Real Time Measurement of Work Zone Travel Time Delay and Evaluation Metrics

by

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ABSTRACT

This paper describes the collection of 1.4 million travel time records over a 12-week period which were used to evaluate and communicate quantifiable travel mobility metrics for a rural Interstate Highway work zone along I-65 in Northwestern Indiana. The effort involved the automated collection and processing of probe data from multiple field collection sites, communicating travel delay times to the motoring public, assessing driver diversion rates, and developing proposed metrics for a state transportation agency to evaluate work zone mobility performance.

Collected travel time profiles were compared against traditionally measured hourly flows in both incident and non-incident conditions. Through the 12-week period over which work zone performance was measured, the work zone had 422 hours of congested conditions in which travel time delay was greater than 10 minutes. Despite display of real-time delay measurements to the motoring public via portable dynamic message signs, a negligible percentage of the travel probes were observed to divert from the upstream congestion through self-guidance. Implementation of a targeted alternate route starting the weekend of July 24th resulted in an increase of observed probes diverting along the trail blazed route from virtually none, to over 30%.

MOTIVATION FOR THE STUDY

Interstate Highway 65 in Indiana serves as the southeastern commercial gateway to the Chicago metropolitan area. Figure 1 graphically represents the study area in which approximately 10 miles of I-65 was resurfaced during the summer of 2009 by the Indiana Department of Transportation (INDOT). This segment of roadway consists of a four lane facility with an Annual Average Daily Traffic (AADT) volume of 35,000 in which 40% are classified as trucks. Holiday and summer traffic loading along this corridor yielded disproportionate spikes in travel demand on Friday and Sunday where daily volumes were observed to be 30-40% higher than the AADT. Table 1 documents how the lane configurations changed throughout the project. Figure 2 provides additional detail illustrating how the active area of the work zone shifts as work progresses.

This work zone was identified prior to construction to be a challenging work zone due to the projected holiday and weekend traffic volumes. Constructability and safety concerns associated with deep bituminous patching and edge of pavement drop offs prompted a more semi permanent maintenance of traffic configuration that lacked the flexibility to accommodate expected increase of volumes on the weekends. The installation of temporary pavement and bridge widening for this resurfacing project was deemed to be cost prohibitive. Exceptions were made to INDOT’s Lane Closure policy to accommodate the geometric configuration of the work zone. The revised sequencing of the project involved installation of temporary crossovers and concrete barriers to provide a two-way single lane traffic pattern on half of the facility while the other half was
resurfaced. Narrow bridge clearances in conjunction with the temporary concrete barriers necessitated a wide load detour to the east of the project.

Passive data collection took place during Easter weekend (April 9-12th) and post processing of the collected probe travel delay times during the peak demand periods showed delays greater than 70 minutes. These measurements prompted an immediate endorsement by the INDOT executive leadership team to accelerate the transition from the passive data collection effort to an active system that would integrate with other real-time traveler information products.

**DATA COLLECTION**

Data collection for this effort was facilitated through the deployment of both semi-permanent and portable Bluetooth data collection devices. Portable battery powered suitcase units were used for initial mainline Interstate data collection prior to the deployment of active traveler information devices. These portable units were also used to collect periodic data from adjacent alternate routes around the work zone. The locations these battery powered suitcases were installed on diversion routes is shown as BP 101 on US-41 and BP 103 on US-231 in Figure 1. Photographs of these installations are shown in Figure 3a,b. Semi-permanent data collection units consisted of retrofitted solar powered portable dynamic message signs that were already integrated into INDOT’s Advanced Traveler Information System (ATIS) and contained a Linux based field processor and commercial cellular data communications (Figure 3c).

Data from both collection methods was consolidated in an SQL database which resided at INDOT’s Traffic Management Center (TMC). Figure 4a represents the system architecture of the real-time data collection system. The semi-permanent devices installed on portable dynamic message boards (pdms) inserted collected data in near real time whereas the portable suitcases maintained a local data store that was harvested and ingested into the database through post processing after deployment. Travel time was estimated by matching time stamped Bluetooth MAC addresses (8) to display travel time information to the motoring public in real-time and produce weekly workzone travel time statistics (Figure 4).

An existing Automatic Traffic Recorder (ATR) site was located to the south of the work zone near the 186 mile marker and its hourly volume information was used to reflect the northbound travel demand trends along the I-65 corridor.

Crash record information was obtained from the Indiana Criminal Justice Institute’s Automated Reporting Information Exchange System (ARIES).
One of the challenges in designing work zone traffic control plans is the difficulty in predicting work zone capacity. For example, Figure 5a shows a week of traffic volume at a count station just south of the study area (Figure 1) at MM 186. In general, a rural interstate can expect to have a capacity slightly higher than 2000 vph. Assuming no capacity constraints are introduced by the work zone, the traffic profile shown in Figure 5a would not be expected to result in any queuing. However, the plot of the observed work zone travel time shown in Figure 5b suggests the work zone, which reduces to one lane for several miles, has capacity near or below 1500 vph. Since queue formation (and duration) is quite sensitive to capacity assumptions, there has historically been no easy way to measure work zone travel time in real-time (9), until the development of Bluetooth tracking techniques that can provide probe vehicle travel time measurements for approximately 8% of the passing vehicles. Upon visual inspection, the impact of the flow peaks shown in Figure 5a on Thurs, Friday, and Sunday, are clearly evident in the observed probe vehicle travel time plots in Figure 5b where the travel time peaks at about 1hr 45 minutes for each of those days, in comparison to approximately 20-25 minutes during lower flow rate periods. So, a 1 hr 45 minute travel time corresponds to a delay time on the order of 1 hr 20 to 1hr 25 minutes.

The small bump in travel time on Wednesday, suggest capacity of the work zone is slightly less than 1500 vph, at least during certain periods. In addition to plotting the travel times of all of the observed probes, Figure 5b plots a trace along the top that indicates when delay exceeds 10 minutes, an indication that a queue is present. For this example week, the total hours where a queue was present, was approximately 29 hours. Table 2 summarizes the weekly summation of the time periods where the presence of a queue is indicated by delay exceeding 10 minutes. Figure 6 graphically shows the proportion of a week that each direction has delay exceeding 10 minutes. The dramatic improvement in southbound operation on Weeks 10 and 11 is clearly evident as the contractor prepared to shift to the next segment and had two lanes open.

Figure 5 illustrates how probe vehicles can be used to characterize travel time during periods of heavy congestion. Figure 7 illustrates the finer grain fidelity that can also be observed with the Bluetooth probe data. In this case, the contractor had finished a South bound segment on or around July 1 and opened the Southbound segment to two lanes on the afternoon of July 2. The boxes around the tight grouping of travel times before and after this period illustrate that opening the second travel lane decreases average travel time on the order 3-4 minutes, even during free flow conditions.
QUANTIFYING RELATIONSHIP BETWEEN CRASHES AND TRAVEL TIME

Freeway crashes and travel times are related in three ways.

1. Crashes in capacity constrained areas often result in capacity reductions that significantly increase travel times and result in queuing.

2. Crashes upstream of capacity constrained areas often result in flow reductions to the capacity constrained areas. This reduced flow may eliminate queuing in the capacity constrained area, but shift the queuing to another segment of the network.

3. Capacity constraints that result in queuing are widely reported to increase crash rates.

The first two cases are exceptionally hard to accurately model, because of the large number of factors, and their impact, that cause capacity reduction in freeways. In the third case, it has historically been very hard to accurately determine the presence of congestion or queuing to quantify that impact queuing has on interstate crash rates.

To illustrate the relationship between crash impact and flow rates on travel times in a capacity constrained work zone, Figure 8 shows the impact a crash 59 miles from the work zone in which all lanes were closed for approximately 2 hours had on travel time. In this particular example, the Sunday afternoon flow rates observed at mile marker (MM) 186 begin to exceed the work zone capacity (approximately 1500 vph) around noon on May 3 (Figure 8a) and vehicles departing the work zone at MM 241.1 about an hour later begin to exhibit the first indications of increased travel time (Figure 8b). The work zone travel time shown in Figure 8b increased to a peak travel time of approximately 75 minutes near 1900 and rapidly dropped off. Examining Sunday May 3 flow rates at MM 186 in Figure 8a shows a sharp reduction in flow rate from near 1800 vph to 550vph. As a result, the travel time shown in Figure 8a rapidly recovers to eliminate work zone queuing by approximately 2000. By coincidence, this corresponds approximately to the same time the lanes are reopened at the crash site near MM 158 and the queue at MM 158 begins to discharge. The flow rate at the ATR site is seen to recover around 2030. By 2100 the heavy flow rates reach the construction work zone (Figure 8a) and a secondary spike in travel time is observed near 2230 (Figure 8b).

The interaction of queuing and travel time with crashes within the work zone is much more dynamic. Figure 9 shows the travel time through the work zone during the week that spanned the 4th of July holiday.

- Figure 9a shows the northbound travel time with numbered callouts indicating when crashes occur.
- Figure 9b shows the southbound travel time with numbered callouts indicating when crashes occur.
Figure 9c shows the spatial location of the crashes on a work zone map using the same numbers as shown in the callouts in Figure 9a and Figure 9b.

For this particular period, the southbound direction increased from 1 lane to 2 lanes on Thursday July 2 and was previously shown in Figure 7. Of particular interest in this example is the coupled relationship between crashes and travel times. The following sequence of bullets represent a chronological summary of the relationship between crashes and travel times based upon observed travel time and examination of crash reports.

- On Friday July 3rd, crash N42 occurred just prior to the work zone as traffic was beginning to queue.
- Shortly after crash N42, Northbound travel times (Figure 9a) begin to sharply increase.
- Subsequently crashes N44 and N45 occurred further back in the resulting queue. The spatial location of those crashes is shown in Figure 9c.
- Crash N43 occurred during this time period. However, based upon the officer’s narrative on the crash report, this crash was likely unrelated.

A second noteworthy crash/travel time relationship is shown in Figure 9a on Sunday July 5 about 1500. In this case, N47 was a personal injury crash that resulted in short term total lane closure. The impact of this can be seen in Figure 9a as a period where there are no probe travel times, followed by a peak travel time of about 100 minutes after the lanes are reopened and travel time reducing back to their normal 25 minute range by midnight.

Figure 10 illustrate a similar relationship between crashes and work zone queuing. In this case, crash N29 occurred at approximately 1416 north of the work zone. The resulting increase in travel time Figure 10a is a strong indicator of a building queue and crash N30 is shown approximately 16 minutes later.

Figure 10b illustrate the overlapping impact of two apparently unrelated crashes. In this case, crash S21 occurred at 1220 that resulted in an increase in travel time of approximately 20 minutes. That crash was cleared, but before the travel time had recovered, an additional, crash S22 occurred at 1620.

QUANTIFYING RELATIONSHIP BETWEEN DYNAMIC MESSAGE SIGNS AND MOTORIST ROUTE CHOICE

The Brickyard 400 is the second largest single day sporting event in the world. That event occurred on Sunday July 26 in Indianapolis, approximately 120 miles south of the work zone. Figure 11 shows the travel time through the work zone and Figure 12 compares the volume characteristics of count station at MM 186. Figure 12 clearly shows the peak northbound flow rate on Sunday increasing from about 1600 vph to 2200vph around 2100, and a shift in peaking time by about 4 hours. In anticipation of this, INDOT established a diversion route that promoted a diversion route to SR-114, to US-41, to I-80/94. This diversion route shown on dynamic message signs during periods where work zone queuing was
observed. The shaded rectangles in Figure 13 shows the periods that the message signs were active, as well as the observed travel time from the portable dynamic message sign (pdms) at MM 218 to a second monitoring station on US-41. The locations of these monitoring points are shown in Figure 1. At the time of writing, the crash reports for this time period were not available (but will be updated in October revision if paper is accepted). However, it is clear from Figure 13, that few motorist took the diversion route unless the dynamic message signs advising them of the route were active. This quantitative data shown in Figure 13 is consistent with surprising anecdotal observations that only displaying the expected delay (Figure 4), was not effective at encouraging motorist to seek an alternative route.

CONCLUSIONS

In summary, this paper has shown data and provided discussion that illustrates:

1. Leveraging the pervasive presence of consumer Bluetooth devices provides a signal of opportunity to obtain travel time measurement samples in construction work. This information can be displayed on message boards, web sites and disseminated to the media to provide motorists with improved trip planning, both prior to and during their trip.

2. Delay information is useful, but leads to meaningful driver behavior changes (i.e. diversion quantities) only when alternative routes are available and actively communicated to travelers in conjunction with delay times.

3. The 24/7 measurement of work zone travel time provides quantitative data an agency can use to evaluate alternative maintenance of traffic techniques, and identify best (and most cost effective) practices.

4. Queuing traffic conditions and in particular the transition from free-flow to standing queue correlate to increased probability of crashes. Crashes themselves lead to congestion and increased queuing conditions.

5. Travel time delay data can easily validate volume/capacity thresholds in which queuing conditions occur. A detailed database of this relationship is currently being developed to assist in improving work zone queue forecasts for future projects.

6. Travel delay and/or travel time reliability measurement have the potential to facilitate more flexible innovative contracting methods while strongly advocating for travel mobility when demands warrant.

In regards to future activities, work is underway to continue the instrumentation on the alternative routes shown in Figure 1 to develop models to estimate diversion traffic based upon the combination of informing motorist of travel time delay (Figure 4) and trailblazing signs. In addition, both upstream count data and segment travel time is being archived to develop short term predictive travel time models.
ACKNOWLEDGEMENTS

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REFERENCES


Figure 1. Map of study area
a) Construction zone 5/4 to 7/21, MM228 to MM235

b) Construction zone 7/21 to 7/25, MM228 to MM238

c) Construction zone 7/25 to present, MM233 to MM238

Figure 2. Diagram of construction zone limits
a) Battery powered case with internal Bluetooth receiver (case BP103 @ US-231)

b) Battery powered case with external Bluetooth receiver (case BP101 @ US-41)

c) PDMS mounted Bluetooth receiver

Figure 3. Methods of Bluetooth data collection
a) Block diagram real-time system to collect MAC addresses and update message boards.

b) Example messages displayed to northbound motorists.

Figure 4. Real-time display of I-65 travel time
a) Northbound flow rates (vph) at MM186 on I-65

b) Northbound travel time (hours) from MM 217.8 to MM 241.1

Figure 5. Traffic volumes and travel times along I-65 from June 29 through July 5
Figure 6. Percentage of week with delay > 10 minutes
Figure 7. Effect of opening second southbound lane on southbound travel time (hours)

After second southbound lane opened, travel times decreased about 3-4 minutes
Figure 8. Effects of severe lane closing crash on travel times and traffic volumes, May 1 to May 3
Figure 9. June 29–July 5, 2009

a) Northbound travel times, crash history, and queue trace

b) Southbound travel times, crash history, and queue trace

c) Crash location map
a) Northbound travel times, crash history, and queue trace

b) Southbound travel times, crash history, and queue trace

c) Crash location map

Figure 10. June 1 – June 7, 2009
Figure 11. July 20 – July 26, 2009

a) Northbound travel times, crash history, and queue trace

b) Southbound travel times, crash history, and queue trace

c) Crash location map
Figure 12. Comparative hourly traffic volume counts at MM186 on I-65

a) Northbound volumes (vph)

b) Southbound volumes (vph)
Figure 13. Travel Times Observed for probes between PDMS at MM218 and BP101 on US 241; July 24-26, 2009.
Table 1. Construction Zone Lane Configuration Timeline

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<th>Date Range</th>
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<td>7/25 on, MM233 to MM238</td>
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Table 2. Hours with delay > 10 minutes present and configuration of construction zone

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