Analysis of Dynamic Advisory Messaging – Phase II

Final Report
August 2018

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16. Abstract

Transportation agencies spend significant portions of their annual budgets to facilitate safe and efficient travel under hazardous weather conditions. This project is a continuation of the project titled Evaluation of Dynamic Advisory Messaging – Phase I that further supports the Iowa Department of Transportation's (DOT's) desire to explore how a dynamic advisory system might work within the Iowa DOT Intelligent Transportation Systems (ITS) platform through data obtained for a segment of I-35.

The evaluation contrasted sensor-driven messages (dynamically derived), based on an algorithm developed in Phase I, with measurements of speed data under various winter weather conditions. In addition, other data inputs such as friction sensors were considered by comparing their outputs to traffic sensor data.

Overall, the dynamic advisory messaging system performed as desired by providing alerts of deteriorating conditions during severe winter events. The system can also identify other sources of traffic impacts outside of winter weather conditions, such as slow speeds that occur as a result of an incident. The signature of winter events was present in both the friction and traffic data; however, the friction data at times had more latency. This may be due to the different data reporting frequencies. The findings showed that speed sensors provided awareness of winter events as well as other non-weather related traffic slowdowns.

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ANALYSIS OF DYNAMIC ADVISORY MESSAGING – PHASE II

Final Report
August 2018

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EXECUTIVE SUMMARY

This project was a continuation of the project titled Evaluation of Dynamic Advisory Messaging – Phase I. It supported the Iowa Department of Transportation's (DOT's) desire to explore how a dynamic advisory system might work within the Iowa DOT Intelligent Transportation Systems (ITS) platform through data obtained for a segment of I-35 between the cities of Huxley and Ankeny. The ultimate deployment of a dynamic system has the potential to advise motorists of deteriorating roadway conditions (winter weather) and prevent sudden lane departures, braking, and crashes.

The research team compared the existing logic to the new logic (proposed algorithm) developed in Phase I. Figure 1 shows a comparison for a specific weather event between the existing logic (red line) and the proposed advised speed limit control logic (black line).
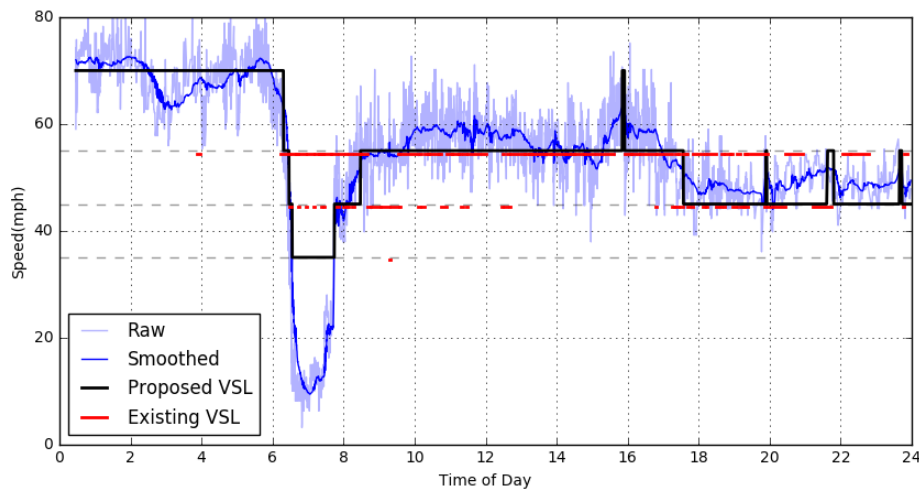
Figure 1. Proposed versus existing logic

When a big snow event hit the roadway, between 6 a.m. and 8 a.m., most drivers were traveling at a speed below 20 mph. During this time, the existing logic advised a speed limit of 45 or 55 mph as compared to the proposed logic that advised a more reasonable speed limit of 35 mph.

The research team implemented the new advisory logic for a real-world evaluation where the messaging was simulated but based on actual weather, traffic, and friction sensing (i.e., messages were generated; however, no motorists saw these messages along the road).

Winter Storm Event #1 on December 24, 2017

A snow event on December 24, 2017 impacted I-35 near the NW 36th Street interchange. Figure 2 shows the measured traffic sensor (upper chart) and friction data (lower chart).
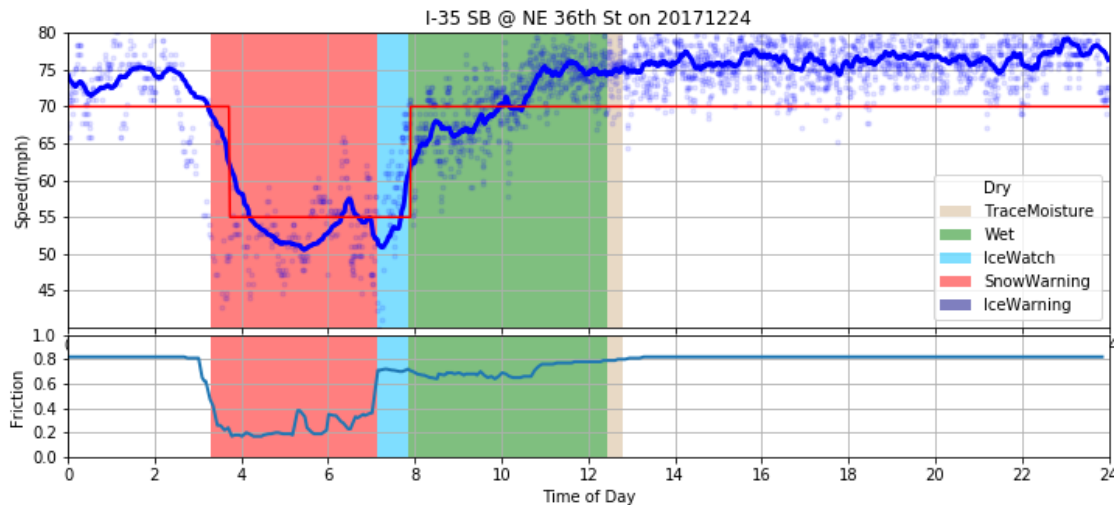
Figure 2. Event #1 at I-35 SB @ NE 36th St: Speed profile and roadway surface condition

As shown, speeds dropped at around 3 a.m., hovered around 50 mph between 5 a.m. to 8 a.m., and then gradually returned to normal around noon. In the chart in Figure 1, the light blue points were raw sensor data and the solid blue line represented smoothed speeds used to trigger the advisory messages (straight red line). The new algorithm successfully displayed the message of "Advised 55 mph" between 3 a.m. to 7 a.m. This was further validated using the TransSuite Traveler Information System (TIS) software report. The friction conditions illustrated a similar pattern, changing from the worst condition of snow warning from 3:30 a.m. to 7:15 a.m., then to ice warning from 7:15 a.m. to almost 8 a.m., to wet, trace moisture, and then finally, dry.

In addition to the quantitative description, the research team downloaded the nearby camera images during the event. Figure 3 shows this location's camera view; from top left to bottom right, it shows the conditions of snow warning, ice watch, wet, and trace moisture, respectively. The color bordering each camera image can also be related to the friction color shading in Figure 2.
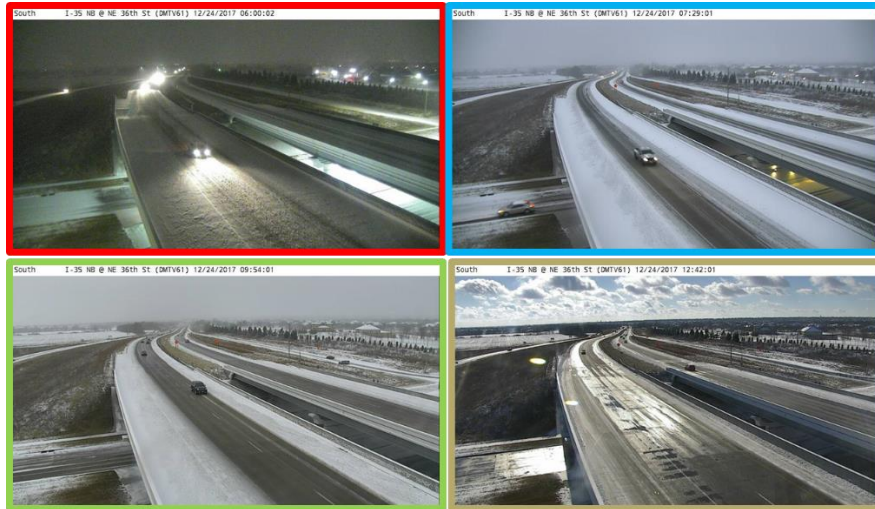
Figure 3. Event #1 at I-35 SB @ NE 36th St: Roadway surface conditions

Overall, the new dynamic advisory messaging system performed as desired by alerting motorists of deteriorating conditions during severe events. The system also has the ability to identify other sources of traffic impacts outside of winter weather conditions. This leads to a responsive system that can notify motorists, and the agency, of slow speeds for any incident on the roadway.

This effort served as a good starting point toward considering these data streams and the capability to enhance traveler information during critical travel times.

The use of dynamic message sign (DMS) systems is aimed at providing useful roadway information, harmonizing traffic flow, and preventing traffic congestion; such goals depend on realistic, reliable, and real-time traffic messages. The newly designed algorithm for a dynamic message display system has shown significant improvement over the existing system and its accuracy was verified using multiple data sources, including surface friction, video cameras, and the TIS historical messaging reports.

The system developed could be further modified to produce advisory messages (i.e., "slow traffic," "traffic delays") that may be more suitable in a variety of conditions including winter weather. The benefit of the current system design is the applicability to other situations, such as work zones or other non-recurring traffic conditions. The system should continue to be improved by incorporating additional data inputs such as probe speed data, weather data, and friction data. The current system will continue to be tested and implemented by the Iowa DOT (specifically related to work zones).

INTRODUCTION

This project was a continuation of the project titled Evaluation of Dynamic Advisory Messaging – Phase I. It supported the Iowa Department of Transportation's (DOT's) desire to explore how a dynamic advisory system might work within the Iowa DOT Intelligent Transportation Systems (ITS) platform through data obtained for a segment of I-35 between the cities of Huxley and Ankeny. The ultimate deployment of a dynamic system has the potential to advise motorists of deteriorating roadway conditions (winter weather) and prevent sudden lane departures, braking, and crashes.

Objective

The goal was to contrast sensor-driven messages (dynamically derived), based on an algorithm developed in Phase I, with measurements of both speed and friction data under various winter weather conditions.

Background

Interstate roadways in Iowa have the highest travel speeds and truck and passenger car volumes of roadways in the state. They are relied upon each day to accommodate a wide range of vehicle types. Roadway authorities are acutely aware of the need for reliable travel on the interstate system and, when problems occur, to provide alerts and warnings to motorists about events that may impact their travel, such as weather, incidents, and crashes, through the use of dynamic message signs (DMS). These messages can be manually input, by a traffic management center operator, or generated automatically based on sensors and set thresholds that are tied to outgoing message sets.

Dynamic advisory, or variable speed limit (VSL) systems, triggered by atmospheric, surface, and/or traffic conditions, are a commonly used safety counter-measure to warn drivers about imminent risks and to suggest an appropriate speed for the existing conditions. Dynamic advisory systems aim to reduce traffic crashes, postpone or prevent congestion, minimize speed differences, and harmonize traffic flow during peak periods (Bertini et al. 2006). These systems can also improve lane utilization and provide a calmer driving experience because of the measured reductions in crash frequency and severity (Allaby et al. 2007).

Many researchers have studied the effects and logic of VSL in work zones. Lin et al. (2004) explored the effectiveness of VSL on highway work-zone operations and proposed two online VSL algorithms to minimize the queue in advance of the work zone and to maximize the throughput through the work-zone area. Bertini et al. (2006) collected lane-based, 1-minute loop data on a German autobahn and then extracted information about speed, count, and density between sensors to drive their VSL logic. Their analysis illustrated a strong correlation between the displayed speed limit and real traffic dynamics, and they found that a reduced speed limit before a bottleneck could help manage dense traffic.

Wilkie (1997) mentioned that, to provide drivers with realistic, reliable, and real-time roadway information, the advised speed limit from a VSL system should be based on real-time prevailing traffic data and/or roadway weather information. The author also proposed several control strategies such as: setting the data sampling rate to less than or equal to 30 seconds, integrating weather sensors with each sign, changing speed displays only once per minute, basing smoothing speed on 1 minute, etc. Katz et al. (2012) provided several guidelines for the use of VSL systems in wet weather, including displaying changes for at least 1 minute and setting a minimum speed limit of not less than 30 mph. These authors also reported on several VSL projects related to weather and their control strategies, based on pavement conditions, weather conditions, visibility, etc. (Katz et al. 2012, Goodwin and Pisano 2003). For example, the Alabama DOT operates a 7-mile long corridor with 24 VSL signs along I-10 in Mobile. Based on the visibility distance, speed limits are changed from 35 mph to 65 mph in increments of 10 mph. The Washington state DOT has implemented several VSL systems in both urban areas and mountainous areas. In urban areas, the speed is changed based on speed and occupancy sensors, whereas in mountainous areas, the speed limits are set manually based on weather information.

The Center for Transportation Research and Education (CTRE) research team developed and implemented a condition-based dynamic advisory messaging system that could be used to alert motorists of slow traffic during winter weather conditions. The dynamic advisory messaging was developed using k-means clustering to label data, which was then used to develop a supervised learning algorithm. Based on the preprocessed dataset, a support vector machine (SVM) was then employed to replicate the experts' engineering judgment, such that as sensor data streamed in, the proposed dynamic advisory control logic would automatically map the new data to a proper advisory speed. The performance of the system was evaluated in simulation for multiple winter weather events over the course of two winter seasons. Due to existing policies, the dynamic system was not activated for the public, so no evaluation under live conditions was possible. Friction data were evaluated as an additional input for advisory messaging, and compared to the speed-based algorithm that was developed.

Existing Performance

The Phase I findings from CTRE about the performance of the existing control logic in real time are summarized as follows.

The existing logic used to generate sensor-based messages (in this case advisory speeds) is not designed for the task. Figure 4 displays three advisory speeds, shown as dashed lines, 55 mph, 45 mph, and 35 mph. The solid red lines are messages, which would have appeared on a dynamic message sign.
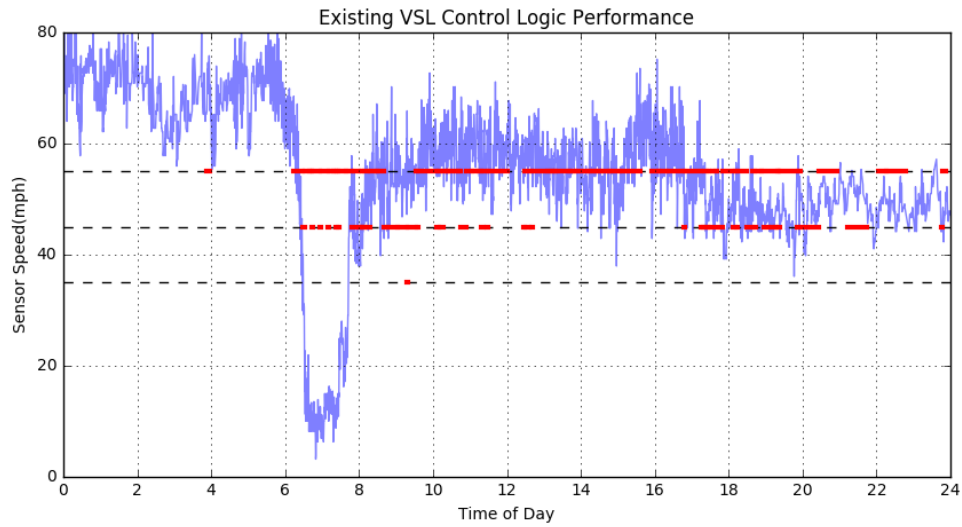
Figure 4. Performance of existing VSL control logic

Figure 4 indicates room for improvement, especially from 6 a.m. to 8 a.m., when the speed had already dropped to 10 mph due to the severe snow, but the existing control logic was still posting messages of 55 mph or 45 mph.

Figure 5 provides another example, although this time the messages would be text based.

3
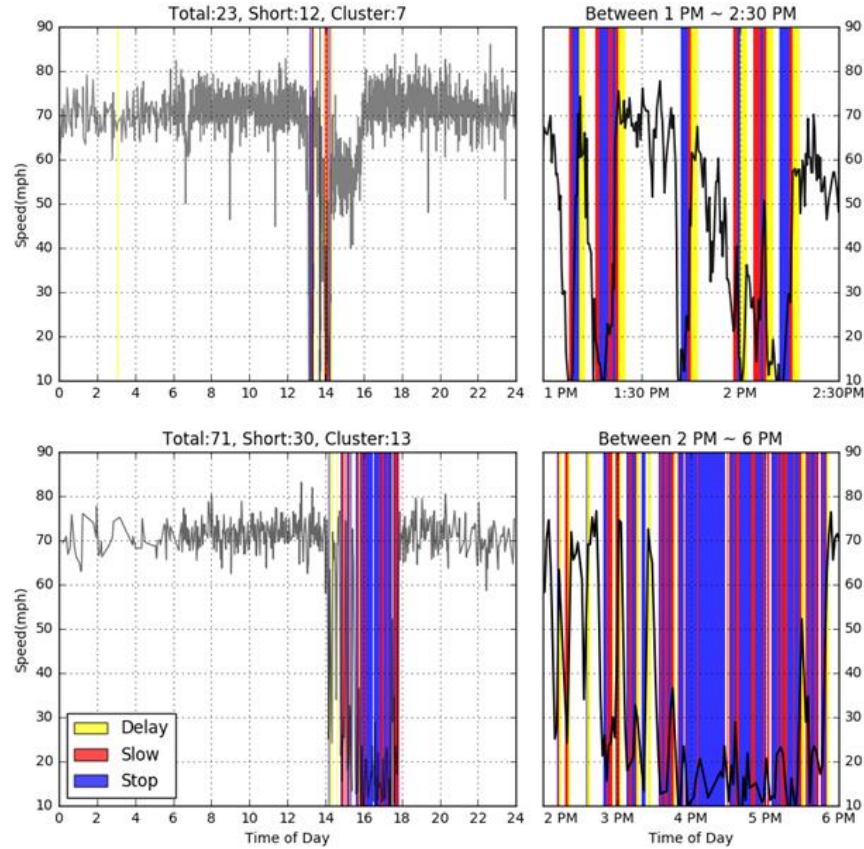
Figure 5. Performance of existing DMS control logic

The yellow color represents the message of "traffic delay possible," red represents "slow traffic ahead," and blue represents the "stopped traffic ahead" message. The width of each color block denotes the duration of the message displayed and the DMS performance measures for the day are reported above the plot. The current control logic generates multiple short-duration messages and clusters as shown in Figure 5. In addition, the existing messaging strategy did not operate properly in some situations as a certain message was not displayed at the expected time. The white strips (no messages displayed) are evidence that the message display control was not functioning during times of low speed, from 2 p.m. to 4 p.m. at the top and 2 p.m. to 6 p.m. at the bottom of the left panels.

The above-mentioned examples suggested opportunities for improvement, which prompted the research team to develop a novel control algorithm based on:

- Data smoothing to find the prevailing traffic characteristics
- Clustering/Classification to build a data-driven message control logic

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Project Activities

This report documents the Phase II project findings as follows:

- Data Description
- Dynamic Advisory Algorithm Development
- Implementation of Advisory Algorithm
- Verification of Messaging
- Additional Data Inputs

DATA DESCRIPTION

Study Corridor

Figure 6 shows the study corridor of southbound I-35 between Huxley and Ankeny with four Wavetronix sensors installed.

Figure 6. Dynamic advisory corridor and sensors

These sensors were associated with four virtual simulated DMS display boards: (1) SIM I-35 NB @ Millis Civic-OH, (2) SIM I-35 SB @ Corp Woods-OH, (3) SIM I-80 EB @ Jordan Creek-OH, and (4) SIM I-35 WB @ 4-Mile-OH. By operating these virtual message boards in the background without display messages, the researchers could verify the accuracy of the messages before deployment. The posted speed limit for this corridor is 65 mph for the two southern sensors and 70 mph for the two northern sensors. Table 1 shows the sensor listings used along with their association with TransSuite Traveler Information System (TIS) software communication.

Table 1. IDs for sensor, location, and TransSuite communication

Wavetronix ID	SIM DMS ID	TIS ID	Internal Comm. ID
I-35 SB @ MP 94	SIM I-35 NB @ Millis Civic-OH	1001	310
I-35 SB @ NE 36th St	SIM I-35 SB @ Corp Woods-OH	1002	317
I-35 SB @ NE 126th Ave	SIM I-80 EB @ Jordan Creek-OH	1003	309
I-35 SB @ NE 158th Ave	SIM I-35 WB @ 4-Mile-OH	1004	389

Data Accessibility

Vehicle speed data were collected through a feed from the DOT ITS network on a 20-second frequency. In contrast, the friction data were not integrated to the ITS network, which prevented real-time reporting. For this analysis, friction data were obtained from the DOT's Office of Maintenance after each winter event. The frequency of data from the friction sensor ranged from 1 minute to 10 minutes but typically was reported every 5 minutes.

DYNAMIC ADVISORY ALGORITHM DEVELOPMENT

The dynamic advisory logic was developed following the flowchart shown in Figure 7.
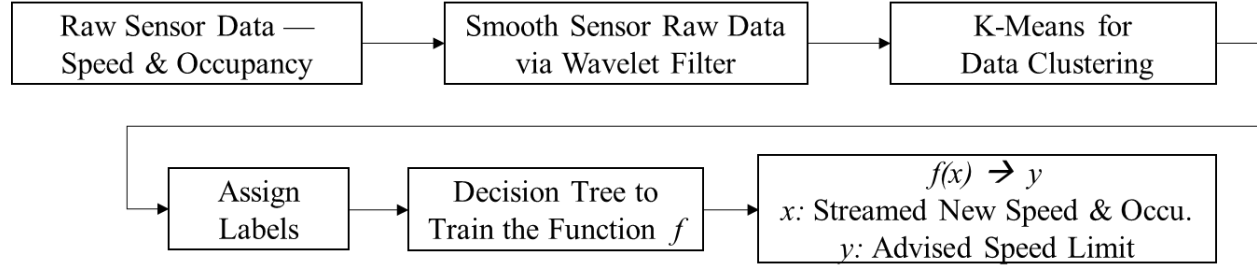
Figure 7. Proposed dynamic advisory control logic development flow

The raw data (Extensible Markup Language [XML] format) from Wavetronix sensors were first parsed, and then traffic speed and occupancy data were extracted. A wavelet filter was then applied to de-noise the sensor data. The Iowa DOT decided to use four advisory speed classes to implement advised speed limits of 70 mph (no message), 55 mph, 45 mph, and 35 mph. Following this policy, the k-means clustering algorithm was applied to identify distinct groups in the data. Based on the preprocessed data with labels, a supervised learning algorithm decision tree was trained to find the underlying function (experts' engineering judgment) that mapped the new incoming sensor data (speed and occupancy) to a desired advised speed limit.

To find the prevailing traffic condition, sensor data quality is critical; however, sensor readings always have inherent noise and a wavelet filter was applied to smooth the sensor data. For the application of the dynamic advisory message display, real-time noise filtering had to be performed; therefore, the data were treated as if received in a streaming fashion. To address this issue, a sliding window approach was used for data smoothing, where the window used a small subset of recent historical data (previous ~20 minutes).

After smoothing the data, a clustering analysis was applied to assist in the development of the new DMS control logic. Clustering analyses deal with unlabeled data, whereas supervised learning algorithms need labeled data, and it is expensive to obtain a labeled dataset. One approach to labeling data is to apply a clustering method to find reasonable clusters, assign labels based on the number of clusters, and then use these labeled data for subsequent supervised classification. Similar to this concept, for this new DMS control logic system, k-means clustering was applied to cluster unlabeled data into several groups, which could then be used to aid traffic engineers in assigning specific DMS messages to each cluster.

Based on the preprocessed dataset, a decision tree was used to replicate the engineering judgment, such that as sensor data streamed in, the improved DMS control logic system automatically mapped the new data to a proper message and replicated the decision making of a traffic engineer. The logic was based on different traffic conditions with four types of variable speed limits generated:

- Normal condition without display (70 mph)
- 55 mph advised
- 45 mph advised
- 35 mph advised

Comparison between Existing and Proposed Logic

To compare the performance of the generated dynamic message display with the existing system, three criteria were applied for the number of: (1) total messages, (2) short-duration messages, and (3) fluctuating clusters. Data from two past snow events in December of 2015 were used for this preliminary analysis.

Comparisons between the proposed advised speed limit control logic (black line) and the existing logic (red line) for a weather event are shown in Figure 8.
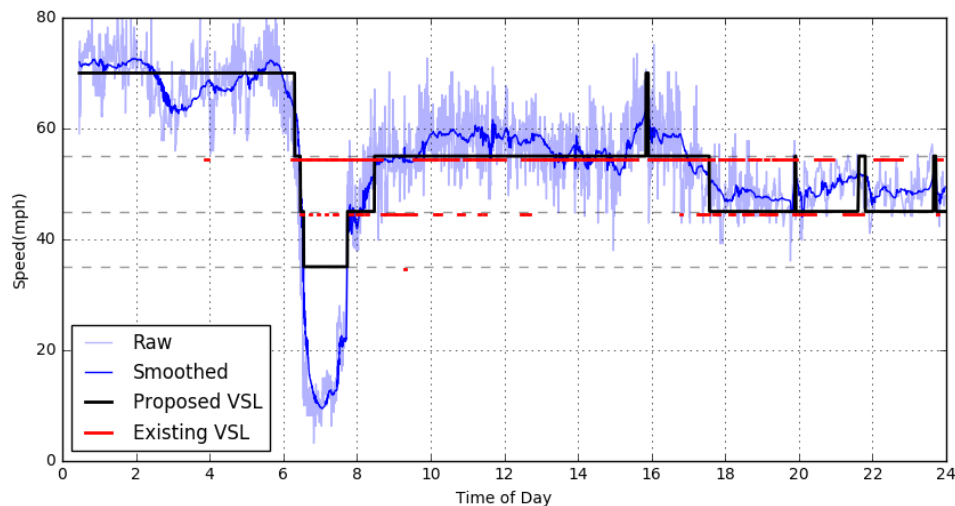
Figure 8. Proposed logic versus existing logic

The raw speed data and smoothed speed data using wavelet transformation were plotted as light blue and dark blue lines, respectively. As for the three performance measures, the proposed logic generated 0 clusters, 0 short messages, and 13 total messages compared with 12 clusters, 27 short messages, and 120 total messages generated with the existing logic for the winter weather event in Figure 8. In addition, a closer look at the period between 6 a.m. to 8 a.m., showed a large speed drop due to a severe snow event and revealed that the proposed logic improved the relevance of the advisory messaging. Although most drivers were traveling at a speed below 20 mph, the existing logic still advised a speed limit of 45 or 55 mph. On the other hand, the proposed logic correctly detected the severe traffic condition and provided a more reasonable advised speed limit of 35 mph.

A comparison of the criteria for both the proposed logic and existing logic, for all four testing sites along the study corridor, appears in Table 2.

Table 2. Comparison between proposed and existing logic

Location	Date	Proposed/(Existing)		
		Cluster	Short Msg.	Total
I-35 SB @ NE 158th Ave	Dec 24, 2015	1/(6)	0/(13)	23/(35)
	Dec 28, 2015	0/(1)	0/(2)	14/(33)
I-35 SB @ NE 126th Ave	Dec 24, 2015	0/(1)	0/(1)	13/(6)
	Dec 28, 2015	1/(1)	0/(1)	22/(30)
I-35 SB @ MP 94	Dec 24, 2015	1/(1)	0/(2)	13/(13)
	Dec 28, 2015	0/(12)	0/(27)	13/(120)
I-35 SB @ NE 36th St	Dec 24, 2015	0/(0)	0/(0)	3/(5)
	Dec 28, 2015	0/(3)	0/(10)	12/(85)

The reason there were no short messages in the proposed control logic was because, besides the dynamic advisory function, a display time constraint was also implemented (each message was to be displayed for at least 2 minutes) to avoid short-duration messages.

The preliminary comparison demonstrated a significant improvement of the newly designed algorithm with the next step of integration within TransSuite and real-time implementation.

IMPLEMENTATION OF ADVISORY ALGORITHM

The architecture of real-time implementation shown in Figure 9 includes the following: (1) downloading the sensor XML data feed, (2) XML parsing, (3) data smoothing, (4) message classification, and (5) message display.
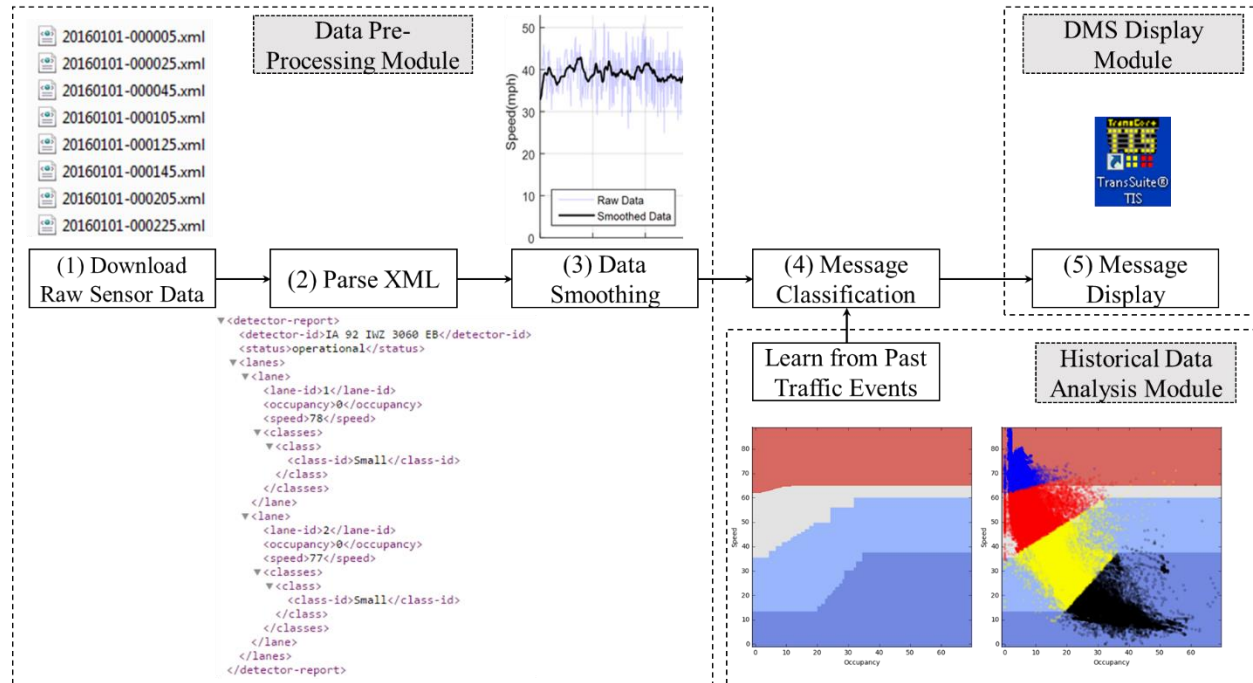
Figure 9. Dynamic advisory real-time implementation pipeline

The real-time implementation was written in Java with its Weka data mining package for message classification, JWave for wavelet data smoothing, and TransSuite's advanced traffic management system (ATMS) web service application programming interface (API) for posting classified messages to field DMS signs. The process was grouped into three modules, each of which will be discussed below.

Data Preprocessing Module

The Iowa DOT maintains over 500 Wavetronix radar sensors statewide with high resolution traffic data transmitted from these devices every 20 seconds via XML feeds. This program includes a set of Java methods to download and parse sensor XML files continuously. The need for data smoothing is critical to find the prevailing traffic conditions (determined by sensor speed and occupancy), and an example of the smoothing result is shown in the sub-graph in Figure 9, where the raw data appears in light blue and the smoothed data is shown as a solid black line.

Historical Data Analysis Module

The research team applied a data-driven approach to design the control algorithm including (1) k-means clustering to find a reasonable number of advisory message groups and (2) use of a classification tree to replicate the experts' engineering judgment based on smoothed data.

The decision boundaries are illustrated in the bottom-right plot of Figure 9, where the x-axis is the smoothed sensor occupancy and the y-axis is the smoothed traffic speed. The domain is coded into four different sections as shown in the left chart, and the decision regions are represented by color. From top to bottom, the decision regions are: normal conditions with no message display (red), "Advised 55 mph" (grey), "Advised 45 mph" (light blue), and "Advised 35 mph" (blue).

Message Display Module

Historical data analysis can find functions that are stored in memory by reading the smoothed speed and occupancy as inputs and then classifies a proper advisory message as output. To send a message to field DMS signs, TransSuite provides an XML web service interface that allows for interaction with the Iowa DOT's ATMS. The messaging history report can be retrieved from the TransSuite TIS software.

VERIFICATION OF MESSAGING

Before deploying the dynamic advisory messaging to the public, the process was implemented in simulation mode, which allowed for verification of the system without displaying anything to the public. The real-time dynamic advisory application was launched in fall 2016. The research team reviewed all events for two winter seasons (2016/2017 and 2017/2018) to validate the accuracy of the system. In order to validate the accuracy of the real-time implementation, the generated dynamic messages were compared with multiple data sources, including the roadway weather information sensor (surface friction), TransSuite TIS internal message logging report, roadway cameras, and Wavetronix speed sensor profiles. However, these data sources were not available for all the sites/events; Table 3 summarizes sample data availability for three sample events.

Table 3. Dynamic messaging validation methods

Event ID & Date	Location	Speed	TIS	Friction	Camera
Event # 1 December 24, 2017	I-35 SB @ NE 36th St	✓	✓	✓	✓
Event # 2 December 27, 2017	I-35 SB @ NE 36th St	✓	✓	✓	✓
Event # 3 February 6, 2018	I-35 SB @ MP 94	✓	✓		

Additional event summaries for system verification can be found in Appendix A.

Winter Storm Event #1 on December 24, 2017

A snow event on December 24, 2017 had snow conditions between 1 a.m. and 11 a.m. Figure 10 shows the sensor data during the winter snow event near the 36th Street interchange.
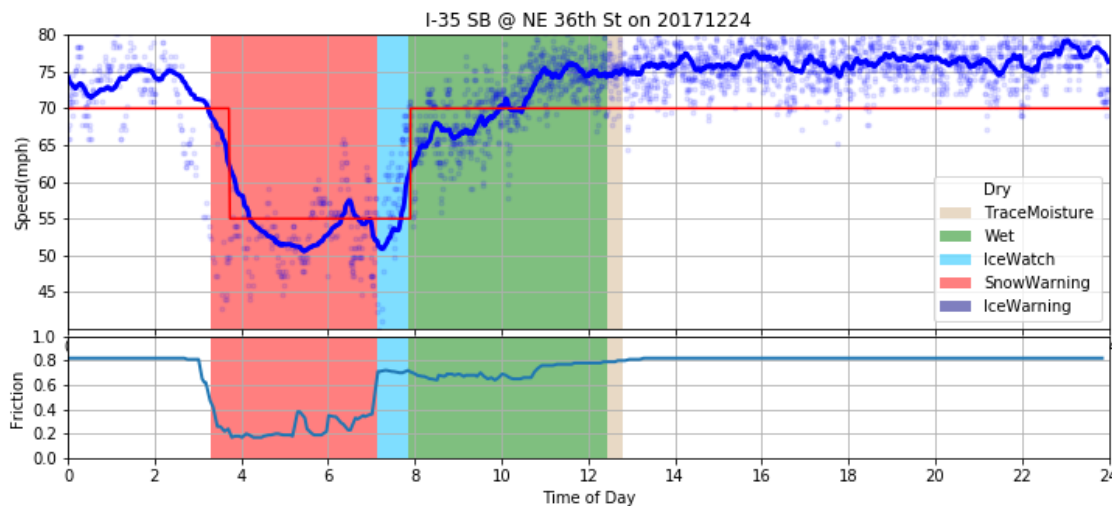
Figure 10. Event #1 at I-35 SB @ NE 36th St: Speed profile and roadway surface condition

The speed started to drop around 3 a.m., hovering around 50 mph between 5 a.m. to 8 a.m., and gradually returned to normal by noon. Meanwhile, the friction conditions illustrated a similar pattern—changed from the worst condition of snow warning/ice watching to the normal situation (wet and trace moisture, then dry). In the top plot of Figure 10, the light blue points were raw sensor data and the solid blue line was smoothed speed that was used to trigger the advisory messages (straight red line). The new algorithm successfully displayed the message of "Advised 55 mph" between 3 a.m. to 7 a.m. This was further validated using the TransSuite TIS Software Report in Figure 11.


| 1,003 - SIM I-80 EB @ Jordan Creek-OH | | Duration | | |
Source Type /Name	Started /Stopped	Message	Blank	Phase 1
USER intrans	12/24/2017 12:02:57AM 12/24/2017 3:09:55AM	186	0	70
NONE NONE	12/24/2017 3:09:55AM 12/24/2017 3:10:46AM	0	0	
USER intrans	12/24/2017 3:10:46AM 12/24/2017 4:34:24AM	83	0	70
USER intrans	12/24/2017 4:34:24AM 12/24/2017 5:51:53AM	77	0	55
USER intrans	12/24/2017 5:51:53AM 12/24/2017 11:56:05PM	1,084	0	70
INTERNAL INTERNAL	12/24/2017 11:56:05PM	0	0	

Figure 11. Event #1 at I-35 SB @ NE 36th St: TransSuite TIS software report

Besides the quantitative description from the sensor/report, the research team also downloaded the nearby camera information for better visualization. Figure 12 shows the camera view for the roadway surface at this location on the same day. From top left to bottom right, it shows the conditions of snow warning, ice watch, wet, and trace moisture, respectively. The color bordering each camera image can also be related to the friction color shading in Figure 10.
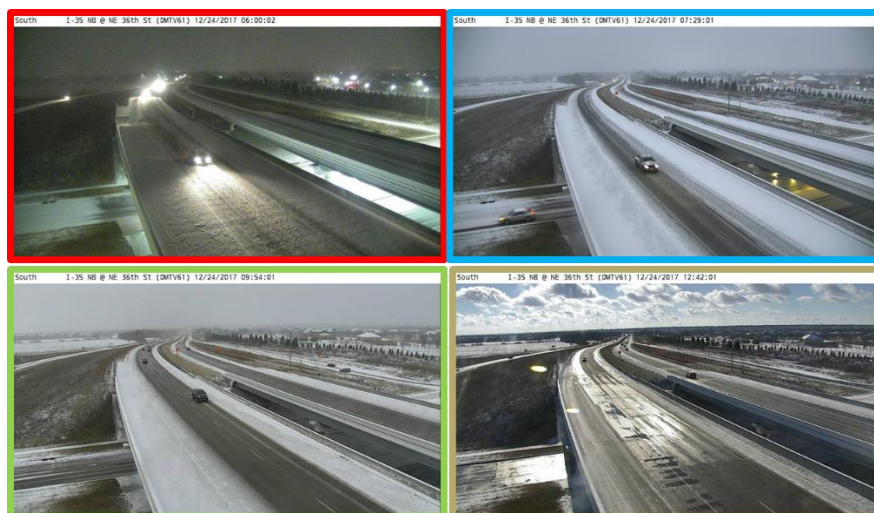
Figure 12. Event #1 at I-35 SB @ NE 36th St: Roadway surface conditions

Winter Storm Event #2 on December 27, 2017

Three days after the previous event, another snow storm arrived late at night on December 27, 2017. This section illustrates the advisory messaging results for that day. In addition to the winter weather advisory messaging, the system was again able to provide alerts for other severe traffic events that occurred (incidents due to crashes).

Figure 13 illustrates the speed profile at the 36th Street interchange, where the red patched region indicates the snow warning logged by the roadway friction sensor.
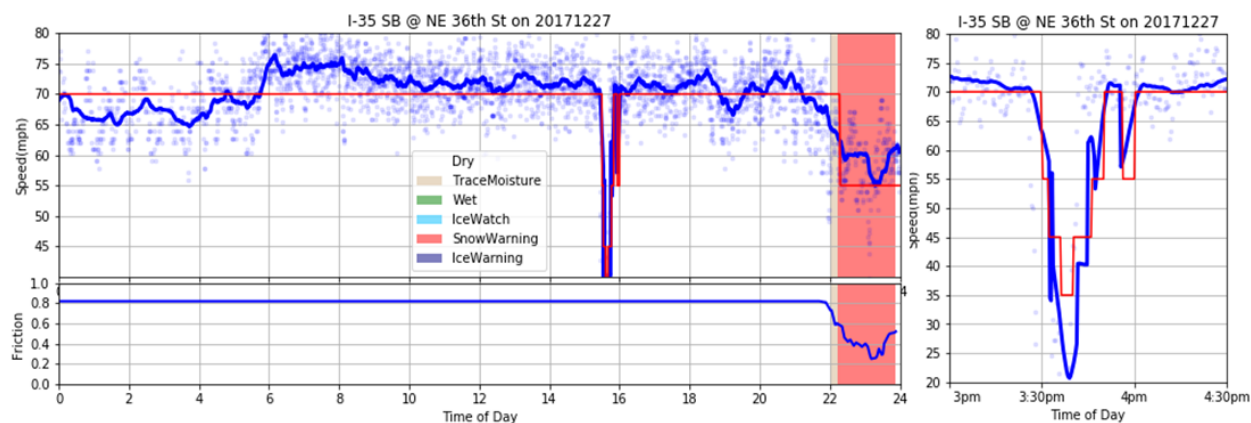
Figure 13. Event #2 at I-35 SB @ NE 36th St: Speed profile and surface condition

This event started around 10 p.m., but speeds were beginning to slow down before that due to the roadway surface conditions. The advisory messaging logic detected the slow down at 10:20 p.m. (as the TIS report in Figure 14) and displayed an advisory 55 mph message accordingly.

Figure 14. Event #2 @ I-35 SB @ NE 36th St: TransSuite TIS software report

One highlight from the plot is that, besides responding to the snow storm, the new algorithm also reacted correctly to a crash around 3:30 p.m. The traffic conditions during the accident are visible in Figure 13 on the right, where the speed dropped to 20 mph. A nearby camera's

imagery data were also retrieved to double-check the algorithm's accuracy, as illustrated in Figure 15.

Figure 15. Event #2 @ I-35 SB @ NE 36th St: Camera images of roadway conditions

Winter Storm Event #3 on February 6, 2018

This snow event occurred on February 6, 2018, just after 6 p.m. No roadway camera nor surface condition data were available; therefore, only the speed profile and TIS report were available for this event.

The speed profile in Figure 16 reflects the weather conditions.
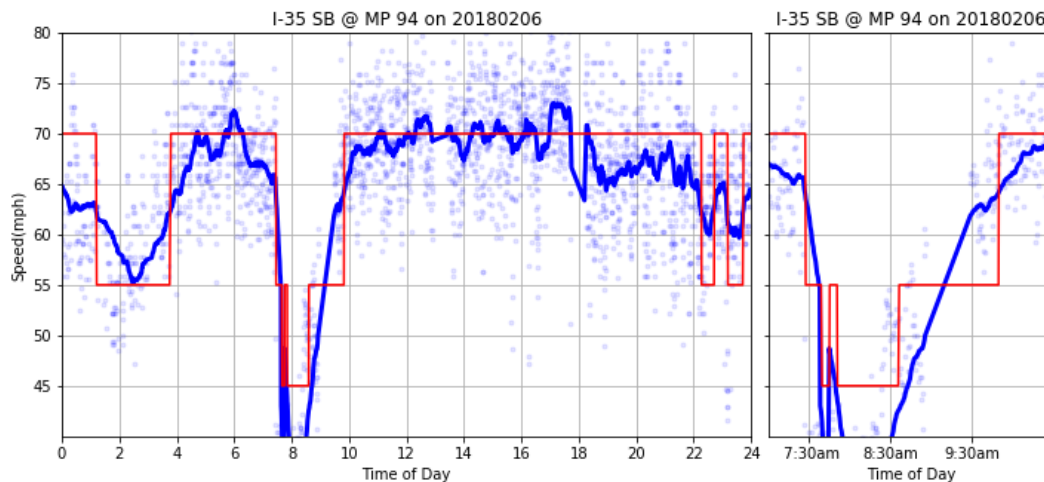
Figure 16. Event #3 at I-35 SB @ MP 94: Speed profile

The speeds did begin to slow down (lower than 70 mph) around 6 p.m. However, the decline in speed was not significant enough to trigger the advisory messaging until 10 p.m.

Moreover, the advisory messaging logic also detected a traffic incident around 8 a.m. and posted reasonable messages (55 mph and 45 mph reported) based on the severe traffic conditions. This event lasted for approximately 2 hours and the traffic was back to normal near 10 a.m.

Summary of Message Verification

Overall, the dynamic advisory messaging system performed as desired by alerting motorists of deteriorating conditions during severe events. The system also has the ability to identify other sources of traffic impacts outside of winter weather conditions. This allows for a responsive system that can notify motorists of slow speeds for any incidents on the roadway.

During light snow events, with minimal impacts to speed, the system did not activate even though speeds were lower than typically observed. An additional threshold could be defined but would risk incidental activation due to the characteristics that are similar to free flow conditions. Additionally, the system was designed for three advisory speeds; however, traffic speeds could be above or below the advisory speed in any condition, which could cause drivers to go faster than what conditions allow. It was determined that advisory speeds may not be the most applicable during these conditions as opposed to providing advisory messaging such as "slow speeds ahead" and "traffic delays," which may be preferred.

The Iowa DOT does not currently have policies in place to activate this type of system. However, a research methodology for this test section of I-35 is in place when implementation becomes possible.

ADDITIONAL DATA INPUTS

Dynamic alerting systems can use a variety of data sources to inform the public depending on the conditions and rules for alerting (weather, incident, slow speeds, etc.). The dynamic advisory messaging logic developed by CTRE used traffic data to identify an advisory speed but other additional data inputs could be used for similar systems. Friction sensors were also installed along the corridor and were evaluated to determine the suitability of using them in an advisory messaging system

The speed and friction data from three different sites along I-35 were evaluated based on four winter events in December 2015, December 2017, and January 2018. The three sites are shown in Figure 17 along with the corresponding sensors (colored dots) and four virtual DMS locations (small grey rectangles with orange text).
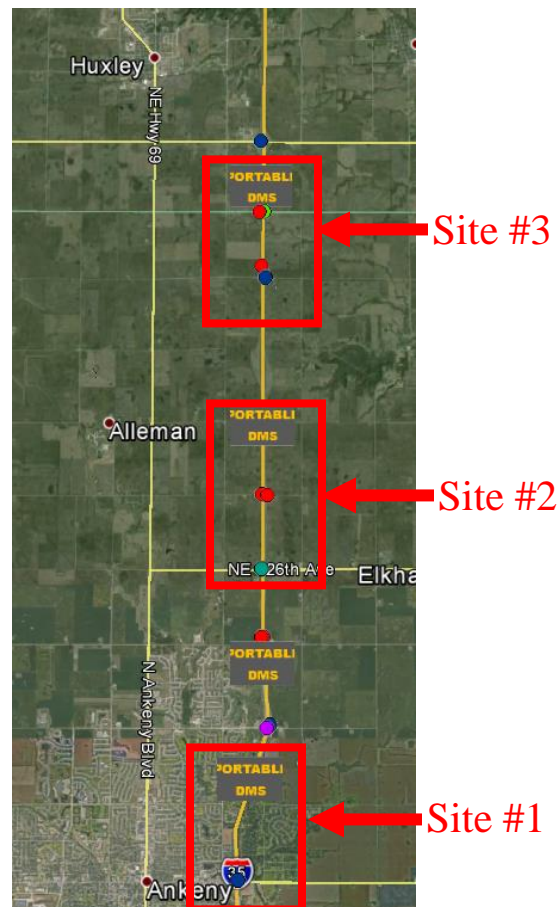
Figure 17. Map of sites for comparison

In Figure 17, the red dots represent the locations of the friction sensors, the blue dots show the speed sensors, and the other dots correspond to other sensors, including road weather information system (RWIS) and visibility sensors. The separation, or physical distance, between the speed and friction sensors varied at each site. At site #1 the speed and friction sensors are

located around 2 miles apart, at site #2 the sensors are spaced 1 mile apart, and at site #3 the sensors are at the same location.

Speed versus Friction Data Comparison

The following section describes some of the events where speed and friction data were compared. Additional summaries are provided in Appendix B.

Figure 18 and Figure 19 show the speed and friction data at Site 1 on December 24 and 28, 2015, respectively. The friction sensor for Site #1 is about 2 miles north of the speed sensor. The upper plot in each figure shows the raw speeds (light blue points) and the smoothed speed (solid blue line). The lower (line) plot shows the friction sensor values and the (vertical) shading represents the reported surface condition, which is generated by the sensor (see legend).

Figure 18 shows that vehicle speeds were decreasing prior to any change in reported surface condition (speed decreased around 10 a.m., which was roughly 30 minutes before the friction sensor detected that the road was wet).
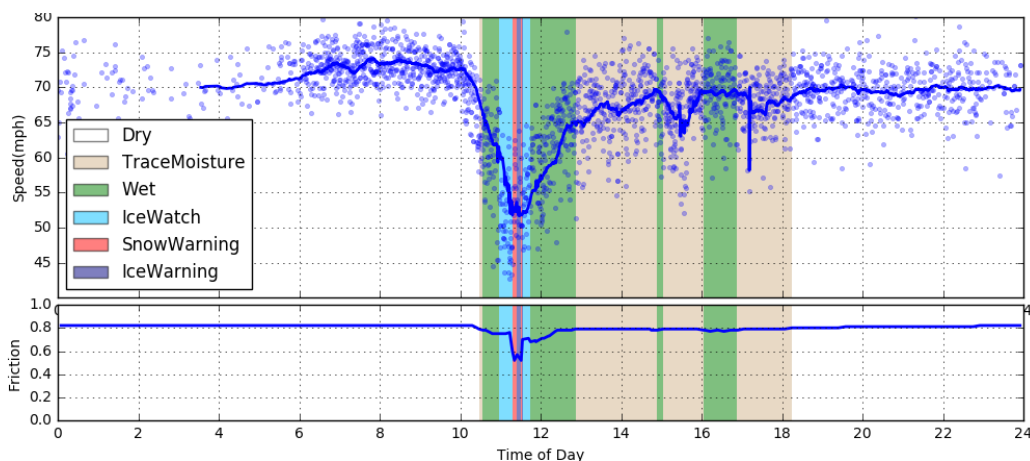
Figure 18. Site #1 on December 24, 2015

The Figure 18 lower line plot indicates surface changes around the same time as speeds began to decrease, but were not changed enough to trigger a wet or icy condition (vertical shading). In this case, it appears that speed provided a better indicator of deteriorating conditions. An RWIS sensor in the Ames area was also used as a baseline to confirm the surface conditions reported for December 24 and 28.

Figure 19 shows the speed and friction data during the December 28, 2015 winter event.

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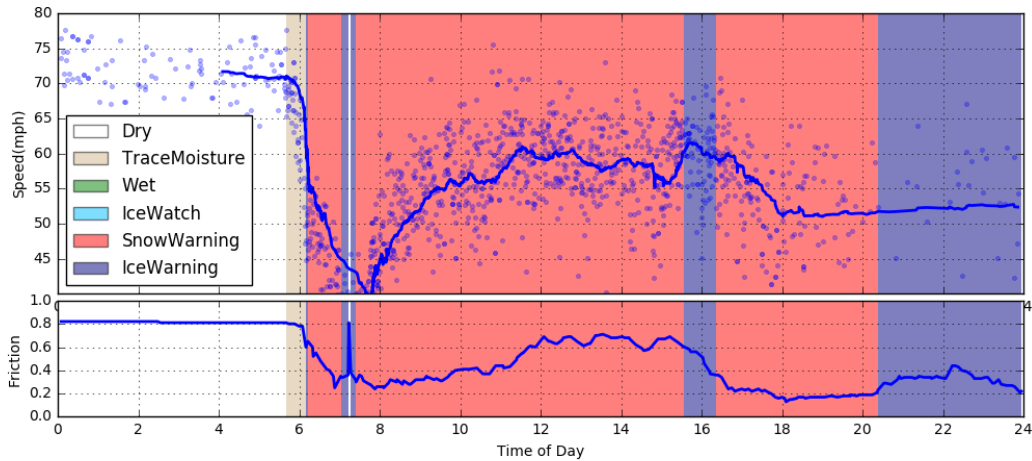
Figure 19. Site #1 on December 28, 2015

As shown, prior to 6 a.m. the friction sensor identified trace moisture (brown vertical shading) while speeds were still at free flow; however, speeds began to drop off and continued to decrease as the snow warning was identified after 6 a.m. In this case, both sensors appeared to detect the change in condition around the same time. There was also a time around 7 a.m. where the friction sensor peaked and reported a dry condition. This was likely due to a snowplow passing through with no observed impact on speeds.

Figure 20 shows the sensor data for Site #3 during the winter event of December 24, 2015.
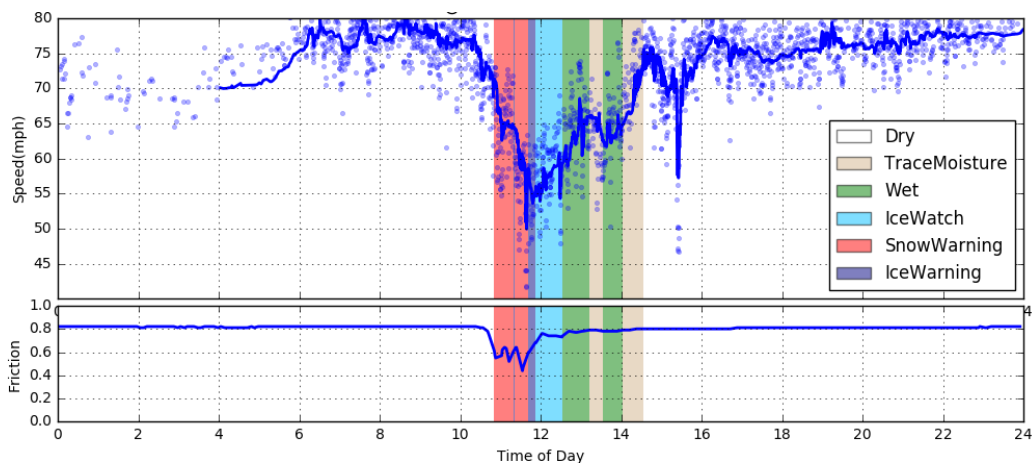
Figure 20. Site #3 on December 24, 2015

These speed and friction sensors are located at the same location. As shown, around 9 a.m. speeds began decreasing with no apparent change in friction data. Around 10 a.m., speeds continued to fall yet the friction data did not change until roughly 10 minutes later with the message going from dry to snow warning.

Figure 21 illustrates another snow event for Site #1 on January 11, 2018; however, the speed did not drop significantly due to the weather.
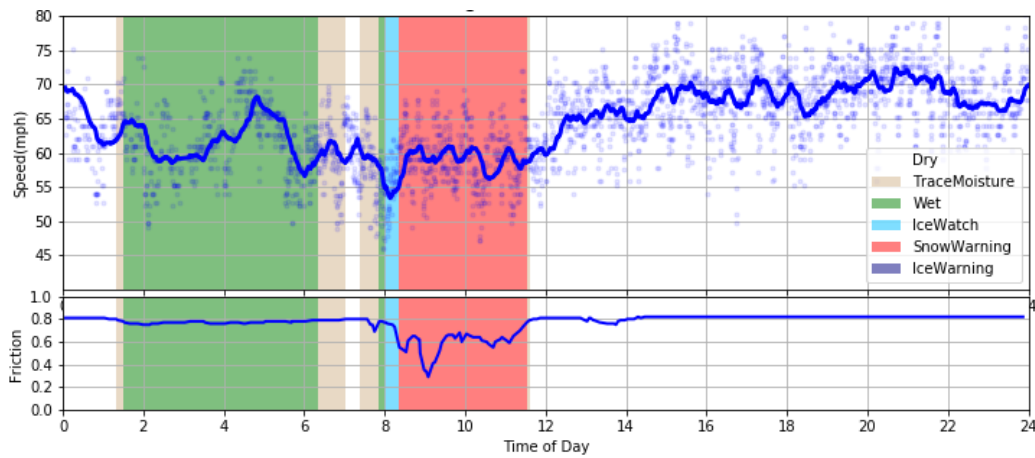
Figure 21. Site #1 on January 11, 2018

The relatively low speed between 2 a.m. to 6 a.m. was probably due to the wet road conditions and slow driving trucks. The weather during the morning was getting worse, the sensor was signaling a warning of snow, and drivers were driving at lower speeds (~60 mph). Figure 22 shows the roadway surface conditions of wet, ice watch, and snow warning, from left to right. The speed remained relatively the same for the entire duration of the winter event but would not have captured the variance in conditions as reported by the friction sensor.

Figure 22. Roadway surface conditions of Site #1 on January 11, 2018

Site # 2 is about 2 miles to the north of Site #1 and its speed profile in Figure 23 was similar to Site #1 on December 24, 2017.
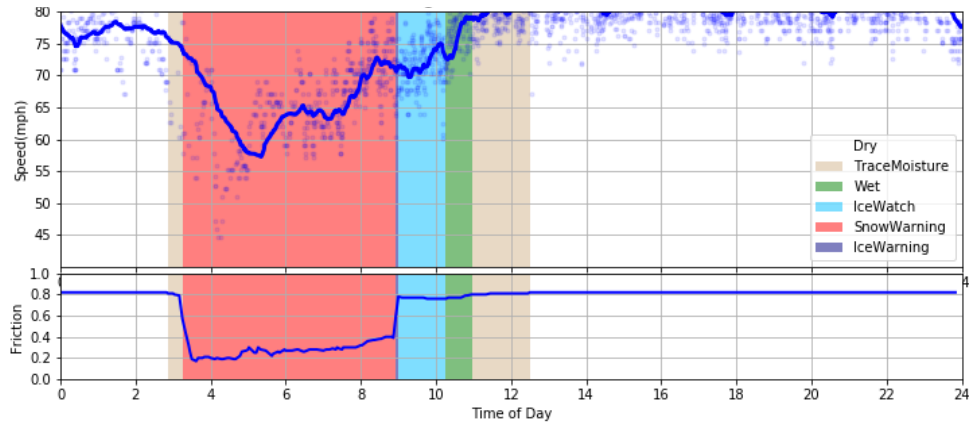
Figure 23. Site #2 on December 24, 2017

Figure 24 shows a similar pattern where roadway surface conditions changed from the worst snow warning level to trace moisture and back to normal dry conditions in afternoon.

Figure 24. Roadway surface conditions of Site #2 on December 24, 2017

Speeds began to drop around the same time as the friction sensor but did not decline as significantly as the friction sensor was reporting. This is an example where the friction sensor was a better indicator for reporting of the road conditions. Note that at 8:56 a.m., the sensor reported a quick warning to watch out for ice, where the friction factor was about 0.6. There was no observed evidence (speed, friction factors, cameras, etc.) indicting this inclement weather event. Additional information as to how the conditions were detected by the sensor may be needed to understand why conditions were reported as ice watch.

Summary of Speed versus Friction Comparison

Overall, both the speed and friction sensors did respond to the winter weather events. Adverse driving conditions were sometimes indicated first by vehicle speeds (turbulence and continual drop) with the friction data lagging in time, but in some situations, the friction sensor better

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detected the road conditions and when alerts should be sent. It is important to keep in mind that the speed and friction data sources are not on equal footing in that the speed data (accessible on the ITS network and available every 20 seconds) are of superior fidelity to the friction data (not on the ITS network and reported every 5 minutes). Contrasting these two potential data streams as a method to drive dynamic messages should correct for this bias. Any comparison should also recognize the utility of speed sensors in having the flexibility to detect other traffic slowdowns (which may not be caused by winter weather), such as crashes, disabled vehicles on the shoulder, towing activities, or other sources of incidents and congestion.

This effort served as a good starting point toward considering these data streams and the capability to enhance traveler information during critical travel times.

CONCLUSIONS

The use of DMS systems is aimed at providing useful roadway information, harmonizing traffic flow, and preventing traffic congestion; such goals depend on realistic, reliable, and real-time traffic messages. The newly designed DMS display logic system has shown significant improvement over the existing system and its accuracy was verified using multiple data sources, including surface friction, video cameras, and TIS historical messaging reports.

Friction data have the potential to enhance the advisory messaging system, but overall perform similarly to the traffic data that are already being collected. The Iowa DOT has a vast network of traffic sensors, which supports a system primarily reliant on traffic data, but friction sensors could be used in specific locations to provide additional inputs to the advisory messaging system. The friction data are also currently limited by collection frequency.

The system developed could be further modified to produce advisory messages ("slow traffic," "traffic delays"), which may be more suitable for use in a variety of conditions including winter weather. The benefit of the current system design is the applicability to other situations such as work zones or other non-recurring traffic conditions. The system should continue to be improved by incorporating additional data inputs such as probe speed data, weather data, and friction data. The current system will continue to be tested and implemented by the Iowa DOT (specifically related to work zones).

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APPENDIX A. MESSAGE VERIFICATION

CTRE reviewed all events for two winter seasons (2016/2017 and 2017/2018) and summarized these events for validation of the system. Appendix A contains additional event summaries from the Verification of Messaging section. This includes additional winter events analyzed as well as additional sensors.

In order to validate the accuracy of the advisory logic real-time implementation, the generated dynamic messages were compared with multiple data sources, including the roadway weather information sensor (surface friction), TransSuite TIS internal message logging report, roadway cameras, and Wavetronix speed sensor profiles. However, these data sources were not available for all the sites/events with Table 4 summarizing data availability by location (rows) and event number (columns).

**Table 4. Validation events summary**

Event ID & Date	Speed	TIS	Friction	Camera
Event # 2 December 27, 2017	✓	✓	✓	✓
Event # 4 January 24, 2017	✓			
Event # 5 January 11, 2018	✓	✓	✓	

Event #2 on December 27, 2017

Three days after a previous winter weather event, another snow event arrived late at night on December 27, 2017. This section illustrates the advisory logic results for that day. In addition to the winter weather advisory messaging, the system was again able to provide alerts for other severe traffic events, including crashes.

Event #2 @ I-35 SB @ MP 94

The sensor at MP 94 is about 1 mile to the north of 36th Street and the crash that happened at 36th Street propagated back to this site as well. There was a significant speed drop due to the abnormal traffic event and the advisory logic displayed proper advisory messages of 55 mph, 45 mph, and 35 mph based on different traffic conditions (as evidenced in Figure 25 and Figure 26). Around 4:30 p.m., the traffic returned to normal, and the advisory logic turned off (displaying 70 mph).
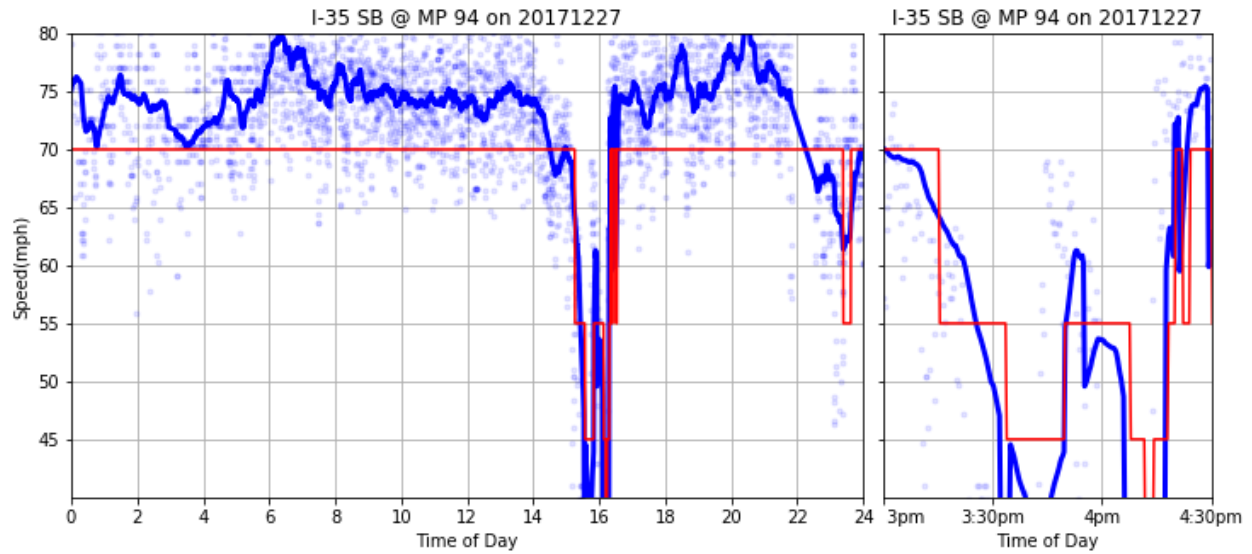
Figure 25. Event #2 @ I-35 SB @ MP 94: Speed profile

Figure 26. Event #2 @ I-35 SB @ MP 94: Camera view of traffic event

Event #2 @ I-35 SB @ NE 126th Ave

Figure 27 profiles the remaining site where during Event #2 drivers were slowing down at night due to the light snow event but the traffic conditions (determined by speed and sensor occupancy) were not severe enough to trigger the advisory message of 55 mph. Hence, the advisory logic did not generate messages while the friction sensor site did show a snow warning alert.
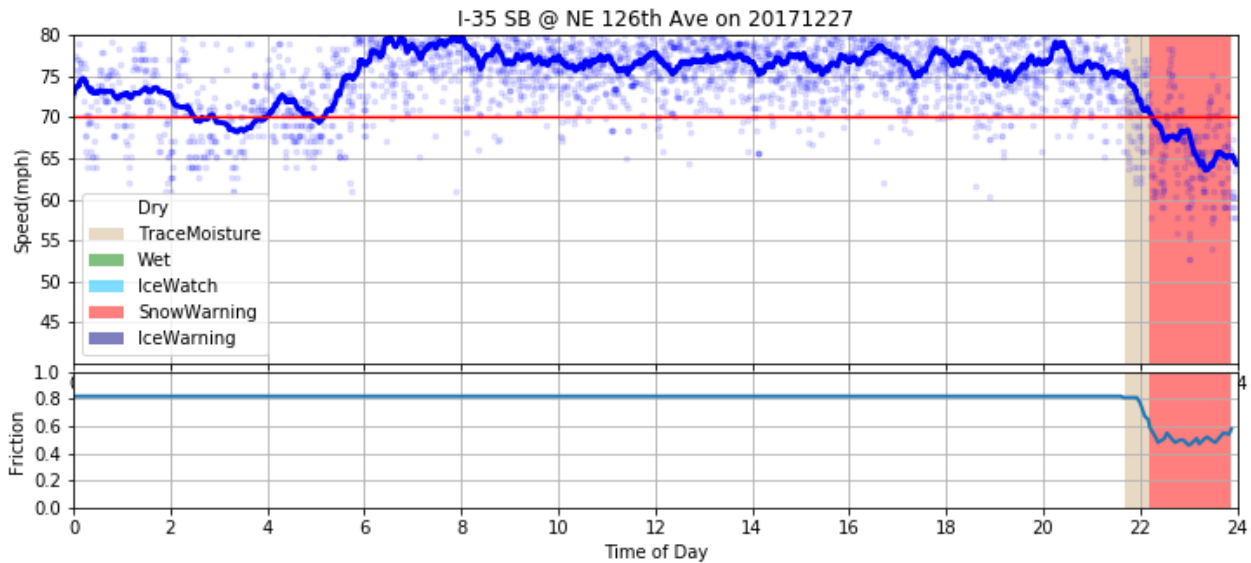
Figure 27. Event #2 @ I-35 SB @ NE 126th Ave: Speed profile and surface condition

Event #4 on January 24, 2017

The third snow event considered, which occurred in early 2017, was analyzed by parsing the downloaded historical data in a streaming fashion, implementing the designed advisory logic locally, and validating the message with speed profiles. This snow event began after 7 p.m. on January 24, 2017, and the following section summarizes the findings for all four sites along I-35 SB between Huxley and Ankeny.

These generated messages were plotted using a red straight line in the following graphs.

Figure 28, Figure 29, Figure 30, and Figure 31 show the speed profiles for each site as well as the displayed messages represented by the red line. It was apparent that drivers reduced their speed when the winter weather event started after 7 p.m. for all sites, which was consistent with the beginning of snowfall on that day. The advisory logic responded appropriately to the traffic and displayed the advisory speed messages of 55 mph. The advisory logic significantly reduced the fluctuation in messages, which were generated through the previous alerting system.

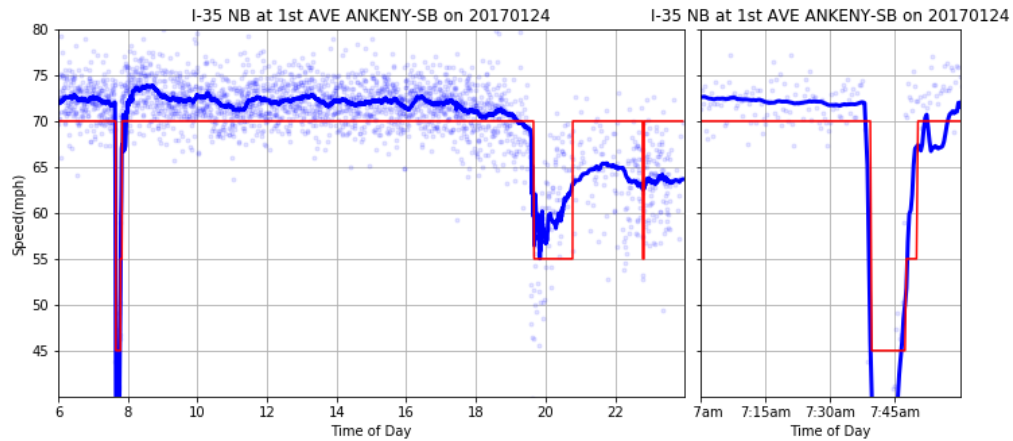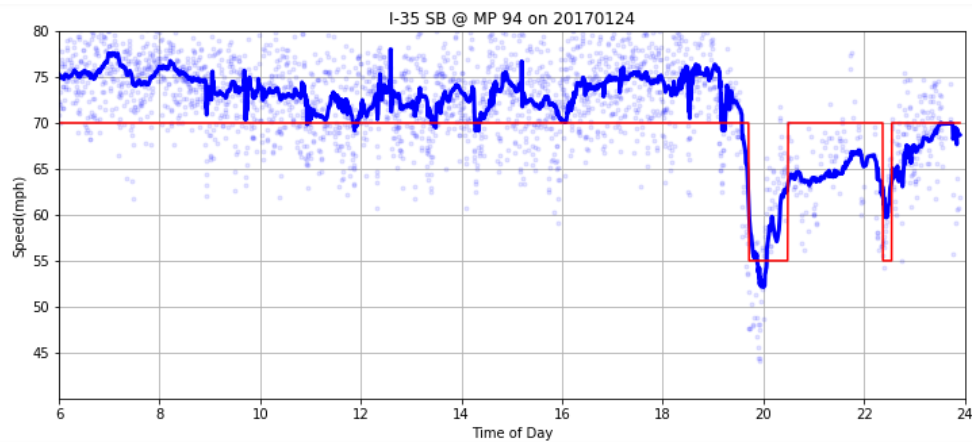**Figure 28. Event #4 at I-35 NB at 1st Ave Ankeny SB: Speed profile**

Figure 29. Event #4 at I-35 SB @ MP 94: Speed profile
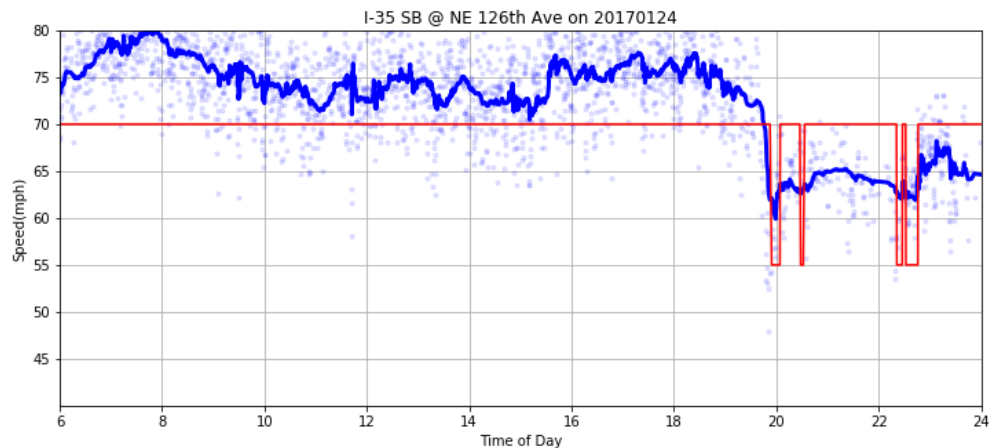
Figure 30. Event #4 at I-35 SB @ NE 126th Ave: Speed profile

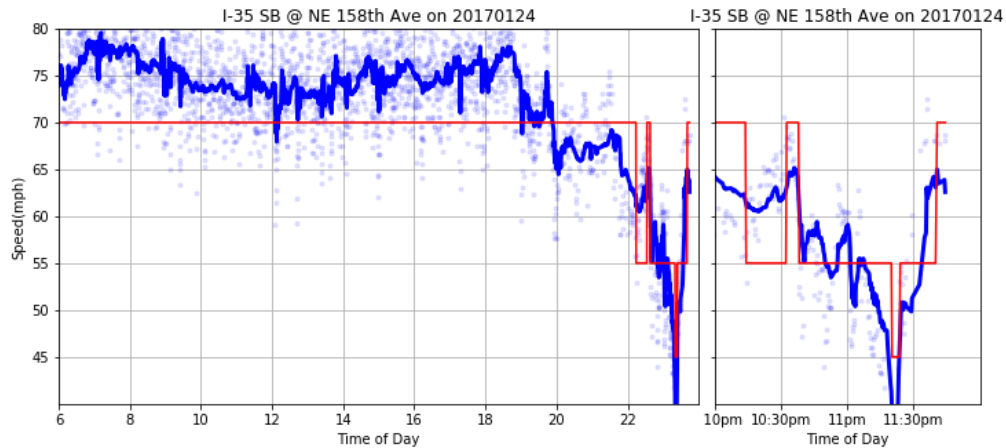**Figure 31. Event #4 at I-35 SB @ NE 158th Ave: Speed profile**

One thing worth mentioning is the sudden speed drop near 8 a.m., which lasted for about 10 minutes, as shown in Figure 28. This likely was the result of a traffic accident. In addition to the benefits of using the system during winter weather, the newly designed advisory algorithm also detected the abnormal patterns quickly and released the proper advisory messages (55 mph and 45 mph) accordingly.

Another irregular traffic pattern was observed in Figure 31 at close to 11:30 p.m., when the traffic speed decreased significantly. This might have been due to another traffic accident caused by the inclement weather that triggered the advisory algorithm to display a message of 45 mph for a few minutes.

Event #5 on January 11, 2018

The weather event on January 11, 2018 brought snow conditions throughout the morning along the I-35 corridor.
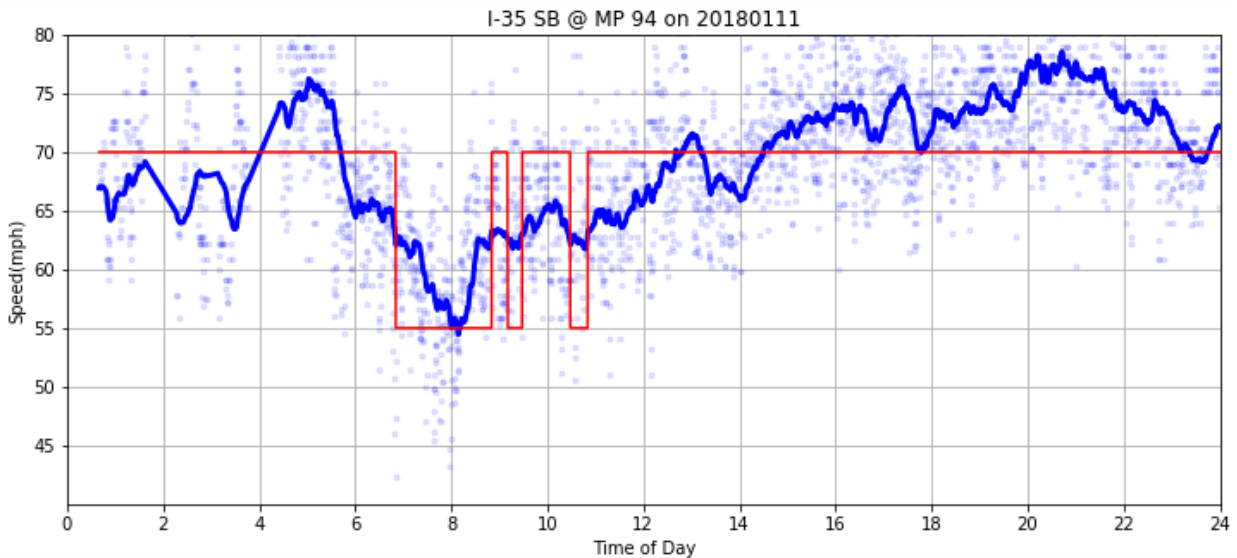
Event #5 @ I-35 SB @ NE 36th St

Due to the inclement weather and bad roadway surface conditions, most of drivers were choosing a relatively lower speed. Figure 32 visualizes the speed profile, friction factors, and displayed 55 mph messages for most of morning time period.
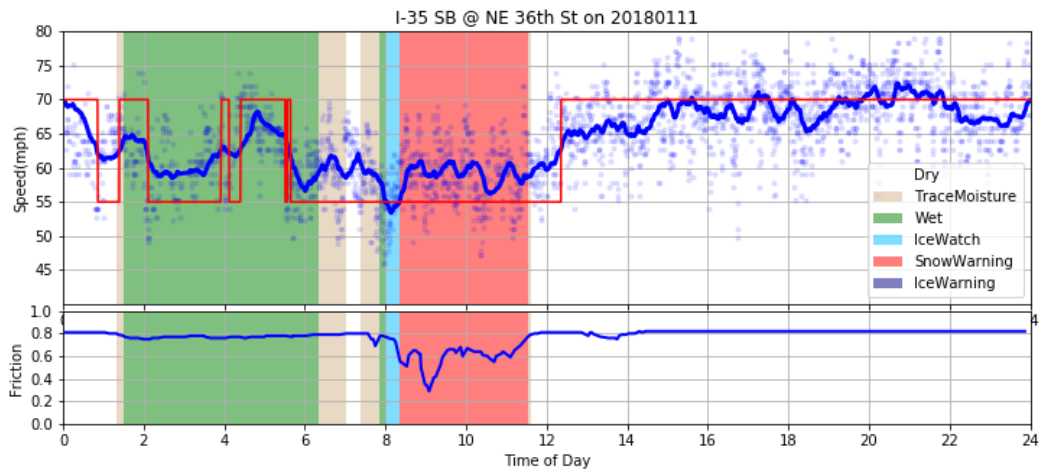
Figure 32. Event #5 @ I-35 SB @ NE 36th St: Speed profile and surface condition

Event #5 @ I-35 SB @ MP 94

Unlike 36th Street, this site still had higher observed speeds (~ 65 mph) during the early morning; thus, the advisory logic was not triggered until 7 a.m. (Figure 33). This advisory messaging lasted for about 2 hours until 9 a.m. After the morning peak, as speed and occupancy improved, there were two additional minor speed drops, which triggered the advisory messaging of 55 mph.
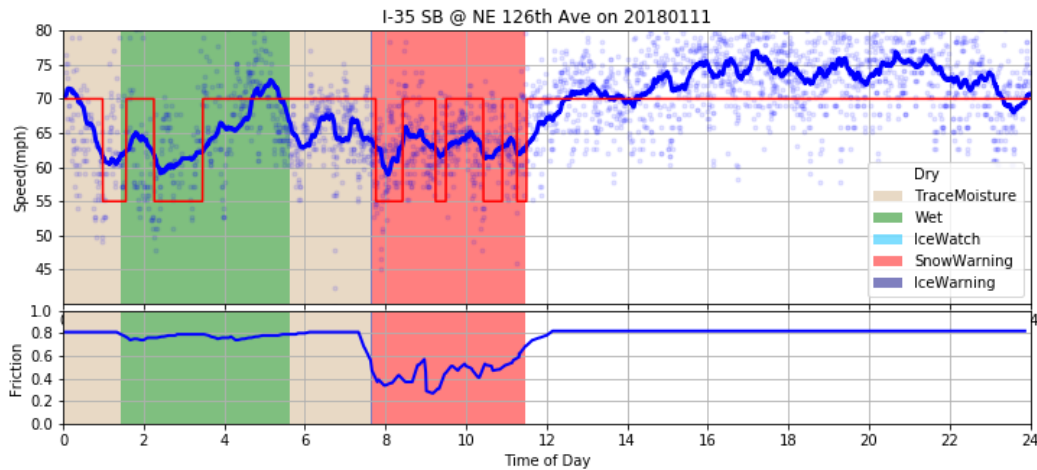

Figure 33. Event #5 @ I-35 SB @ MP 94: Speed profile
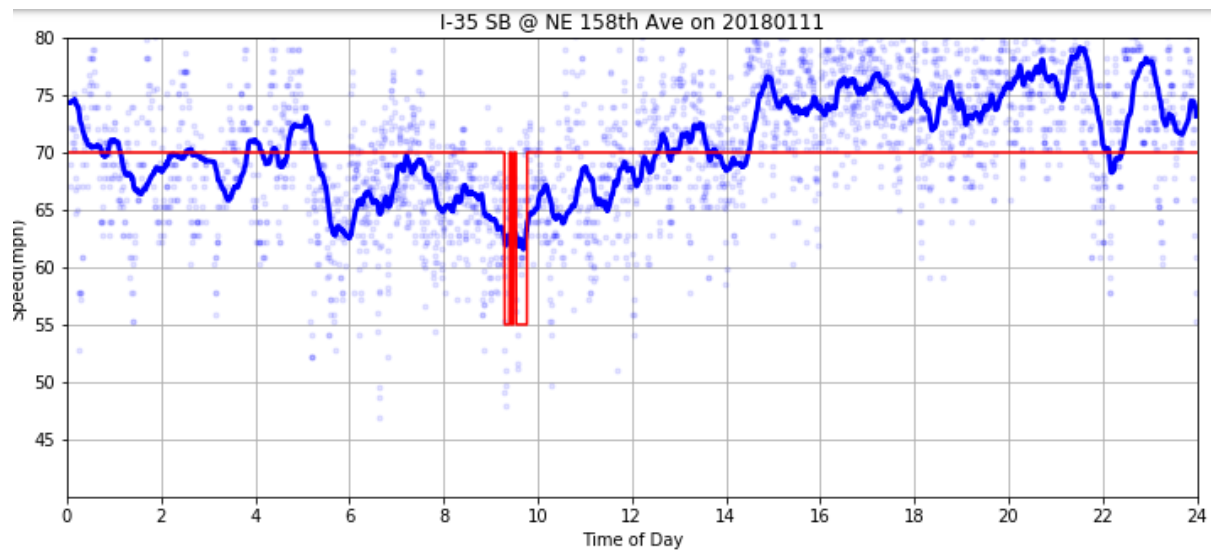
Event #5 @ I-35 @ SB @ NE 126th Ave

Drops in speed were sporadic at NE 126th Avenue as shown in Figure 34. The advisory logic detected the speed trend and responded with 55 mph advisory messages as shown in Figure 34. Note there was another speed drop around 6 a.m.; however, it was still around 65 mph, which was not significant enough to trigger the messaging system. Compared to the friction sensor, the advisory messaging was sporadic between 8 a.m. and 12 p.m. The raw friction factors (shown in the bottom plot) also showed varying friction factors during this time but were not significant enough to change the snow warning condition.

Figure 34. Event #5 @ I-35 SB @ NE 126th Ave: Speed profile and surface condition

Event #5 @ I-35 SB @ NE 158th Ave

The traffic conditions at 158th Avenue are illustrated in Figure 35. Overall, the speed profile matched the weather conditions with slower speeds during the morning due to snow, and higher speeds during afternoon when the weather was getting better without snow. There was a message cluster around 9:30 a.m., which was likely due to the unstable/complex traffic conditions (determined by both speed and occupancy). Note that the current message display limit was 2 minutes, a longer setting of display time (for example, forcing the message to display at least 5 minutes) might eliminate the clustering effect.

Figure 35. Event #5 @ I-35 SB @ NE 158th Ave: Speed profile

## APPENDIX B. SPEED VERSUS FRICTION DATA COMPARISON

CTRE reviewed compared friction and speed data for additional events not included in the Additional Data Inputs section. Appendix B includes the additional event summaries comparing the performance of speed and friction sensors.

Figure 36 and Figure 37 show the speed and friction data at Site #2 for the winter events of December 24 and 28, 2015, respectively. For Site #2, the friction sensor is located approximately 1 mile north of the speed sensor. In Figure 36, the speed and friction data both begin to drop at approximately the same time.
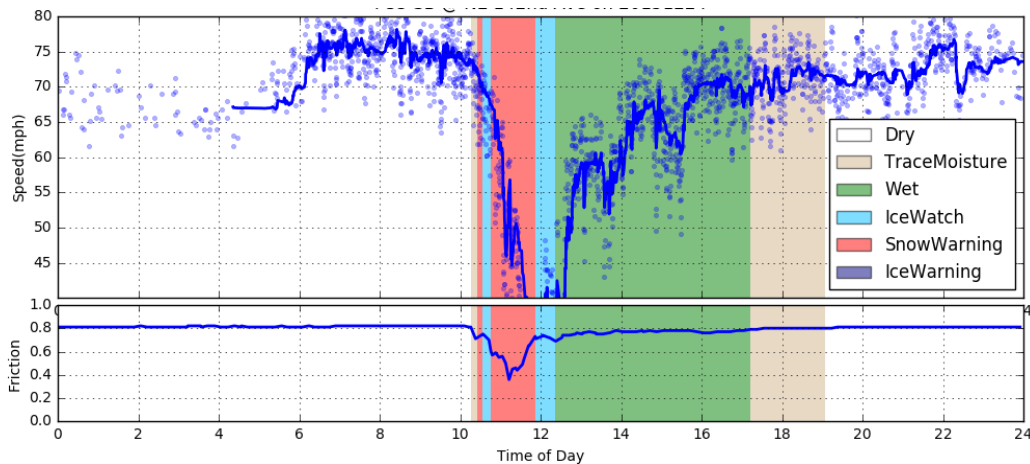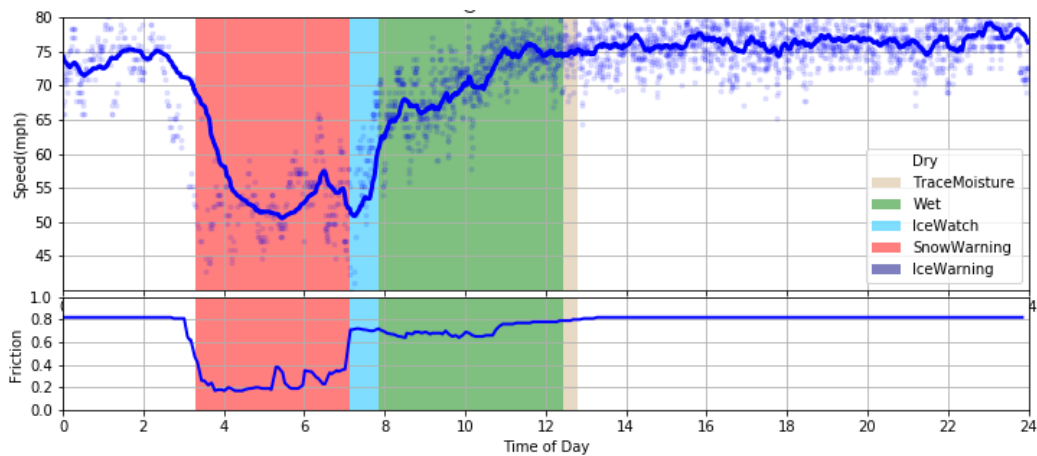

Figure 36. Site #2 on December 24, 2015

Figure 37 shows speeds slowing down just before 6 a.m., and the friction data began dropping around the same time, but do not show a road condition change or snow warning until almost an hour after speeds began dropping. A spike in friction data, at around 7 a.m., was likely due to a snow plow. Also of interest, during the snow storm the friction sensor showed dry conditions multiple times with significant gaps between 12 a.m. (midnight) and 3 p.m. and again around 10 p.m. Speeds during all of these time periods remained variable and below the free flow speeds, which was in contrast to the dry condition reported by the friction sensor.
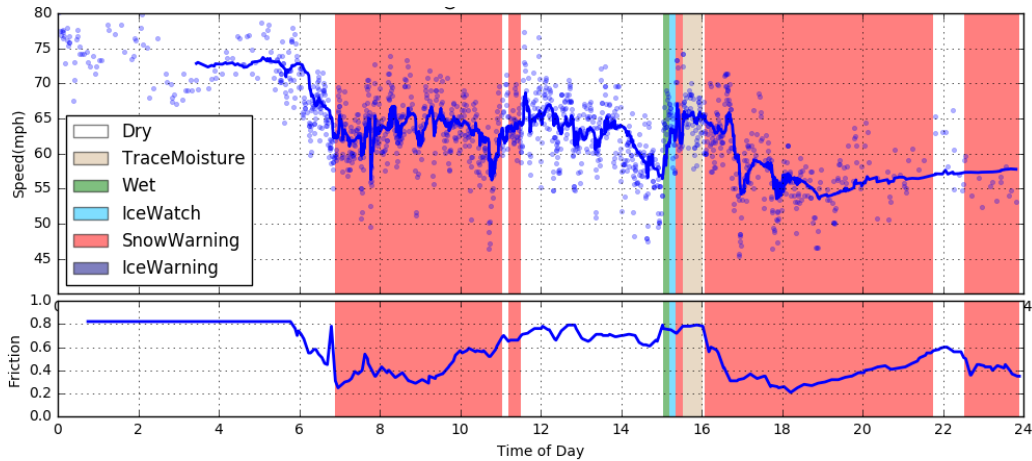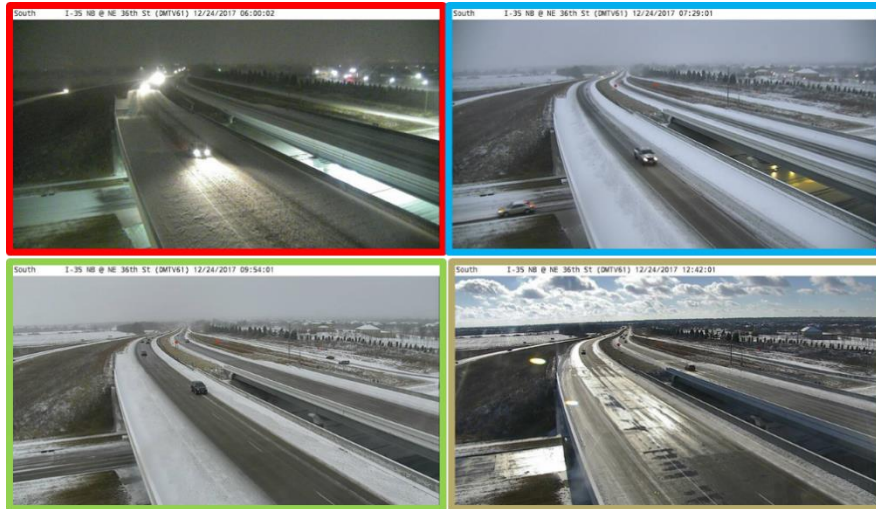
Figure 37. Site #2 on December 28, 2015

Figure 38 shows the sensor data for Site #1 during one winter snow event on December 24, 2017. The speed started to drop around 3 a.m., hovered around 50 mph from 5 a.m. to 8 a.m., and gradually returned to normal by noon. Meanwhile, the friction conditions exhibited a similar pattern—changed from the worst condition of snow warning/ice watching to the normal situation (wet and trace moisture, then dry). Both the speed and friction sensors appeared to detect the impact to traffic at a similar time. Figure 39 provides camera views of the roadway for Site #1 on the same day. From top left to bottom right, it shows the conditions of snow warning, ice watch, wet, and trace moisture, respectively. The color bordering each camera image can also be related to the friction color shading in Figure 38.


Figure 38. Site #1 on December 24, 2017

Figure 39. Roadway surface conditions of Site #1 on December 24, 2017

Figure 40 and Figure 41 show the speed profile and roadway surface states for Site #2 on January 11, 2018. Both the speed and surface condition were in the worst situation during the morning, when the speed was about 10 mph slower than the posted speed limit (70 mph), and the sensor was triggered by the snow warning. Once again, at 7:38 a.m., the sensor was sending out the warning of ice for a very short period of time (shown by an extremely thin purple patch).
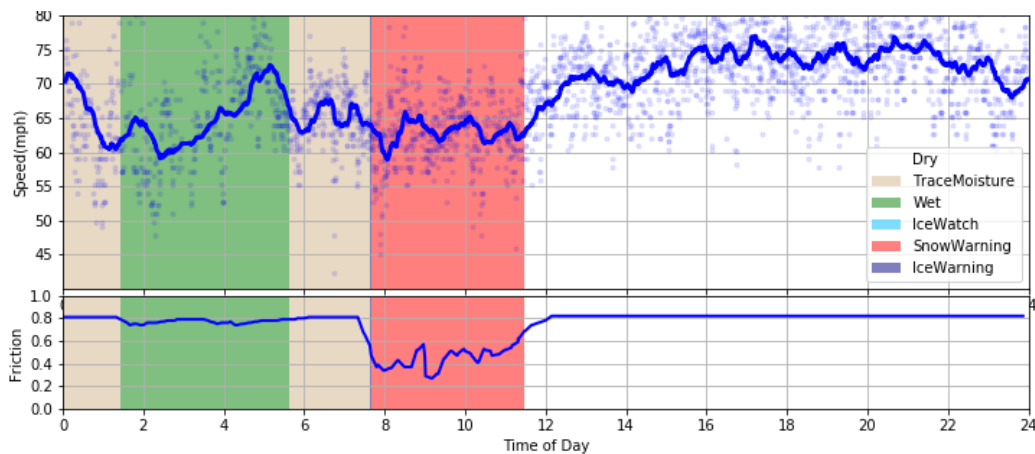
Figure 40. Site #2 on January 11, 2018

Figure 41. Roadway surface conditions of Site #2 on January 11, 2018

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