# Assessing the Performance of SpeedInfo Radar Traffic Sensors

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## Abstract

Traffic speed is a crucial input for real-time traffic management applications. Operating agencies typically deploy their own sensors to collect the measurements, e.g., loop detectors. Recently SpeedInfo emerged with a different paradigm for traffic speed collection: instead of selling hardware to operating agencies, at each link the company deploys their own Doppler radar in a self-contained wireless unit to measure traffic speeds and then sells the speed data. This study uses well-tuned loop detector based speed measurements to evaluate 15 of the Doppler radar sensors over several months while the two traffic data collection systems were operating concurrently. The extended study period includes potentially challenging and transient conditions for the radar sensors: both recurrent (rush hour congestion and late night low flow), and non-recurrent (incidents and precipitation). The analysis took a broad overview, comparing speed measurements from the radar sensors against the concurrent loop detector data and then explicitly looked for any anomalous patterns in the radar data such as latency and system outages. The work found the radar measurements are generally good, but also identified several points that should be considered before deployment, including: latency, different biases in free flow and congestion, vulnerability to precipitation, and sensitivity to mounting angle.

**Key words**: SpeedInfo; speed measurement; Freeway traffic; performance evaluation

# 1. Introduction

Until recently real-time freeway traffic data used by operating agencies were almost exclusively collected in-house using fixed location detectors, e.g., loop detectors. Recently SpeedInfo, a new company, emerged with a different paradigm for traffic operations data collection [1]. The new approach is revolutionary in two ways. First, at the sensor level, they employ a wireless sensor unit that can be strapped to an existing pole. The unit contains a Doppler radar to directly measure traffic speeds, a wireless modem, a solar panel, a battery, and an onboard processor. In principle they should provide very accurate speeds because the radar sensor operates similarly to speed enforcement radar units. Typically the radar units report speed in two directions (approaching and receding) every minute. Second, instead of selling hardware, the company sells speed data. SpeedInfo typically owns and maintains the sensors, collects the traffic speed data and covers the communications costs. In effect this approach offers outsourced traffic data collection. At lest seven states and several metropolitan transportation operating agencies have contracted with SpeedInfo [1]. The radar sensor costs are compelling compared to traditional traffic detection and the Ohio Department of Transportation (ODOT) has deployed the radar sensors statewide, with most urban freeways covered at a density of one bidirectional station per mile and rural freeways at a lower density.

There are few published studies explicitly evaluating the performance the SpeedInfo sensors. Only a few documents either directly or indirectly provide insight into the performance of the radar sensors. A PhD dissertation used the sensor data to validate link travel times from a GPS equipped probe vehicle [2], but by extension, the GPS also provides some degree of validation for radar sensors. The study compared the concurrent: 4 min moving average spot speeds from the radar sensors at 13 locations against the instantaneous GPS spot speeds from 31 probe vehicle passes of each location. The author excluded 23% of the radar sensor locations because of large differences relative to the GPS speeds, the average difference at these locations ranged between 6 and 20 mph. A scatter plot of GPS speeds versus the radar sensor speeds from the remaining data (Fig 7.5 in the dissertation) shows strong correlation between the two sources during free flow periods but almost no correlation when either speed is below 50 mph. The overall poor correlation at 23% of the locations and poor performance during congestion at the remaining locations merits further study, e.g., the discrepancies may simply be due to comparing an instantaneous speed in one lane from GPS against the four-minute average across all lanes from the radar sensors. Another study compared the SpeedInfo sensors against other sensors, but typically the radar sensor locations were too far from the other sensor locations to provide meaningful comparisons [3]. Finally, the radar sensors were eliminated from further consideration in an Arizona study due to the proprietary data restrictions [4]. The report discusses experiences at three other agencies that had deployed the radar sensors and at the time of the report, the extent of validation by these agencies was minimal. Needless to say, in spite of the growing number of operating agencies using the SpeedInfo sensors, there have been few independent evaluations and among the few evaluations that do exist they appear to be small scale and largely unpublished.

This paper exploits a unique juncture as ODOT transitioned from loop detectors to SpeedInfo data for real time management. The two traffic surveillance systems operated concurrently for several months in Columbus, Ohio, USA. This paper uses three months of concurrent data to evaluate the radar sensor performance on 14 mi of I-71 in Columbus. The extended study period included potentially challenging conditions for the radar sensor data collection that includes both recurrent events (rush hour

congestion and late night low flow) and non-recurrent events (incidents and precipitation). The extended study period includes potentially challenging and transient conditions for the radar sensors: both recurrent (rush hour congestion and late night low flow), and non-recurrent (incidents and precipitation). The analysis took a broad overview, comparing speed measurements from the radar sensors against the concurrent loop detector data and then explicitly looked for any anomalous patterns in the radar data such as latency, impacts from inclement weather and system outages, and the physical deployment location (in the median or on the shoulder).

The remainder of this paper is as follows: first we present the analysis area and sensors used in this study. Next, we present the evaluation methodology and resulting performance of the radar sensors. Finally, this paper closes with a summary of the results and conclusions of this study.

## 2. Analysis Area and Sensor Data

As noted above, this paper uses concurrent data from the radar sensors and loop detectors in Columbus during the first half of 2011 as ODOT transitioned from in-house data collection to third party traffic data for real time management. When the new radar sensor system was deployed there was no effort made to coordinate sensor placement with the existing loop detectors. Since the I-71 freeway had the highest density of loop detector stations in Columbus (typically 3 stations per mile) this corridor was selected for this study to minimize the distance between the two sensor systems. Figure 1 shows the study corridor, highlighting the radar sensors (circles) and loop detector stations (stars and squares). The southern end of the corridor is at the I-70/I-71/SR-315 interchange in the central business district (CBD) and the northern end is outside the I-270 beltway in the northern suburbs, covering roughly 14 mi, in the shape of a "J". The loop detector station numbers are shown adjacent to the given detector station.

The loop detector stations are unique in their own right, rather than aggregating the data in the field, they send all of the vehicle actuations back to the traffic management center (TMC). Before aggregation at the TMC, the raw actuation data are archived [5]. With the actuation data this work can identify and correct for many errors at the loop detectors [6-8], yielding very accurate measurements- as have been verified by hundreds of GPS probe vehicle runs [7] and manually generated ground truth from concurrent video for over 63,000 vehicle actuations [8].

The native radar sensor dataset averages speed over 1 min intervals. On the other hand, speed from the loop detector system has a much finer resolution because it is based on individual vehicle actuations. As shown in Figure 1, there are roughly 40 loop detector stations in both directions and 15 radar sensors (13 bidirectional and two unidirectional) along the study corridor. From the locations shown in Figure 1, this work selected the loop detector station closest to a given radar sensor, as shown in Table 1, This work will use the Table 1 pairing throughout the rest of this paper and for brevity will refer to a given pairing in this table by the loop detector station number. The pair of radar stations in each row of the table comes from a single sensor (except for the two unidirectional radar sensors, which only have one radar station per row) and the directional loop detector stations used in this evaluation were similarly co-located on both sides of the freeway. So at the 13 bidirectional stations any positional bias seen in the link would be balanced: for one direction whichever sensor (loop or radar) was further downstream in the link would typically see a growing queue first, but this upstream/downstream relationship is flipped when observing the opposite direction. Table 1 also indicates how a given radar sensor is mounted (M: median installation, NBS: northbound shoulder, SBS: southbound shoulder) and the heading of the sensor (SW: looking *freeway south*, NE: looking *freeway north*).

## 3. Evaluation of the radar sensors

This section presents the evaluation methodology and resulting performance of the radar sensors, split over three subsections. The first subsection presents the overall performance of the radar sensors relative to the loop detector system and discusses the results. The second subsection strictly focuses on the radar sensor to investigate outages observed in the data and the possible interaction with weather conditions. The third subsection examines how the radar sensor performance varied across the study locations, depending on where a given sensor was mounted- either in the median or on one shoulder

### 3.1 Evaluation of radar sensor data against loop detector data

Figure 2a shows a summary plot of the loop detector speed (5 min median speed across all lanes) over time and space from the northbound stations listed in Table 1 on a typical day. In this plot the lighter the color the higher the speed, with the exception that white denotes no data. Thus, Figure 2a shows that a heavy queue formed around mile 4.8 at approximately 16:00, grew upstream, and eventually dissipates around 18:00. Over this same period a lighter queue formed around mile 10.5, also grew upstream and overran the heavier queue around 17:00. Figure 2b shows the corresponding summary plot from the radar units, using 5 min averages of the radar sensor's native 1 min sampling period. Comparing Figure 2a with 2b, these two plots are consistent, showing queuing at roughly the same times and locations. At this resolution the overall performance from the radar system in terms of detecting the start and end of congestion is comparable with the loop detector system. However, the measurements from the radar system are typically slower speeds than the concurrent loop detector measurements, indicating a bias between the two systems that is discussed below. Figures 2c-d repeat the comparison for the southbound traffic on the same day, with similar performance. Although not shown here, we generated similar figures for days with incidents and found the performance in the presence of non-recurring congestion was similar to the recurring congestion shown in Figure 2.

To investigate any biases between the two systems this work generated the concurrent time-series speed from a given loop detector station and corresponding radar sensor. Figure 3a shows an example of the two speed time-series from Station 1 northbound and the corresponding radar sensor between 14:00 and 19:00 from the same day used in Figure 2. Now, however, the time-series speed is aggregated to 1 min, the native sampling rate of the radar sensor. Figure 3b shows the difference between the two time-series speeds and the horizontal line at -6 mph shows the median of this difference (i.e., SpeedInfo speeds are slower than the loop detector speeds). The dashed boxes highlight the free flow periods and show most individual differences are below zero, indicating a measurable bias during off-peak periods between the two systems. On the other hand, typical of the sites examined in this study, the radar tends to yield higher speeds than the concurrent loop detector during the congested periods, at least in part due to:

(1) Doppler radar systems tend to favor faster moving targets, in part because these radar systems typically ignore speeds below a threshold to reduce false detections.

(2) The loop detector data are aggregated to find space mean while radar sensors report time mean speed, and time mean speed is always equal to or greater than the space mean speed.

From Figure 3b it is evident that the bias before and after the peak period is consistent with the daily median speed difference. Thus, the bias may reflect a poor calibration of one or the other detector system. One should be able to easily correct the bias by applying a scale factor to the data from either of those systems. Regardless of the calibration, it is also important to note that during congestion the radar sensors report speeds higher than the loop detector stations. While this difference is probably due to

differences in how the two systems sample (thus, not an error per se) it will likely impact several traffic controls, e.g., estimated travel time. This comparison process was repeated for several stations in the study corridor that exhibited recurring congestion, with similar results [9].

Returning to Figure 3a, close inspection shows that the radar sensor measurements lag the loop detector speed by a few minutes; the clearest indication occurs when the speed drops around 16:12 and then fully recovers back to free speed around 17:48. Since this queue grew upstream and receded downstream (as shown in Figures 2a-b), whichever detector system is further downstream should respond to the onset of queuing first, and the recovery from queuing last. Given the fact that the radar station associated with loop detector Station 1 northbound is facing freeway north and the sensor is located at exactly the same location as Station 1 (as per Table 1), the radar detection zone should be downstream of the loop detector station in this case, and thus, the radar sensor should detect the growing queue (around 16:12) before the loop detector station. Figure 3a shows that the loop detector data responded to the onset of queuing before the radar sensor, indicating a latency of a few minutes by the radar sensor. Since the recovery is also seen first by the loop detectors, we can eliminate the possibility that the radar detection zone was somehow upstream of the loop detectors. To measure the amount of latency, this study calculates a correlation coefficient (CF) via Equation 1, while shifting the time-series loop detector data. In this study the amount of time shifted from zero is called the time offset (TO). If there is no latency, one would expect to see maximum CF when the TO is equal to zero. If there is measurable latency, the maximum CF is measured when the TO is greater than zero. The feasible range of TO used for the radar sensors in this study is between -120 sec and 120 sec and the CF is calculated at 10 sec intervals within the range. Since the time shift step of 10 sec is smaller than the sampling period of 60 sec, at each step the individual vehicle actuations from the loop detectors are aggregated with the new start time to ensure the greatest compatibility between the time series speeds from the two detector systems.

Figure 4a shows CF as a function of TO corresponding to Figure 3a. In this case the CF grows until TO equals 90 sec and then decreases as TO is increased further. In other words, when the time-series speed from the loop detector in Figure 3a is shifted 90 sec to the right the calculation of CF from two time-series yields its maximum value, corresponding to the best fit between the two time-series, as illustrated in Figure 3c. After shifting the loop detector data by TO both systems pick up the start and end of the congestion simultaneously, as highlighted with dashed circles in Figure 3c. To investigate the reproducibility of the latency from day-to-day, we repeat this comparison over an additional 20 weekdays exhibiting congestion from April, 2011 (Figure 4b) and May, 2011 (Figure 4c) using the same loop and radar sensor pair. Figure 4d summarizes the results. Generally the radar sensor speed is reported later than the loop detectors, with an average latency of about 1 min (58 sec in April, 56 sec in May). As discussed earlier, since targets from the radar station are generally downstream of the loop detector station, the true average latency should be a little longer than 1 min. This process was repeated for several stations in the study corridor with recurring congestion, with similar results [9]. In any event, the measured latency is within the specifications of the sensor deployment, but from an operational standpoint it is important to know about it for time sensitive applications, e.g., traffic responsive ramp metering.

$$CF(x,y) = \frac{Cov\,(x,y)}{\sqrt{Cov\,(x,x) \times Cov(y,y)}} \tag{1}$$

where,

*x* : Time-series speed from loop detector after shifting by TO

*y* : Corresponding time-series from the radar sensor

*cov (x,y)* : Covariance of x and y

## 3.2 Radar sensor outages

A prior study briefly mentioned degraded radar sensor performance during the onset of rain (without independent speed measurements) and noted that the sensor takes about two minutes before it begins filtering out the impacts of rain, [10]. The present work sought to investigate the details further by studying the impacts of precipitation over an extended period. This work found numerous outages lasting many minutes over the study period. We suspect that the outages are both intrinsic (e.g., power saving at night) and extrinsic (e.g., weather conditions). Strictly focusing on the radar sensors, this section investigates when and how frequently the outages occur, and also investigates whether the outages are correlated with weather conditions.

First consider a single typical sunny day: May 12, 2011, we calculate the total outage duration for every 10 min sample from each northbound radar station in Table 1. For brevity, Figure 5a shows the median outage duration for a given 10 min sample across all of the northbound stations on this day, shown with one square for each 10 min sample period. The maximum duration of the median outages is 3 min, and this rate is steady from 22:00 to 5:00. ODOT reported that the solar powered radar sensors are set to use a power saving mode at night and a lower reporting frequency, which is consistent with these findings. In contrast to the late night outages due to intrinsic settings, the rest of the day exhibits several median outages with 1 min duration, seemingly distributed randomly throughout the day.

Figure 5b repeats this analysis, showing the median outage duration every 10 min across the northbound radar stations on I-71 for a rainy day. The amount of hourly precipitation is color-plotted in the background, based on the hourly summary from the Port Columbus International Airport as reported by the National Oceanic and Atmospheric Administration (NOAA): The darker color, the heavier rain. Like the sunny day, one sees a nearly steady 3 min outage from 22:00 to 5:00. Unlike the sunny day, however, there are four clusters where the median maxes out 10 min (thus, indicating that no data was received over the entire 10 min sample period) between 5:00 and 11:00 and another cluster at 19:00. All four of these clusters were associated with the start or end of a rainy period and for each occurrence the net outage lasted 20 to 50 min. On either side of these clusters are median outages of 5 min or more, capturing either the onset or recovery from the long duration outage. Compared to Figure 5a, it appears that the 5 min or longer duration of outages is a distinctive feature that occurs when it is rainy, and that the long-term outages are correlated with weather conditions.

To check if the outages were indeed associated with precipitation, this paper presents an entire month of radar data (May, 2011). Unlike Figure 5, each station is kept separate, and for a given day Figure 6a highlights every outage lasting 5 min or longer while again using the background color to denote the amount of precipitation. Figure 6a corresponds to Figure 5b; but, this time each individual station falls along a single horizontal line and the plot uses black points at the location of the given radar station to denote outages that last 5 min or longer. The aforementioned four clusters of long-term outrages are evident across all of the stations (characterized by black points at multiple stations falling at the same time instant. i.e., a vertical cut through the plot). Focusing on the start and end times of these long term outages across stations, it is clear that the exact time when an outage starts and ends varies across stations on this day, which indicates that these outages are not simply due to global communications or the central server *going down*. Figure 6b repeats the plot from Figure 6a for every day in May 2011, and presents the daily results in a calendar layout, with one plot per day. Reviewing Figure 6b, there are a total of 8 rainy days where it appears that outages are associated with precipitation (May 2, 6, 14, 15, 16, 17, 19, 23) and

another 2 rainy days with outages that do not appear to be associated with the precipitation (May 13, 18). Though not all rainy days exhibited these large outages (May 3, 4, 7, 22, 26). On the other hand, there are 6 non-rainy days (May 8, 9, 21, 24, 30, 31) where outages occurred across all stations that are not associated with any reported precipitation. In total we observed 27 long-term outages across all radar sensors over 16 days in May 2011.

Detailed investigations of each of the outages reveals that 11 outages correspond to weather conditions and show differing start and end times across different locations. Another 2 outages also showed differing start and end times across different locations but did not correspond to weather, suggesting they correspond to other local conditions at the sensors. The remaining 14 outages exhibited synchronized start time across locations (many but not all of these also exhibited synchronized end times), suggesting some centralized cause. Out of the synchronized start times, 5 of them correspond with rain. Some of these synchronized outages exhibit a pattern that suggests some form of system maintenance, e.g., all five of the Mondays show an outage at about 4:30. While there are some clearly centralized outages, there is no clear indication of where they occurred. In personal conversations with ODOT engineers, they noted that the wireless carrier had far from perfect performance, with the communication links going down more frequently than they had liked. So it is conceivable that changing wireless carriers could rectify some of the problems, but these issues remain within the SpeedInfo product since they sell the data and not the sensors.

To examine the impacts of snow Figure 7 repeats this analysis in January 2011. There were nine days with snow, denoted with "(s)" in the top right corner of the daily plot. As evident in the figure, there were far fewer outages in this month and only three of which appear to be correlated with snow (January 6, 20, 21). So it may be that the radar sensors are more sensitive to rain than to snow; however, this comparison does not account for the severity of the precipitation. So these results should be taken in that context. In any event, to verify a systematic correlation between outages and precipitation, one may need to study radar stations distributed across a metropolitan area to follow storm fronts in two dimensions, rather than just the single one dimensional north-south corridor used herein.

## 3.3 Precision of the radar sensors

Our group had previously investigated a different Doppler speed radar mounted on the side of the road to measure freeway traffic speeds [11-12] and found performance degrades on the far side of the freeway. This degradation was due to the fact that the detection zone grows larger the further it is from the sensor. Thus, yielding systematically lower speeds due to the cosine effect being accentuated by the target traversing a larger distance as it bisects the cone of view at the further range. To see if similar findings were evident in the SpeedInfo data this study compared the loop detector and radar sensor speed measurements by direction, and looked at how performance changed depending on whether the radar sensor was mounted on the nearside shoulder, far-side shoulder, or in the median between the two directions. As illustrated in Table 1, a given radar station is mounted on a pole either in the median (M) or on the roadside (NBS or SBS). There are 7 median installation radar sensors and 6 roadside radar sensors that monitor both directions of traffic. Excluding the two unidirectional Stations (106 and 107), Figure 8 compares the monthly median speed between a given radar sensor and the corresponding loop detector station, individually in each direction. For the shoulder-mounted radar sensors (NBS and SBS) we take the median speed measurement for both directions from the loop detector in the shoulder lane. The southbound traffic is on the nearside for the SBS deployments and far-side for the NBS deployments. For ease of presentation the nearside direction is denoted A and far side denoted B at these shoulder-mounted

radar sensors. For the median-mounted radar sensors (M) this work takes the median speed measurement for both directions from the loop detector in the median lane and in this case the two directions are arbitrarily assigned to A and B.

The abscissa in Figure 8 denotes the loop detector station, and the directional monthly median speed from a given loop detector is shown with a large circle. The corresponding directional monthly median speed from a radar sensor is shown in the same column with a square if the sensor is median-mounted, or a triangle if the sensor is shoulder-mounted. The darker markers correspond to the far-side direction (Direction B) at the stations where the radar sensor is shoulder-mounted (again, in the case of a median-mounted radar sensor the directions are assigned arbitrarily). Finally, to ensure that the results do not depend on lane utilization, we add a smaller circle to show the monthly median loop detector speed from the other lanes (e.g., lane 1 and 2 for a shoulder-mounted installation and lane 2 and 3 for a median-mounted installation).

Reviewing Figure 8, the directional monthly median speed from the loop detector data tends to be 5-10 mph faster than the corresponding measurement from the radar sensors from Stations 102 to 11, consistent with the speed bias observed in Figure 3. While the two sensor systems yield similar monthly median speeds from Stations 13 to 26, adding further support for the possibility that the bias may indeed be due to sensor calibration, and thus, potentially trivial to correct. Comparing the radar sensor monthly median speed from the two directions, for the shoulder-mounted deployments the nearside lane measurements are faster than the far-side lane measurements five out of six times, and for these five cases the corresponding loop detector speeds do not show this nearside bias (the exception being Station 102, where both the loop detectors and radar sensors show the far side is faster, potentially due to a grade at that location). Like the loop detectors, the median-mounted radar sensors do not show any directional bias. Although we have not eliminated all possible confounding factors (e.g., sensor calibration), this comparison suggests that the radar sensor performance depends in part on where the sensor is mounted relative to the roadway. The radar sensors appear to offer more consistent speeds when median-mounted. For new deployments it may be worth mounting the sensor in the median whenever there is the option; however, at least in the study corridor the difference is small enough that for most applications it is not critical to move existing radar sensors that are currently shoulder-mounted.

## 4. Conclusions

Many real-time traffic-monitoring applications only require speed or travel time, e.g., traveler information or detecting the presence of congestion. In recent years SpeedInfo emerged with a new paradigm for traffic operations data collection: the company deploys its own Doppler radar sensors to measure aggregate speed and then sells the data. Unlike most prior traffic monitoring technologies, the company only measures speed. To date there has not been a comprehensive evaluation of the radar sensor performance in the literature, so this study set out to address those omissions and examine the performance of the emerging real-time technology. For much of the analysis this study used individual vehicle actuations from well-tuned loop detectors as the baseline. This work examined an extended period, with several months of concurrent data from the two detector systems, allowing us to catch intermittent events in addition to behavior under normal operation.

At the coarse level of 5 min aggregated speed data plotted in the time space plane, the radar sensor-based summary plots were comparable to the corresponding plots from loop detector data, both showing similar patterns of congestion, queue growth, and so forth. Upon examining the time series speed

data aggregated at the radar sensor's native 1 min aggregation, a couple of issues became apparent. First, the radar sensors tended to measure speeds slower than the loop detectors during free flow periods (by about 5 mph). Although this study could not eliminate all possible confounding factors, the research found evidence suggesting this bias is largely due to miss-calibration of one or both of the sensors. In any case, it should be correctable through further calibration. Regardless of the calibration, it is also important to note that during congestion the radar sensor reports speeds higher than the loop detector stations. While this difference probably arises due to differences in the sensing technology rather than any error (e.g., it is suspected that the radar sensors favor faster moving targets) the difference can impact subsequent traffic controls if it is not accounted for; for example, travel time estimates or dynamic ramp metering thresholds that were tuned to loop detector measurements will likely have to be re-tuned to the radar measurements for optimal performance.

Furthermore, the radar sensor measurements tended to lag the loop detector measurements by approximately 1 min. This latency is within the specifications of the sensor deployment, but from an operational standpoint it is important to know about it for time sensitive applications, e.g., traffic responsive ramp metering. Reviewing the periods when the radar sensors were operational, this work observed long-term outages across all radar sensors in excess of 10 min and a few lasting several hours. This paper showed the results for May 2011, where there were 27 long-term outages, 41% of these outages appeared to be correlated with precipitation, though not all of the precipitation events triggered outages in the radar sensor data.

Finally, this paper examined the performance differences between mounting the radar sensors in the median, and on the shoulder. Indeed, the radar sensor performance depends in part on where the sensor is mounted relative to the roadway. The radar sensors appear to offer more consistent speeds when installed in the freeway median. Whenever there is the option, for new deployments it may be worth mounting the sensor in the median. However, at least within the study corridor the difference is small enough that for most applications it is probably not critical to move existing radar sensors from the roadside to the median.

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Table 1, Details of the SpeedInfo sensors used in this study and the associated loop detector stations.

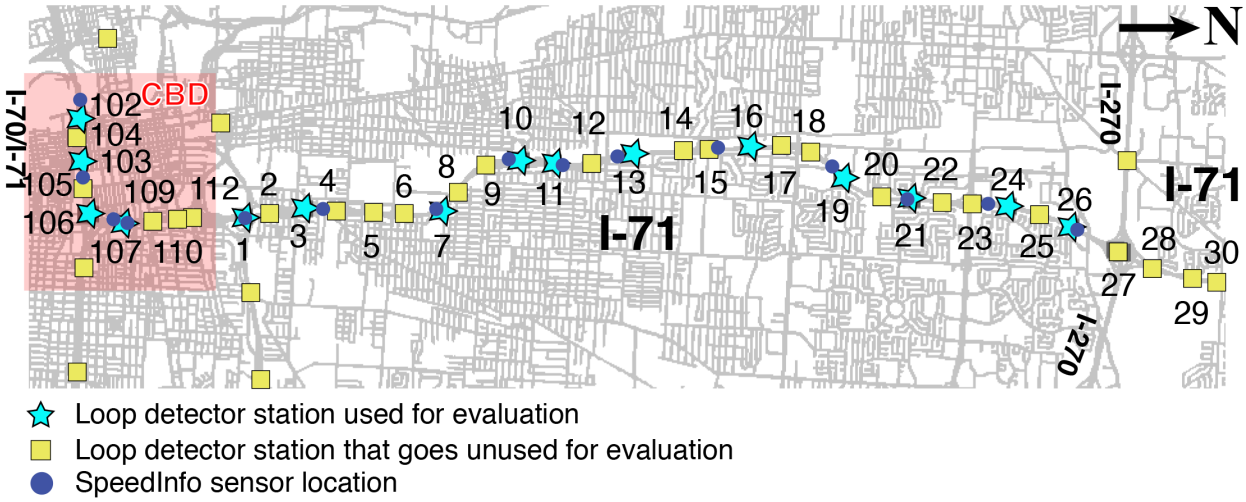
| Northbound | | Southbound | | Installation | SpeedInfo Location |
|---|---|---|---|---|---|
| Loop | SpeedInfo | Loop | SpeedInfo | | |
| 26 | 12747 | 26 | 12748 | M | 363 ft north of loop, facing SW |
| 24 | 12756 | 24 | 12755 | M | 1,097 ft south of loop, facing NE |
| 21 | 12771 | 21 | 12770 | M | 203 ft south of loop, facing NE |
| 19 | 12742 | 19 | 12741 | M | 881 ft south of loop, facing NE |
| 16 | 12740 | 16 | 12739 | M | 1,668 ft south of loop, facing NE |
| 13 | 12752 | 13 | 12751 | M | 740 ft south of loop, facing NE |
| 11 | 12768 | 11 | 12769 | NBS | 450 ft north of loop, facing SW |
| 10 | 12767 | 10 | 12766 | SBS | 716 ft south of loop, facing NE |
| 7 | 12773 | 7 | 12772 | SBS | 194 ft north of loop, facing NE |
| 3 | 12764 | 3 | 12765 | NBS | 941 ft north of loop, facing SW |
| 1 | 12775 | 1 | 12774 | NBS | 0 ft from loop, facing NE |
| 107 | 12759 | - | - | NBS | 288 ft north of loop, facing SW |
| - | - | 106 | 13147 | SBS | 1,266 ft north of loop, facing SW |
| 103 | 12661 | 103 | 12662 | M | 901 ft east of loop, facing SW |
| 102 | 12665 | 102 | 12666 | NBS | 1,088 ft west of loop, facing SW |

Where:

M: SpeedInfo sensor unit is located in the median

NBS: SpeedInfo sensor unit is located on the northbound shoulder

SBS: SpeedInfo sensor unit is located on the southbound shoulder




Loop detector station used for evaluation

Loop detector station that goes unused for evaluation

SpeedInfo sensor location

Figure 1, The I-71 corridor showing the location of the loop detector stations and SpeedInfo sensors used in this study.

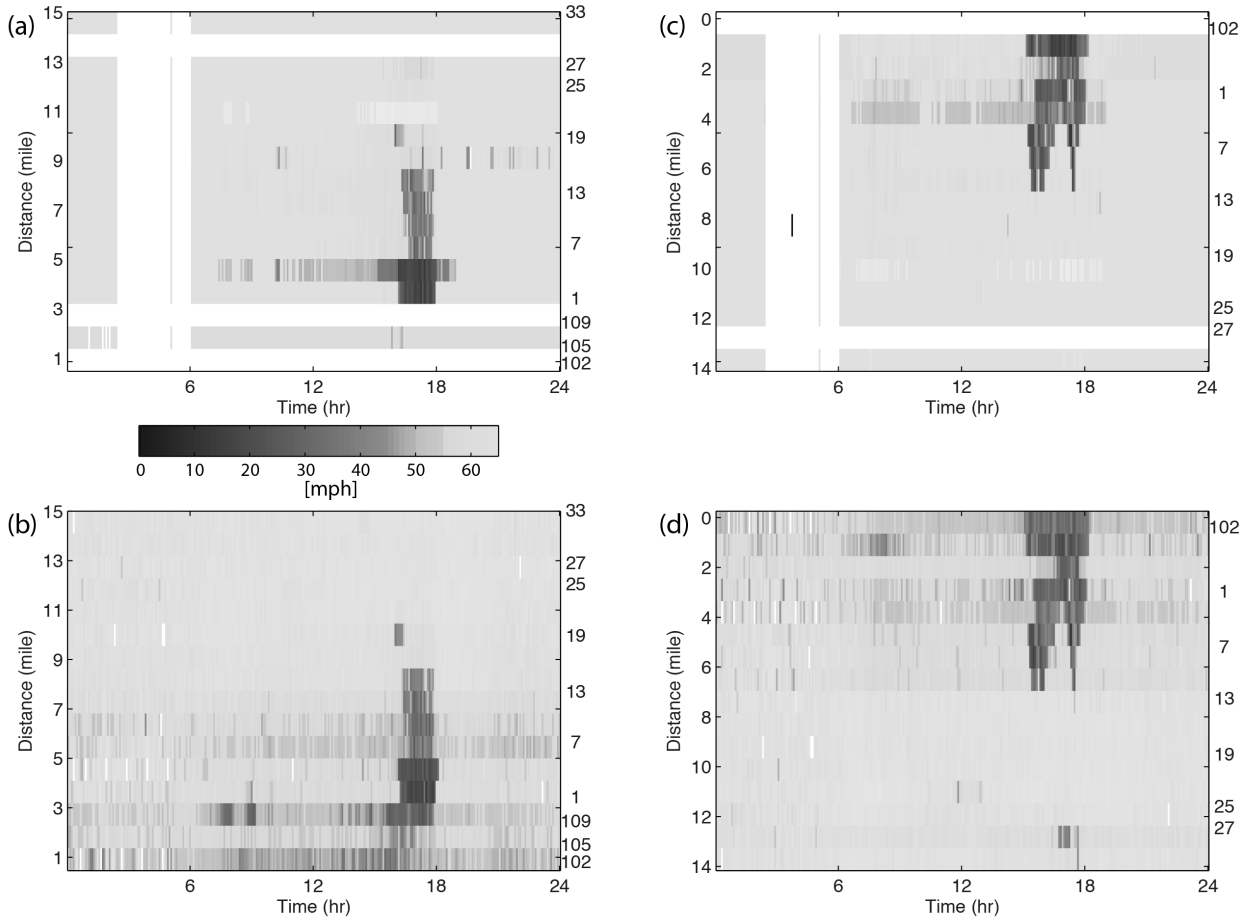



Figure 2, Summary plots of 5 min median speeds along the I-71 corridor on a typical day (April 29, 2011), from (a) the northbound loop detectors (b) the corresponding northbound SpeedInfo measurements, (c) the southbound loop detectors, and (d) the corresponding southbound SpeedInfo measurements. In all of the summary plots traffic flows from bottom to top. The numbers on the right hand side of each plot indicates the location of several of the loop detector stations.

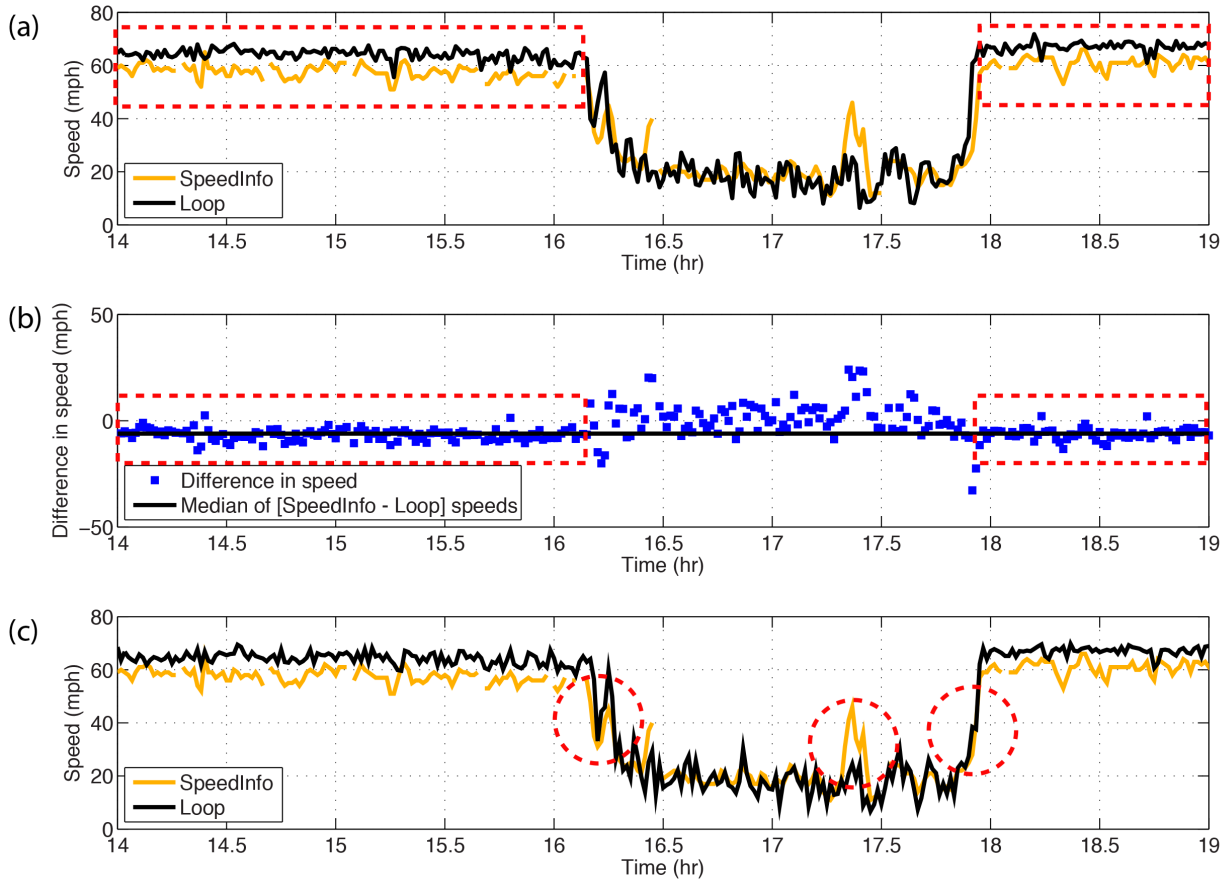



Figure 3, (a) 1 min aggregated speed as a function of time from the loop detector and SpeedInfo systems at Station 1 northbound, (b) difference between the two concurrent time-series speeds in part a and the day's median difference with a horizontal line at -6 mph, (c) time-series speed corresponding to (a) after shifting the loop detector time-series 90 sec later in time.

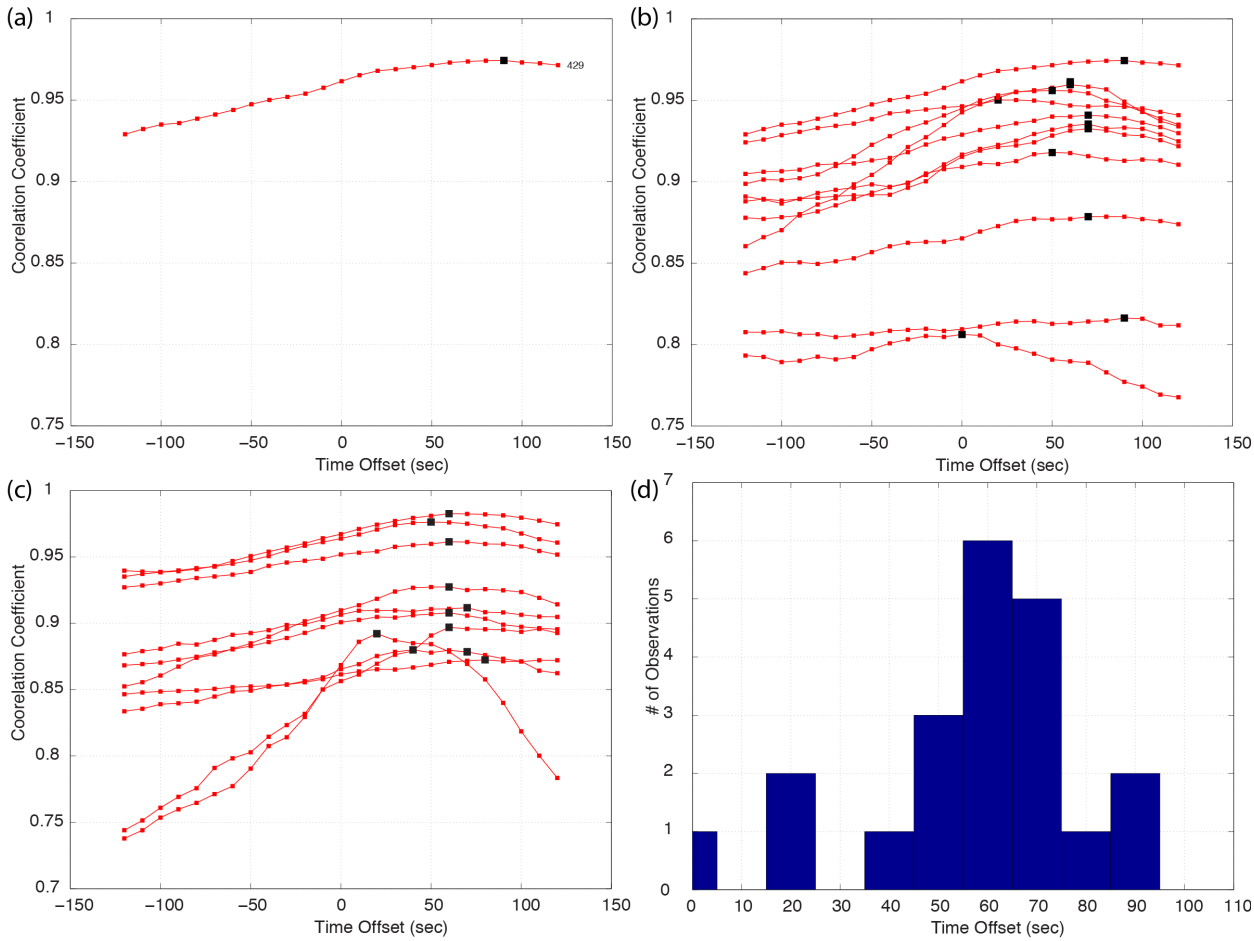



Figure 4, Correlation coefficient (CF) as a function of time offset (TO), Station 1 northbound, (a) April 29, 2011, (b) ten weekdays in April, 2011, (c) ten weekdays in May, 2011, (d) distribution of time offset from parts b and c.

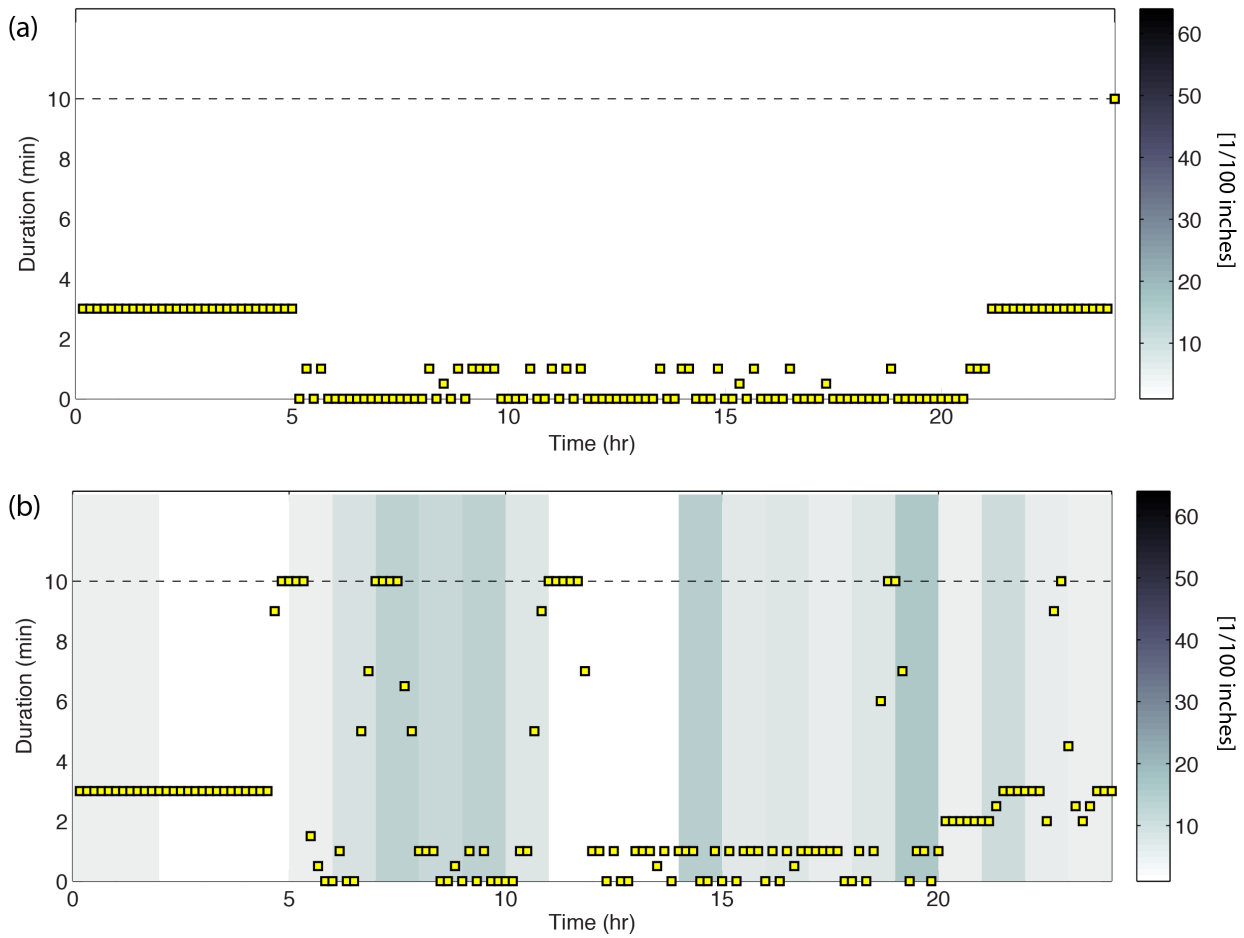
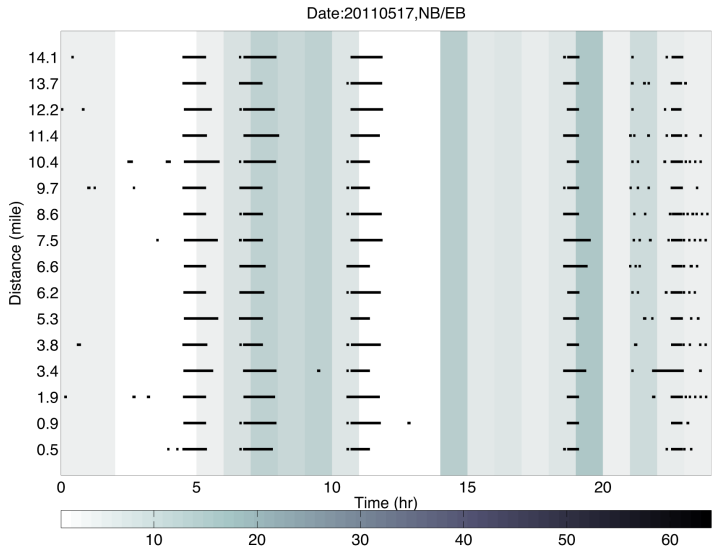



Figure 5. Median outage over a 10 min sample across all northbound SpeedInfo sensors by time of day along the I-71 corridor on (a) May 12, 2011, a clear day, (b) May 17, 2011, a rainy day.

(a)




(b)

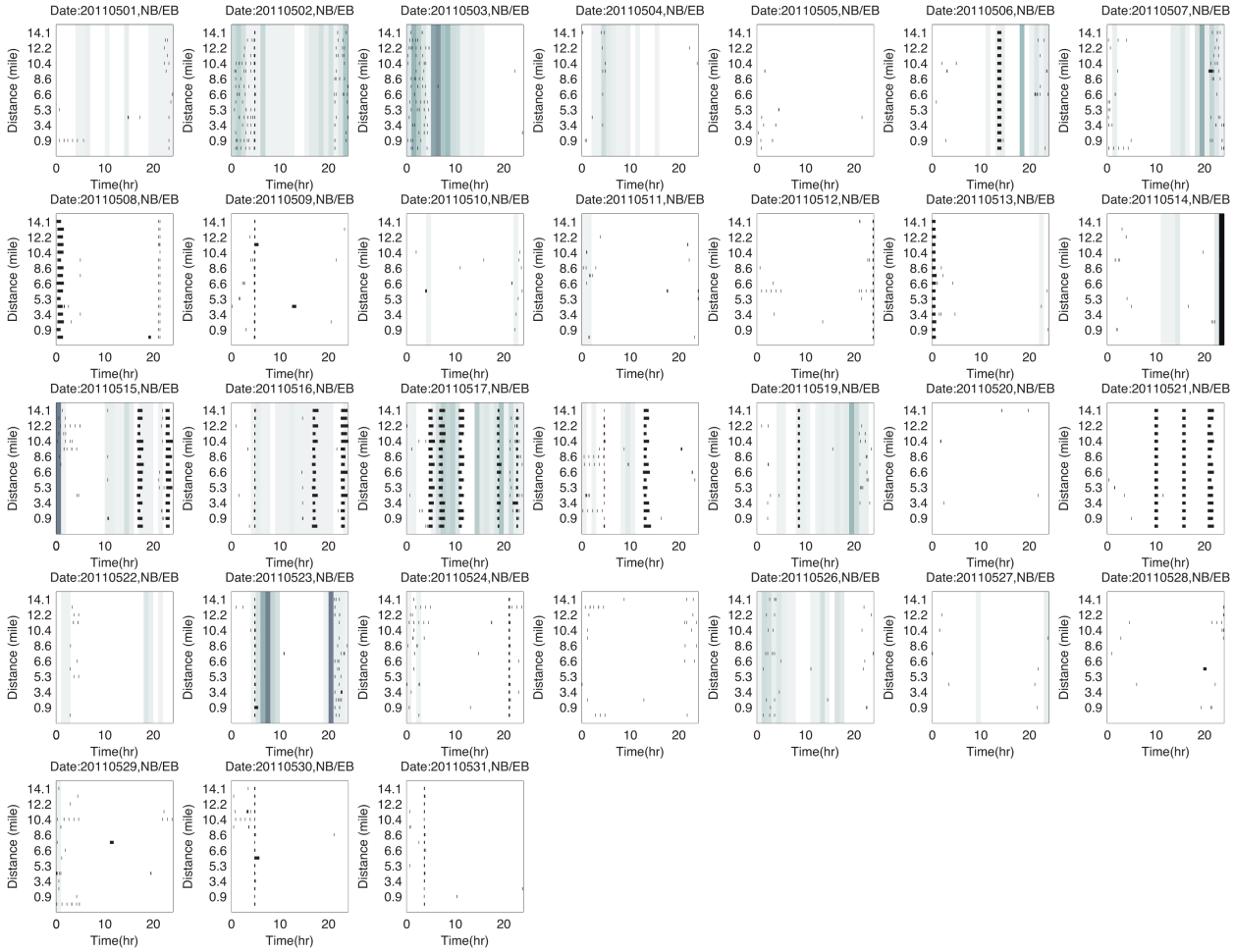



Figure 6, Outages lasting 5 min or longer shown with black points, across the individual northbound SpeedInfo stations in the I-71 corridor, (a) one day, May 17, 2011, (b) monthly across all days in May 2011.

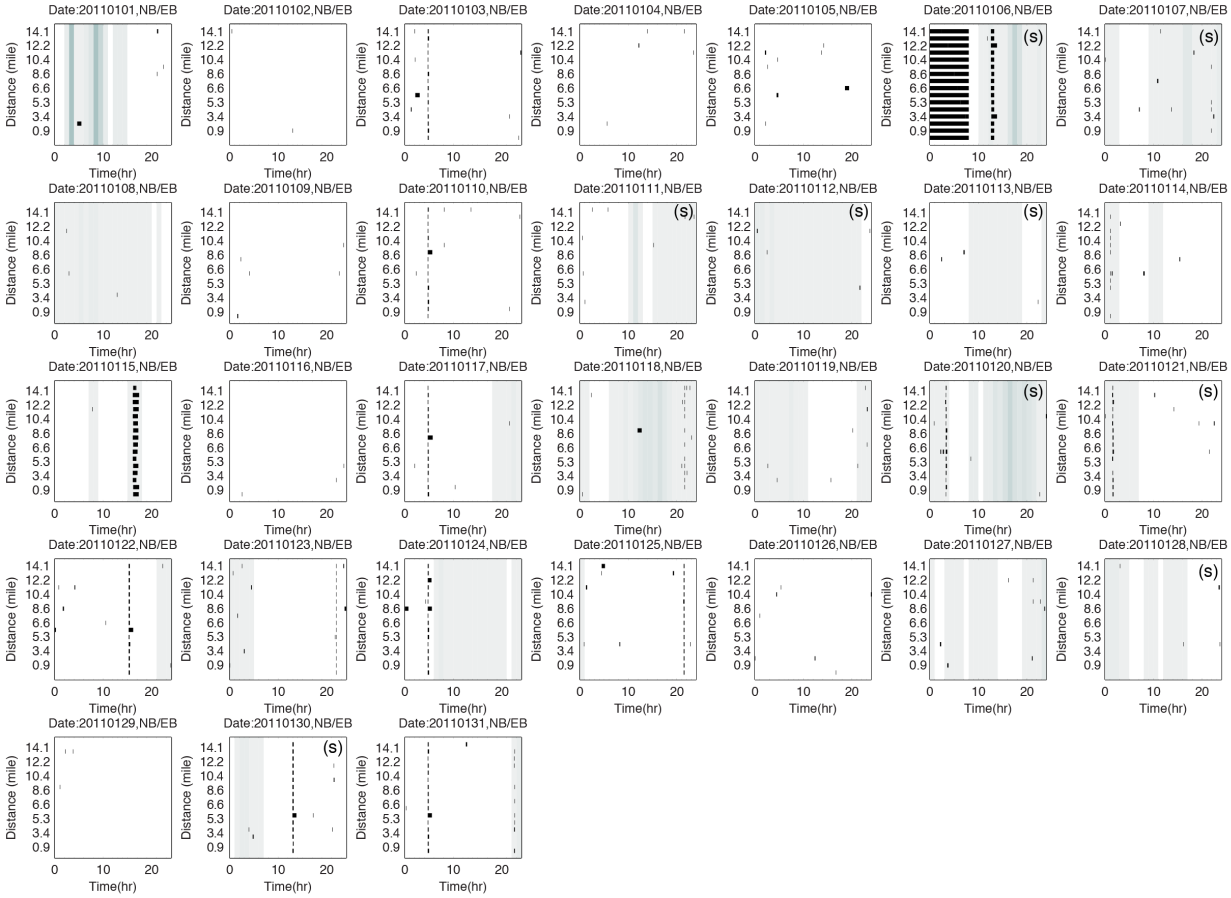



Figure 7, Outages lasting 5 min or longer shown with black points, across the individual northbound SpeedInfo stations in the I-71 corridor, monthly across all days in Jan 2011.

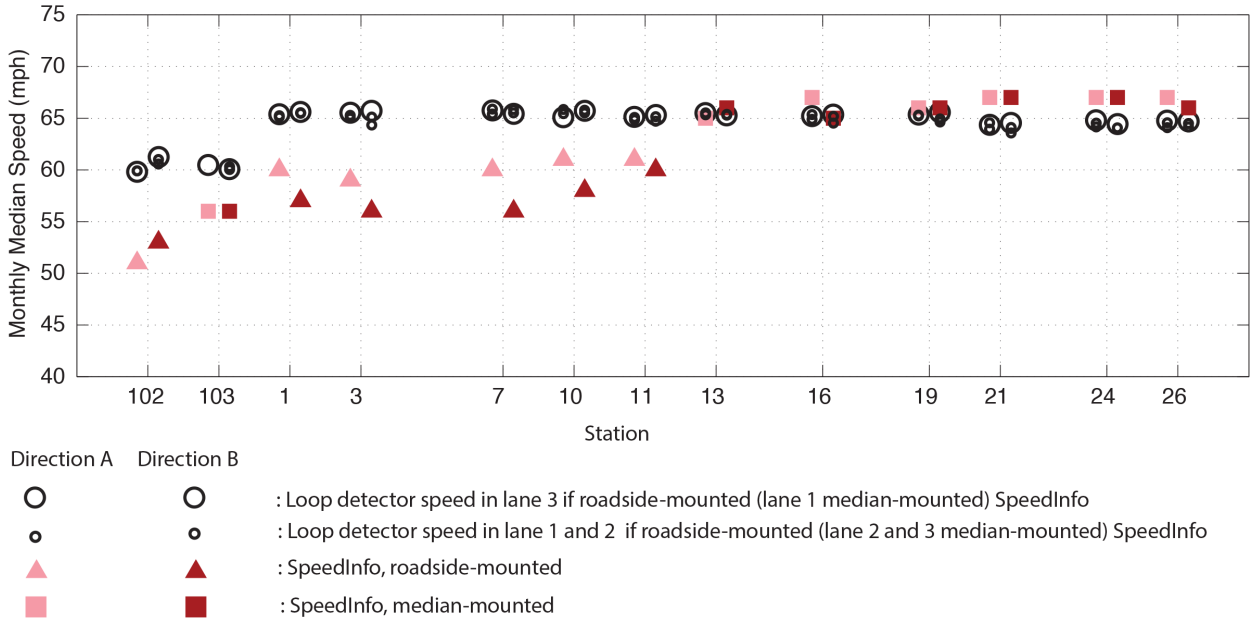



Figure 8, Directional monthly median speed comparison between a given SpeedInfo sensor and the corresponding loop detector station