile marker, but the cleanup lane closure caused two hours of speeds below 15 mph over five miles of Interstate.

The Congestion Ticker shows the impact that these incidents had on Interstate speeds and could be used in the future by the public relations team in news media outreach or social media posts. These software applications provide quantifiable and defensible information for stakeholder dialog during after-action review to objectively assess incident resolution and develop consensus on best practices in traffic operation and management moving forward.
CONCLUSIONS AND FUTURE RESEARCH

MAP-21 has motivated agencies to carefully scrutinize daily operations and identify key performance indicators in order to assess how effectively they are serving the public. This paper described the concept of a near real-time Congestion Ticker and associated drill down reporting capabilities that show:

- Back of Interstate queues (delta speed, Figure 9)
- Hours of speeds below 45mph, referenced to directional milepost and summarized by hour, day, or month (congestion profile, Figure 6)
- Congestion severity, referenced to directional milepost and aggregated in 10 mph speed bins (speed profile, Figure 11)

Use cases for this suite of tools were described for high level situational awareness of executive staff and for traffic management staff tactical operations (Table 1). Two case studies were presented. The first case study was related to winter operations and congestion severity in two northern Indiana agency maintenance districts. The second case study examined a sequence of related crashes and recovery. The first incident affected up to 90 miles of Interstates in night time white-out conditions while the second case study affected up to 25 miles of Interstate in rural areas with no ITS sensors or cameras. The software applications demonstrated that roadway performance monitoring and archival playback can be achieved at sub-optimal observing conditions and in areas without intrusive infrastructure using crowd sourced probe data.

The winter storm was quite severe and was shown to impact approximately 150 miles in the northern two districts, or approximately 8% of the Interstate network on Feb 1st. Different storms impact different regions of the state at different times and with different severity. This high level aggregation of district congestion hours allows the agency to develop normalized performance measures that track usage of costly resources such as salt, miles driven, and man-hours.

The crash case study illustrated the magnitude a single crash can have on Interstate congestion and the challenge that these events create for recovery to normal traffic flow conditions. In this particular example, the incident lasted approximately 8 hours, at its peak impacted 12.5 miles of Interstate, and resulted in 23.2 mile-hours where the interstate operated below 45mph and 6.7 mile-hours where the interstate operated below 15 mph.

In addition to real-time management and after action review, further applications of this website may include media and public information dissemination during an event as well as examining recurring congestion severity in urban areas.

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