# Integrated Modeling for Road Condition Prediction—Phase 3 Evaluation Report

December 2020

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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## LIST OF ACRONYMS

| | |
|---|---|
| °F | degree Fahrenheit |
| a.m. | ante meridiem |
| EB | eastbound |
| FHWA | Federal Highway Administration |
| h | hour |
| I–435 | Interstate 435 |
| IMRCP | Integrated Modeling for Road Condition Prediction |
| KC Scout | Kansas City Scout |
| km | kilometer |
| METRo | Model of the Environment and Temperature of Roads |
| mi | mile |
| min | minute |
| MLP | machine learning-based prediction |
| MLPA | machine learning-based prediction model A |
| mph | mile per hour |
| N/A | not applicable |
| NB | northbound |
| p.m. | post meridiem |
| PCCAT | precipitation category |
| RAP | Rapid Refresh |
| RMS | root mean square |
| RTMA | Real-Time Mesoscale Analysis |
| RWMP | Road Weather Management Program |
| SCOUT | Kansas City Scout |
| SPDLNK | average speed of vehicles on each link |
| TMC | traffic management center |
| TPVT | temperature of pavement |
| TrEPS | Traffic Estimation and Prediction System |
| TSMO | transportation system management and operations |
| VIS | visibility of surface |
| WRTM | weather-responsive traffic management |

# CHAPTER 1. INTRODUCTION

In 2015, the Federal Highway Administration (FHWA) began efforts to describe and create a tool that fuses real-time and/or archived data with results from an ensemble of forecast and probabilistic models to predict current and future overall road and travel conditions for travelers, transportation operators, and maintenance providers.

The Integrated Modeling for Road Condition Prediction (IMRCP) system is a prototype system and demonstration deployment that provides a framework for integrating road condition monitoring and forecast data to support decisions by travelers, transportation operators, and maintenance providers. The system collects and integrates environmental and transportation operations data, collects forecast weather data, initiates road weather and traffic forecasts, generates advisories and warnings, and provides the results to other applications and systems. The model could ultimately become a practical tool for transportation agencies to support traveler advisories, maintenance plans, and operational decisions at strategic and tactical levels.

## PROJECT DESCRIPTION

The foundational tasks for characterizing IMRCP in Phase 1 included development of a concept of operations and requirements. In the IMRCP Phase 2, the research team specified, implemented, tested, and evaluated the IMRCP concept in a demonstration deployment in part of the Kansas City metropolitan area. In IMRCP Phase 3, the objectives were to build upon the Phase 2 demonstration deployment in the Kansas City area. This involved increasing coverage to the entire Kansas City metropolitan area highways, adding an additional (alternative) traffic model, operating the system through two winter seasons, evaluating the operational results, and updating project documents.

Research, development, and operations stakeholders have been involved throughout the IMRCP effort. Operations stakeholders helped identify the system functions and interfaces and provided feedback on the usefulness of the model results. This project included:

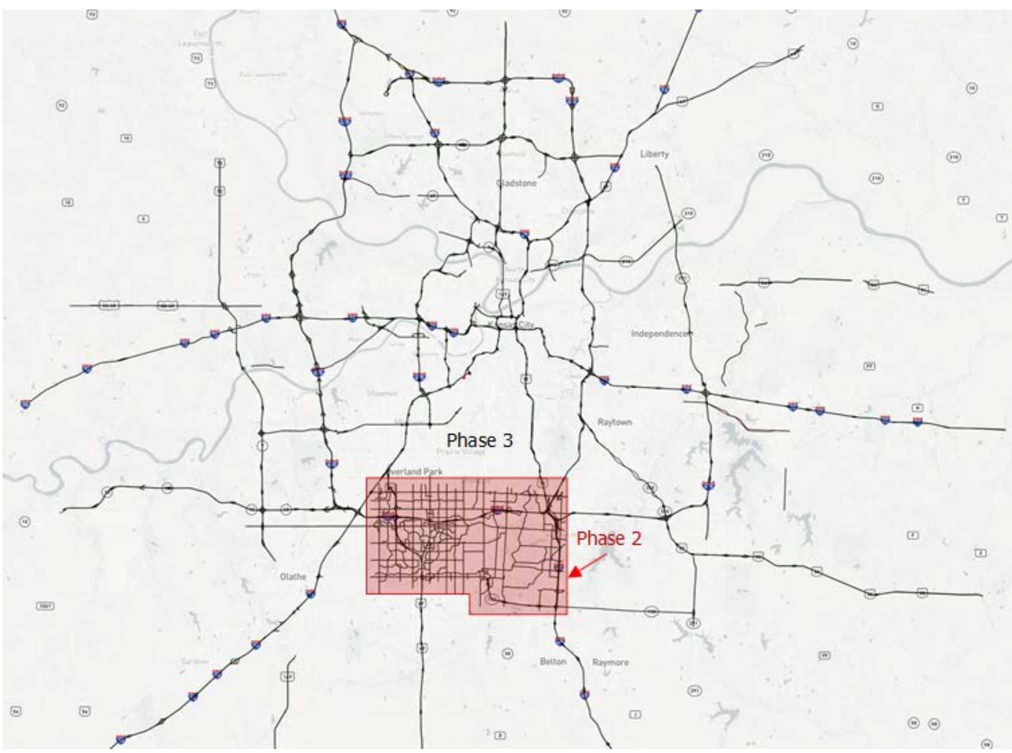
- A survey of available and imminent weather, hydrological, traffic, and related transportation management models;
- Development of a concept of operations and fundamental system requirements;
- Development of a system architecture and system design;
- Implementation of a foundational system;
- Deployment of the system with an operating transportation agency to evaluate its effectiveness.

The IMRCP system provides an integrated view of forecast road weather and traffic conditions for a given road network. The IMRCP model draws input from traffic, weather, and hydrological data sources to estimate current conditions and forecast future conditions. Forecasts are available via web interface on maps, in reports, and in subscriptions. Traffic data sources, such as advanced transportation management systems, provide volumes, speeds, freeway control and traffic signal operations data, incident reports, and plans for work zones and special events. Current and forecast atmospheric and hydrological conditions are drawn from National Weather

Service sources. State and local agencies provide specialized road weather conditions, such as pavement temperatures. Data collected from the various sources are indexed, stored, and archived in a heterogeneous data store by the system.

While atmospheric and hydrological forecasts, work zones, and special events data are taken from external sources, the IMRCP system synthesizes road weather and traffic condition predictions with embedded best-in-class forecast models. The current IMRCP system implementation estimates road weather conditions across the network using field measurements of conditions and predicts conditions based on atmospheric forecasts  using the Model of the Environment and Temperature of Roads (METRo). The system estimates current traffic conditions from detector stations and demand models and predicts conditions from road weather, incident, and demand forecasts using the Traffic Estimation and Prediction System (TrEPS)/Dynamic Traffic Assignment model and a machine learning-based traffic prediction model (MLP).

Phase 3 of the IMRCP project built upon the Phase 2 demonstration deployment in the Kansas City area. This involved increasing coverage to the entire Kansas City metropolitan area highways and adding the additional traffic model (the machine learning-based traffic prediction model). The IMRCP Phase 3 study area greatly extended the Phase 2 area to include all freeways monitored by the Kansas City Scout (KC Scout) traffic management center (TMC), as shown in figure 1.




Source: Federal Highway Administration; OpenStreetMap® contributors.

**Figure 1. Map. Integrated Model for Road Condition Prediction Phase 2 and Phase 3 deployment area in Kansas City area.**

## PURPOSE AND OVERVIEW

The purpose of the evaluation is to explore whether IMRCP had an impact on KC Scout operations and to assess whether the information was useful to KC Scout operators and supervisors. The findings from this evaluation could inform others who may be considering similar deployments and provide FHWA with information to help determine next steps for IMRCP.

This evaluation report consists of five chapters:

- **Chapter 1. Introduction** (this chapter) provides a description of the project, the evaluation purpose, and an overview of the document.
- **Chapter 2. Evaluation Approach** describes the evaluation approach and objectives.
- **Chapter 3. Results** describes the analyses of the IMRCP data and operator interviews.
- **Chapter 4. Findings** discusses the implications of the analyses related to the IMRCP evaluation operational improvements and user satisfaction objectives.
- **Chapter 5. Conclusion** reiterates key results that support the findings.

# CHAPTER 2. EVALUATION APPROACH

The evaluation approach was developed based on reviews of project documents, meetings with Kansas City Scout (KC Scout) staff, and discussions with the development team and the Federal Highway Administration (FHWA) Road Weather Management Program (RWMP). Project goals and objectives served as the basis for the key questions and evaluation objectives. Key questions to be addressed in the evaluation were: (1) Did the Integrated Modeling for Road Condition Prediction (IMRCP) have an operational impact? (2) Did users consider the IMRCP information useful?

The primary users of IMRCP for this deployment are staff at the KC Scout traffic management center (TMC) who monitor traffic speeds, cameras, and weather to identify traffic issues. The speeds and predicted speeds of the models in IMRCP need to be relatively accurate for operators to have confidence in using the system; therefore, the evaluation approach focused on speeds, speed predictions, and user perspectives. The following sections describe the evaluation objectives, approach, and methodology.

## EVALUATION OBJECTIVES

Evaluation objectives were developed to guide the approach. For IMRCP to have an operational impact, the information should be accurate; therefore, the objective was to examine if the speeds and speed forecasts were accurate. To address the usefulness question, two objectives guided the investigation: (1) whether the integrated system improves internal agency operations and (2) whether operators and supervisors found the enhanced integrated information useful. Table 1 shows the key questions of the evaluation and the corresponding objectives.

**Table 1. Integrated Modeling for Road Condition Prediction evaluation key questions and objectives.**

| Key Questions | Objectives |
|---|---|
| Did IMRCP have an operational impact? | Examine if the speeds and speed forecasts are accurate. |
| Did users consider IMRCP information useful? | Investigate if the integrated system improves internal agency operations. |
| | Determine if operators/supervisors find the enhanced integrated information useful. |

IMRCP = Integrated Modeling for Road Condition Prediction.

## APPROACH

Investigating whether the speeds and speed forecasts were accurate involved identifying a variety of road and weather conditions across numerous days during the 2019–2020 winter driving season. Days with high-impact events (e.g., incidents, storms, work zones, and planned events) were selected by the research team for collecting IMRCP predicted speeds; historical Kansas

City Scout (KC Scout) detector speeds; IMRCP speed forecasts that were 15 to 115 minutes into the future; and weather, road, and traffic condition information.

The analyses of IMRCP model prediction performance compared the Traffic Estimation and Prediction System (TrEPS) and machine learning-based prediction (MLP) predictions to the KC Scout detector data. The IMRCP pavement conditions were also compared to the Model of the Environment and Temperature of Roads (METRo). However, modeling of the atmospheric weather forecasts, performed by the National Oceanic and Atmospheric Administration/National Weather Service, was not examined because those methods are external to the IMRCP. The evaluation looked at various 2019–2020 days, weather events, and detector locations to provide a reasonable assessment of the IMRCP model performance across the entire IMRCP road network.

To investigate whether users considered IMRCP information useful, interviews were conducted in 2019 and 2020 to obtain operator and supervisor perspectives about IMRCP and to provide insights that include:

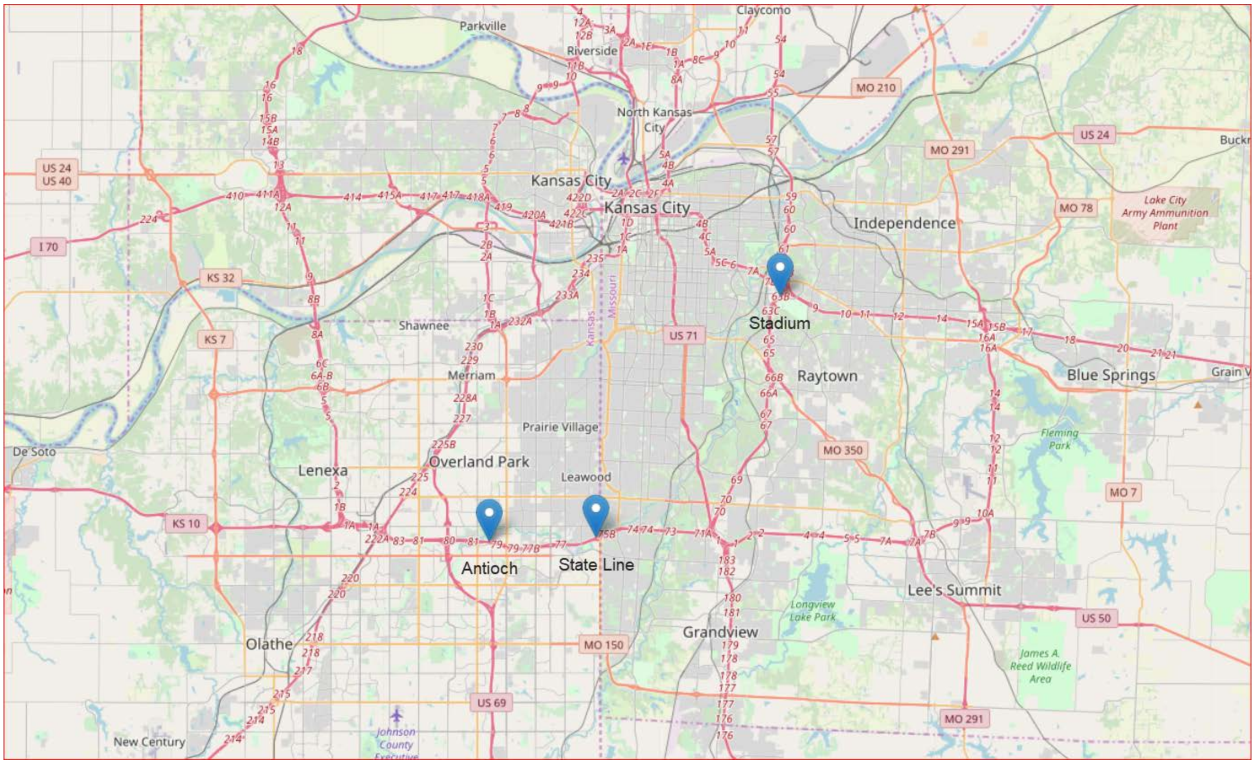
- Investigating whether IMRCP improves internal agency operations.
- Determining whether IMRCP current and predicted road conditions are accurate.
- Exploring whether operators and supervisors find the enhanced integrated information useful.

The following sections describe the operational impacts and usefulness studies.

**Operational Impacts Study**

The operational impacts study compared IMRCP TrEPS and MLP speed predictions with historical KC Scout detector speeds to determine the accuracy of speed predictions at several locations, during various time periods, and for a variety of road and weather conditions.

Three locations along Interstate 435 (I–435) were selected for analysis across five winter events spanning seven 24-hour (h) periods. The detectors and corresponding segments explored were located on I–435 eastbound (EB) at State Line Road, I–435 northbound (NB) at East Stadium Drive, and I–435 EB at Antioch Road. The locations were previously identified as reliable locations for collecting speed link data, which was the basis for comparing the IMRCP historical real-time speeds and speed forecasts. Figure 2 shows a map of the detector locations used in the analyses. According to the IMCRP tool, a work zone was present downstream from the detector and segment of interest during the periods explored at the State Line Road location.




Source: Federal Highway Administration; OpenStreetMap® contributors.

**Figure 2. Map. Link detector locations.**

Table 2 lists the locations, time periods, and corresponding road and weather conditions that were studied. The evaluation team completed the following analyses for each location and date:

- Analysis of historical predicted speeds.
- Analysis of forecast speeds for 15-, 30-, 45-, 60-, 75-, 90-, 105-, and 115-min predictions.
- Analysis of speed forecast error (absolute, relative absolute, and root mean square errors).

**Table 2. Weather conditions by location and date.**

| Location | 11/11/2019 | 11/29/2019 | 12/15/2019 | 12/16/2019 | 12/17/2019 | 1/29/2020 | 2/12/2020 |
|---|---|---|---|---|---|---|---|
| **I–435 EB at State Line Road** | Light snow/ snow and wind gusts; incident; work zone | Wet, frosty roads | Ice, snow, light wind | Afternoon light snow and some haze; evening snow | Morning fog; fair in the afternoon | | |
| **I–435 NB at East Stadium Drive** | Light snow/ snow and wind gusts; incident | Wet, frosty roads | Ice, snow, light wind | Afternoon light snow and some haze; evening snow | Morning fog; fair in the afternoon | | |
| **I–435 EB at East Antioch Road** | | | | | | Freezing rain/light snow/ wintry mixture and windy | Snow, wet roads |

I–435 = Interstate 435. EB = eastbound. NB = northbound.

### *Forecast Speed Error Analyses*

Forecast data were gathered in the same manner as the historical data using the reports page on the IMRCP web application. To evaluate forecast accuracy, the following forecast lead time values were selected: 15, 30, 60, 90, and 115 min.

Forecast values were generated for 2-h durations into the future, with reference values being each time stamp, which is each quarter of the hour for each hour of all five dates of interest. Curves for each of the forecast lead times were constructed and plotted along with the real-time observations provided by KC Scout.

The 30-min forecast plot shows the forecast values for each time point predicted at a reference time 30 min before each time point. The 90-min forecast plot displays the forecast values the models predicted for each time point when the reference value was 90 min before each time point.

Three formulas were used to calculate and compare the speed forecast errors: (1) absolute error was calculated to determine the difference between the forecast speed and the actual detector speed, (2) relative absolute error was calculated to measure how large the absolute error was compared to the actual speed and provided an indication of the relative size of the error, and (3) root mean square error was calculated to measure the spread (or concentration) between forecasts and actual speeds. For all three measures, lower numbers mean forecast and actual speeds are a better match.

Figure 3 shows the absolute error formula:

$$AE_{i,t,l,} = \left|Forecast_{i,t,l} - Detector_{i,t,l}\right| \times 100 \quad \forall i \in Locations, \forall t \in time\ stamps, l \in lead\ times$$

**Figure 3. Equation. Absolute error formula.**

In the above formula, the index *i* represents each location being explored; *t* is the time stamp, which includes 12 a.m., 12:15 a.m., 12:30 a.m., …., 11:30 p.m., 11:45 p.m., and 12 p.m.; and *l* represents the eight different lead time forecast periods used in the analysis, including 15, 30, 45, 60, 75, 90, 105, and 115 min.

Figure 4 shows the relative absolute error formula:

$$RE_{i,t,l,} = \frac{\left|Forecast_{i,t,l} - Detector_{i,t,l}\right|}{Detector_{i,t,l}} \times 100 \quad \forall i \in Locations, \forall t \in time\ stamps, l \in lead\ times$$

**Figure 4. Equation. Relative absolute error formula.**

In the above formula, the index *i* represents each location being explored; *t* is the time stamp, which includes 12 a.m., 12:15 a.m., 12:30 a.m., …., 11:30 p.m., 11:45 p.m., and 12 p.m.; and *l* represents the eight different lead time forecast periods used in the analysis, including 15, 30, 45, 60, 75, 90, 105, and 115 min.

Figure 5 shows the root mean square error formula:

$$RMSE_{i,t,l,} = \sqrt{\frac{1}{T}\sum_{t}\left(Forecast_{i,t,l} - Detector_{i,t,l}\right)^{2}}$$

$$\forall i \in Locations, \forall t \in time\ stamps, l \in lead\ times$$

**Figure 5. Equation. Root mean square error formula.**

In the above formula, the index *i* represents each location being explored; *t* is the time stamp, which includes 12 a.m., 12:15 a.m., 12:30 a.m., …., 11:30 p.m., 11:45 p.m., and 12 p.m.; and *l* represents the eight different lead time forecast periods used in the analysis, including 15, 30, 45, 60, 75, 90, 105, and 115 min.

When observed detector values were not available to compare at a time stamp, an approximated observed detector value was linearly interpolated given data points surrounding the missing value.

## Usefulness Study

The usefulness study investigated KC Scout staff perceptions, attitudes, and behaviors. The evaluation team gathered inputs from four KC Scout operators and supervisors who periodically used the IMRCP system over the last two winter seasons (winter 2018–2019 and winter 2019–2020). The team held phone interviews in June 2019 and followed up with a written questionnaire in February 2020. The team also held periodic phone calls throughout the winter seasons with a KC Scout representative to check-in about status and usage of IMRCP within the KC Scout TMC and Missouri Department of Transportation's maintenance/winter weather response group.

The goals of the interviews and discussions with the operators and supervisors were to learn about the users' experiences and perceptions relating to:

- Usage of IMRCP prior to, during, and after weather events.
- Accuracy of IMRCP information and forecasts.
- Integration of IMRCP into processes.
- Perspectives of IMRCP, overall (i.e., benefits, limitations, and lessons learned).

# CHAPTER 3. RESULTS

This chapter presents the analyses for the Integrated Modeling for Road Condition Prediction (IMRCP) speeds and speed forecast predictions and user satisfaction interviews.

## OPERATIONAL IMPACTS STUDY

The IMRCP analyses examined IMRCP-predicted speeds versus historical Kansas City Scout (KC Scout) detector speeds, IMRCP speed forecasts, and IMRCP speed forecast errors. Real-time speeds and speed predictions were examined for Traffic Estimation and Prediction System (TrEPS) and machine learning-based prediction (MLP) for seven 2019–2020 weather event days.

Appendix A displays tables that contain the absolute, relative absolute, and root mean square errors by date and location for the speed forecasts.

Table 3 describes the weather event dates and weather conditions. The data were collected through the IMRCP tool's reports page. Historical data were collected from the IMRCP tool for each of the seven days from midnight to midnight. The historical data consist of observed real-time values from the detectors and real-time predictions from the model sources.

**Table 3. Description of weather events.**

| Date | Weather and Road Condition |
|---|---|
| 11/11/2019 | Light snow/snow and wind gusts |
| 11/29/2019 | Wet, frosty roads; upstream incident (at State Line Road) |
| 12/15/2019 | Ice, snow, and light wind; downstream incident (at Stadium Drive) |
| 12/16/2019 | Afternoon light snow and some haze; evening snow |
| 12/17/2019 | Morning fog; fair in the afternoon; temperatures in mid- to upper-20s; light winds |
| 1/29/2020 | Freezing rain/light snow/wintry mixture |
| 2/12/2020 | Snow with wet roads |

The following observation types were selected for exploration in this evaluation: SPDLNK (average speed of vehicles on each link), VIS (surface visibility), TPVT (pavement temperature), and PCCAT (precipitation category). Sources for these observations vary. SPDLNK has three sources: KC Scout, TrEPS, and MLP. KC Scout provides real-time data from the detectors, while TrEPS and MLP provide both real-time and forecast data predicted using different model algorithms. The two sources for VIS are Real-Time Mesoscale Analysis (RTMA) and Rapid Refresh (RAP). According to the IMRCP system user guide, RTMA supplies VIS observations collected in 3 x 3-kilometer (km) grids, whereas RAP provides VIS forecast values collected in 13 x 13-km grids. TPVT estimations are supplied by the Model of the Environment and Temperature of Roads (METRo), and PCCAT observations are provided by RAP. The different categories for PCCAT are listed in Appendix D of the IMRCP system user guide.

## Interstate 435 Eastbound at State Line Road

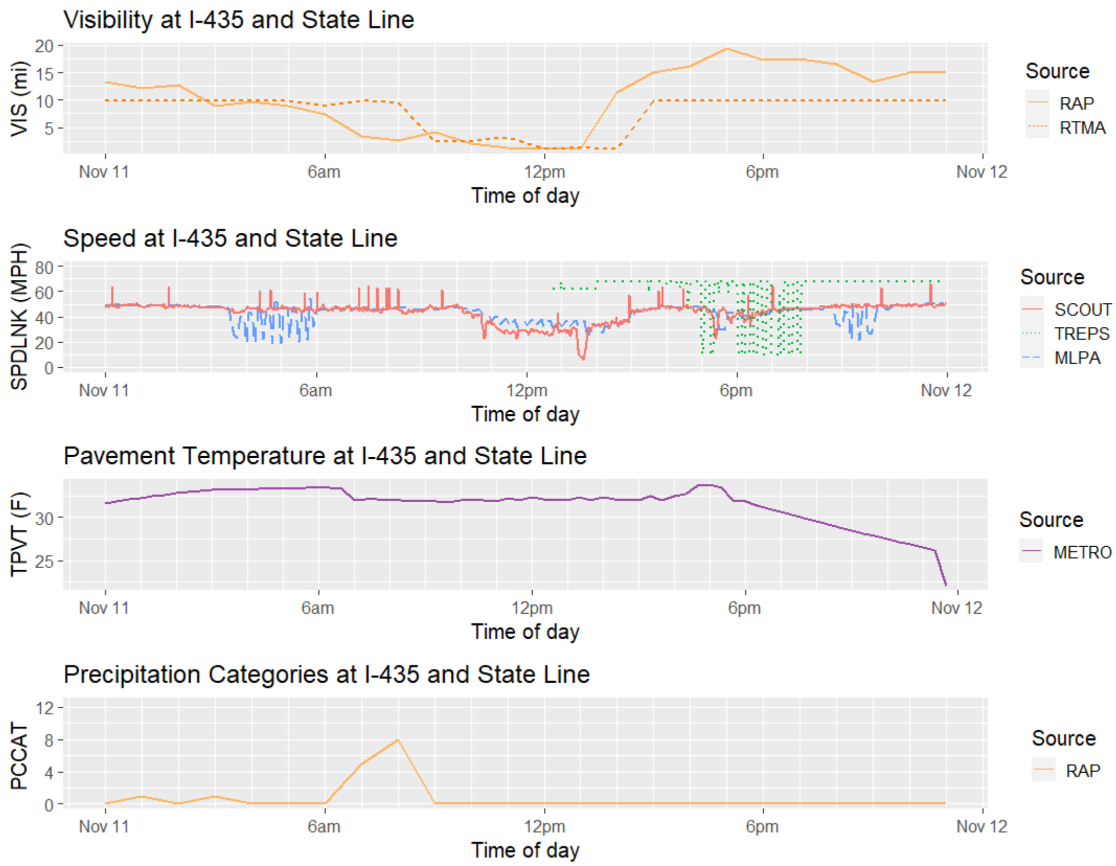
### *November 11, 2019, Weather and Road Conditions*

The following plots display the historical data for real-time speeds obtained for Interstate 435 (I–435) and State Line Road during November 11, 2019. The temperature was in the low 30s and dropped throughout the day to about 12 degrees Fahrenheit (°F) by midnight, with periods of icing rain, light snow, and wind gusts up to 45 miles per hour (mph) from 4 a.m. to 1 p.m. The road conditions were icy with melting snow until about 2 p.m. and were dry afterwards. The road also had an upstream incident that occurred from 6:46 to 7:11 a.m., and the movement of eastbound (EB) traffic was affected by a construction work zone on I–435 at State Line Road. The construction in the area resulted in a lane shift and a reduced speed limit, which also affected traffic speeds.

### *November 11, 2019, Speed Predictions*

The plots in figure 6 depict, from top to bottom, VIS, SPDLNK, TPVT, and PCCAT on November 11, 2019. The *x*-axes in each plot represent the time of day from early morning to midnight. The four plots present a snapshot of the speeds and weather conditions for the day.

- Visibility was reduced between 7 a.m. and 1 p.m., according to the RAP and RTMA sources.
- The speed plot shows the reported speeds from KC Scout roadway detectors, TrEPS, and MLP and the fluctuation and deviations during the day.
- TrEPS speeds were unavailable until early afternoon and then reported fluctuating speeds from 5 to 8 p.m. Sometimes, the speeds were 10–15 mph above/below the speed detector data.
- MLP speeds experienced similar speed fluctuations during two periods: 3:30–6 a.m. and 8:45–10 p.m. Otherwise, the MLP speed predictions appeared to be within about 5 mph of the detector data.



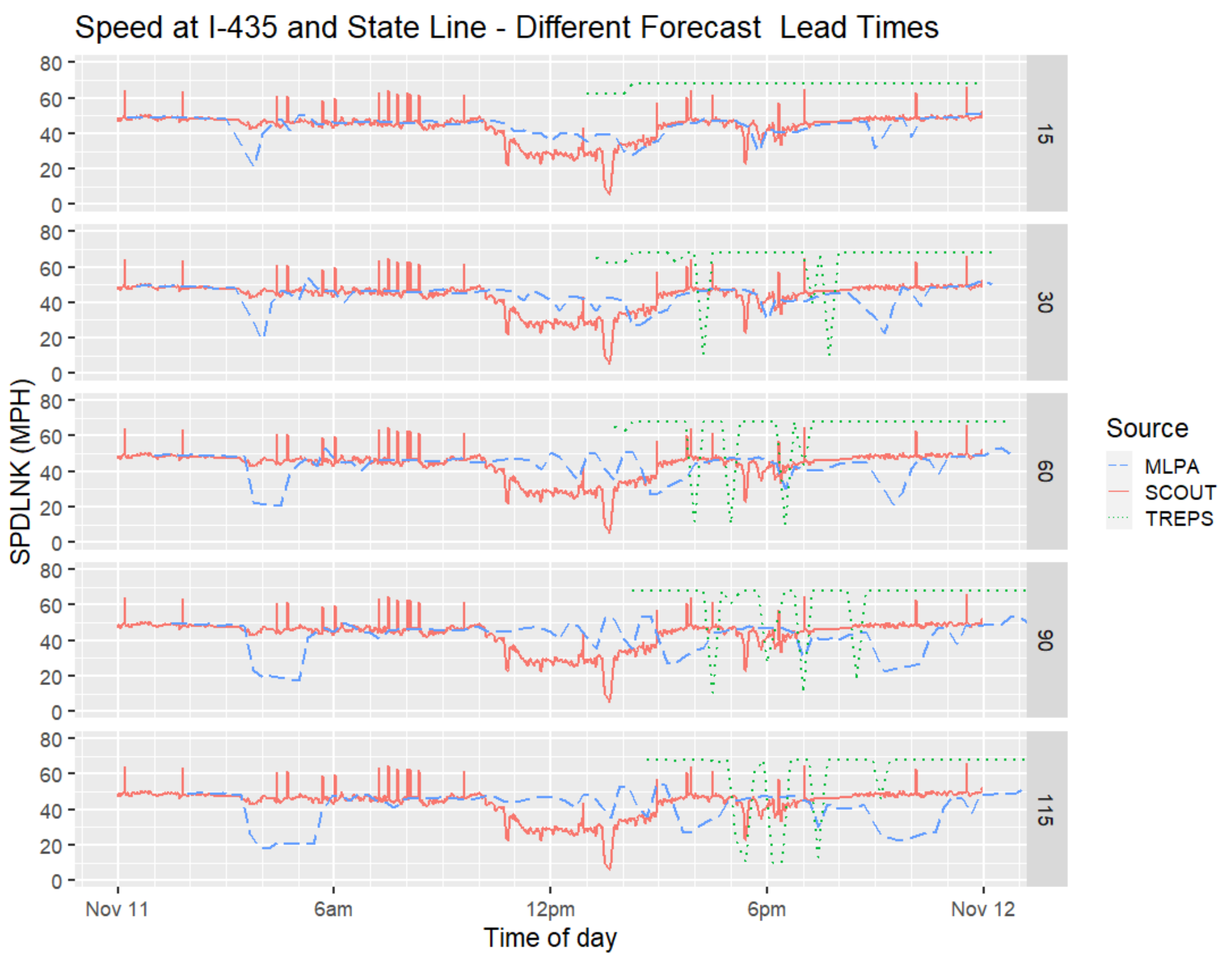

a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. TREPS = Traffic Estimation and Prediction System. VIS = visibility of surface.
Source: Federal Highway Administration

**Figure 6. Plot. Interstate 435 and State Line Road historical speeds, November 11, 2019.**

***November 11, 2019, Speed Forecasts***

The plots in figure 7 display the speed forecasts obtained for I–435 and State Line Road during November 11, 2019. The plots depict, from top to bottom, the real-time prediction (historical speeds) followed by 15-, 30-, 60-, 90-, and 115-minute (min) forecasts. The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations above and below the detector speeds. The deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 7. Plot. Interstate 435 and State Line Road forecast speeds, November 11, 2019.**

### *November 29, 2019, Weather and Road Conditions*

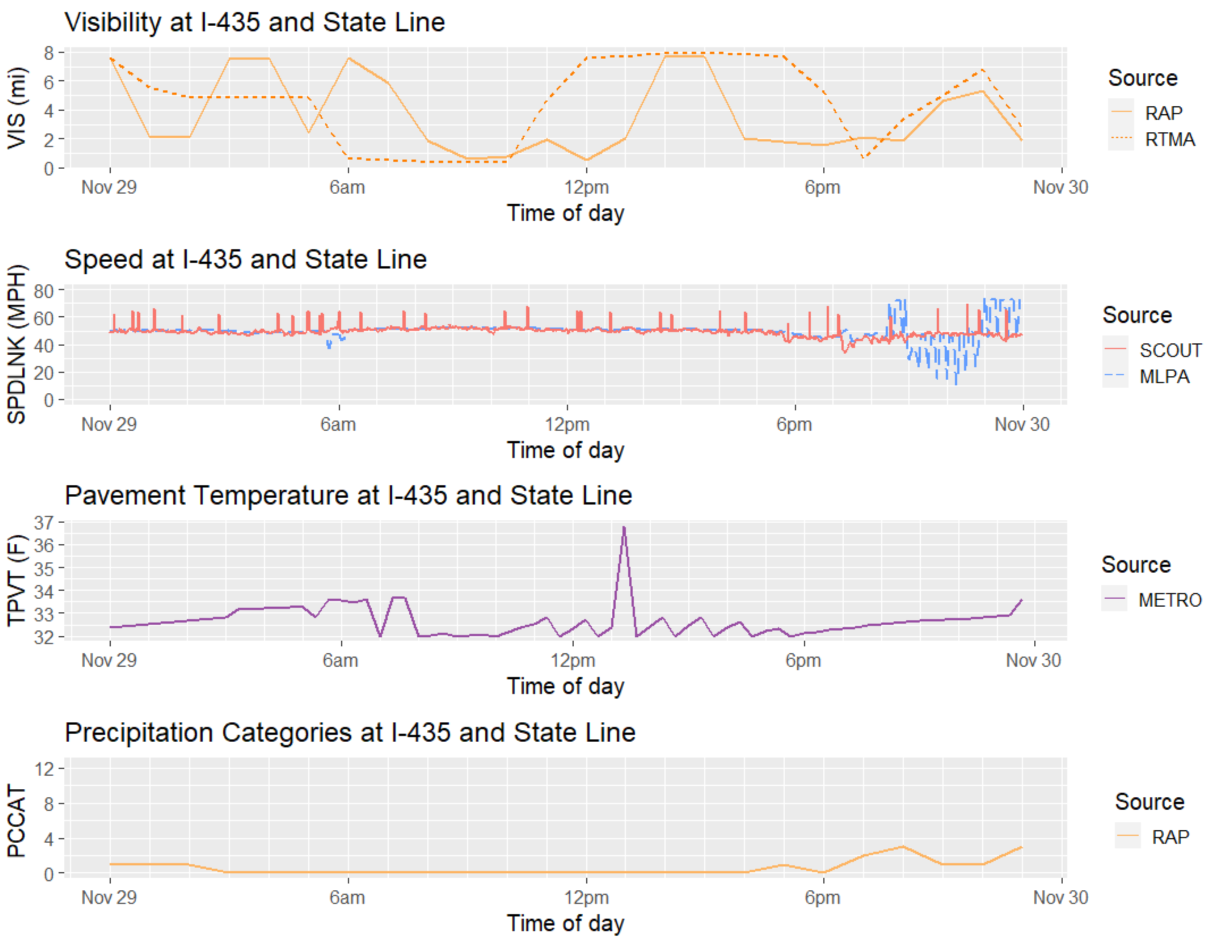
On November 29, 2019, the weather temperature was in the mid 30s, with dew and frost warnings and wind gusts up to 15 mph throughout the day and night. The road conditions were wet and frosty in the morning and wet during the evening. The road also had an upstream incident that occurred from 9:52 a.m. to 12:02 p.m., and the movement of EB traffic was affected by a construction work zone on I–435 at State Line Road. The construction in the area resulted in a lane shift and a reduced speed limit, which also affected traffic speeds.

### *November 29, 2019, Speed Predictions*

The plots in figure 8 display the historical data obtained for I–435 EB and State Line Road during November 29, 2019. On this particular day, only KC Scout detectors and MLP were reporting speeds.

The plots show:

- There was a dip in visibility in the morning and evening, according to RAP and RTMA sources.
- The data for the TrEPS model were not available on this date.
- In general, the speed predictions by MLP are very similar to the detector speeds, even on an atypical Friday with a weather event.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface.
Source: Federal Highway Administration

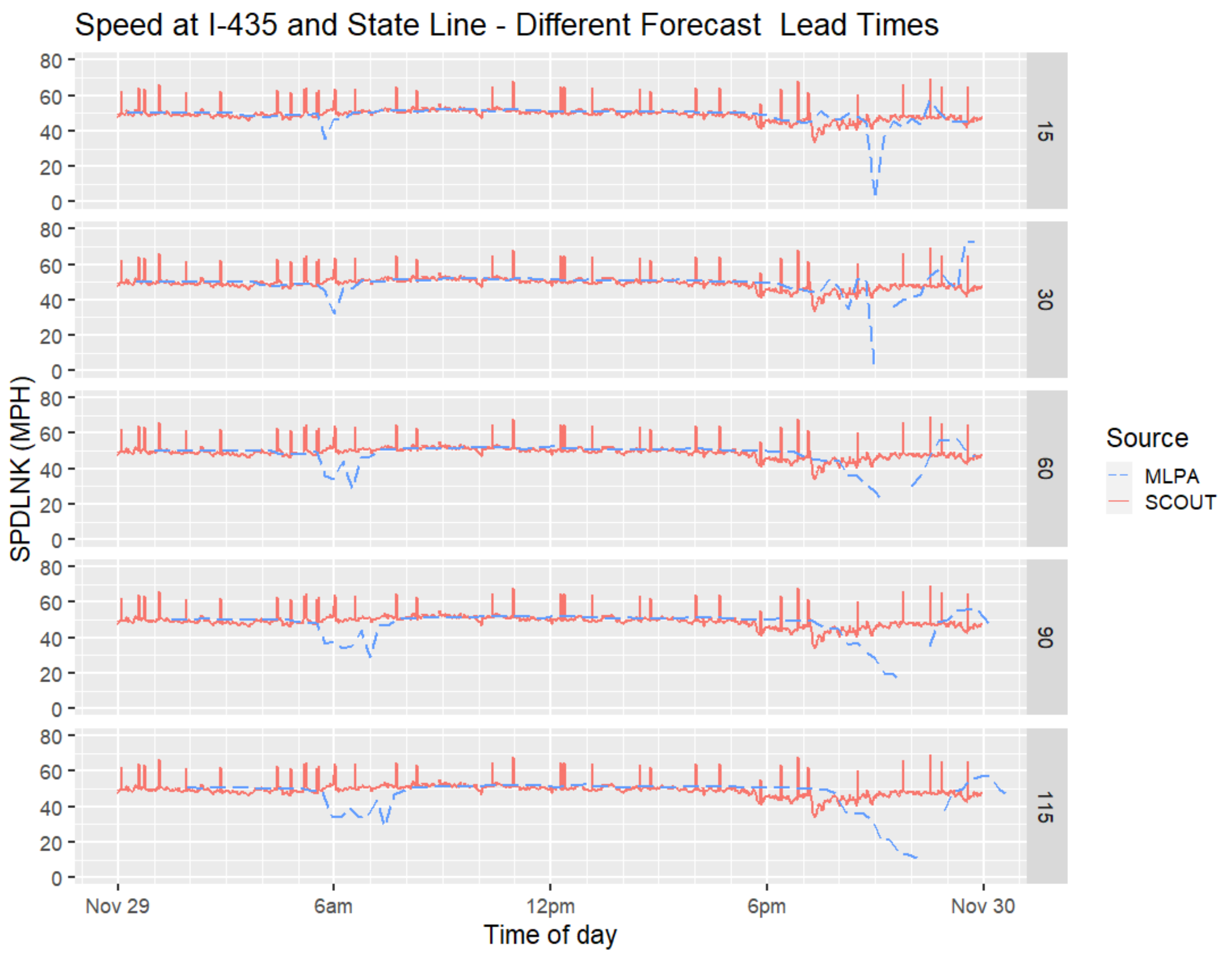
**Figure 8. Plot. Interstate 435 and State Line Road historical speeds, November 29, 2019.**

***November 29, 2019, Speed Forecasts***

The plots in figure 9 display the forecast speeds obtained for I–435 and State Line Road during November 29, 2019.

The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- MLP speed forecasts showed periods where the forecasts appeared to have large deviations above and below the detector speeds. The deviations appeared to grow larger with longer forecasts.
- TrEPS forecasts were not available for this date.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.
Source: Federal Highway Administration

**Figure 9. Plot. Interstate 435 and State Line Road forecast speeds, November 29, 2019.**

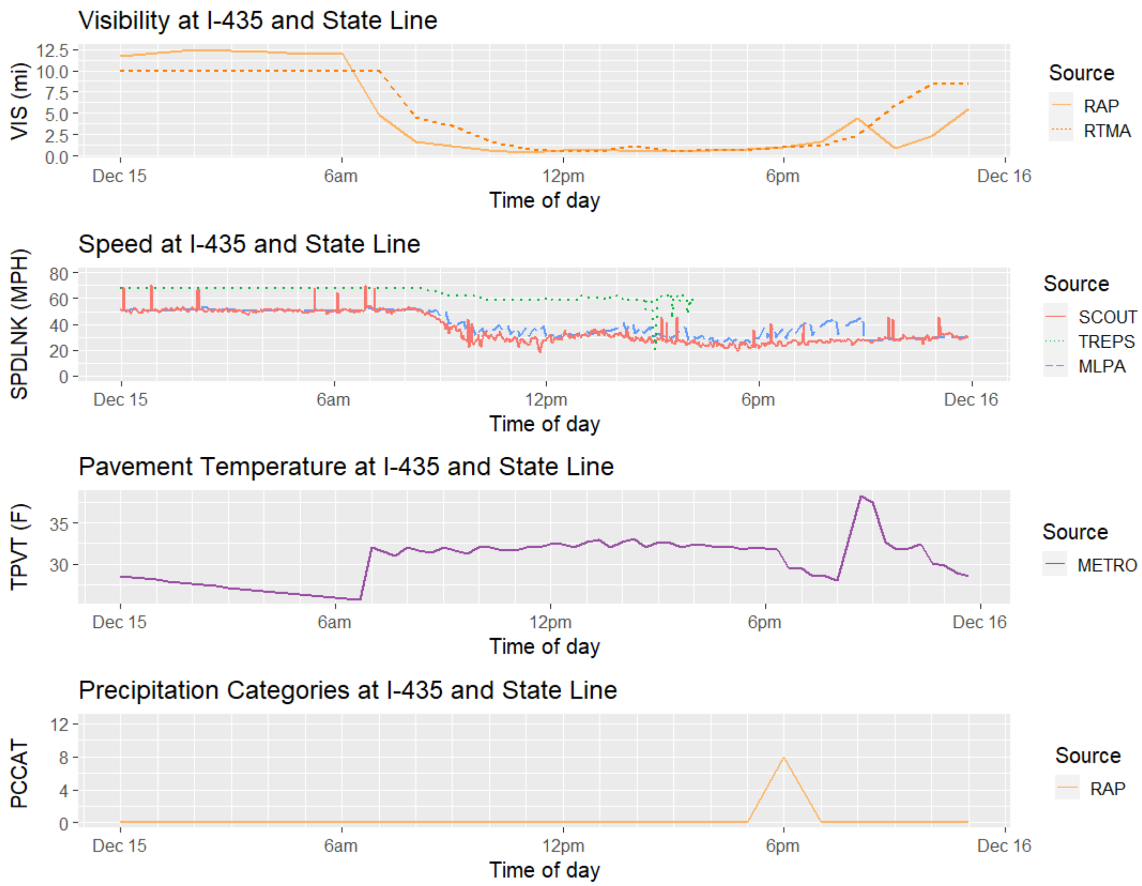
### *December 15, 2019, Weather and Road Conditions*

On December 15, 2019, the weather temperature was in the mid 20s with a light wind (less than 10 mph) in the morning. The road conditions were dry in the early morning but snowy by 9 a.m., slushy at noon, and icy and snowy during the evening commute. The movement of EB traffic was affected by a construction work zone on I–435 at State Line Road. The construction in the area resulted in a lane shift and a reduced speed limit, which also affected traffic speeds.

### *December 15, 2019, Speed Predictions*

The plots in figure 10 display the historical data obtained for I–435 and State Line Road during December 15, 2019. The plots show:

- Visibility was reduced between 7 a.m. and 7 p.m.
- TrEPS speeds were higher than reported by the detectors for most of the day and were unavailable after 1 p.m. on this date.
- Speed predictions by MLP were fairly accurate during the slow down between 9 a.m. and noon.
- There was an increase in MLP predicted speeds at 6 p.m. The predictions between 6 and 9 p.m. were higher than the recorded detector speed data during this time.



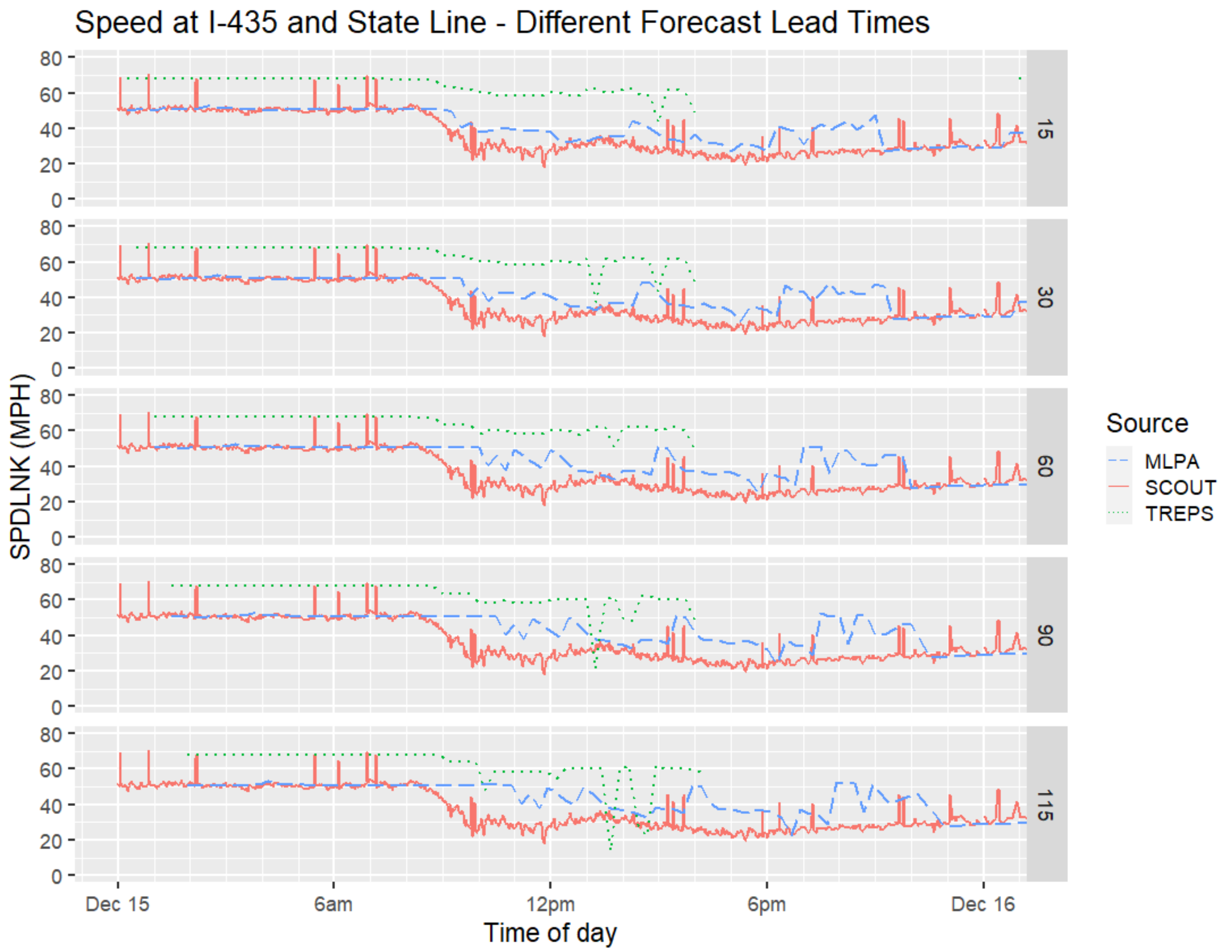

a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 10. Plot. Interstate 435 and State Line Road historical speeds, December 15, 2019.**

***December 15, 2019, Speed Forecasts***

The plots in figure 11 display the forecast speeds obtained for I–435 and State Line Road during December 15, 2019. The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were consistently higher than the detector speeds.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations above and below the detector speeds. The deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 11. Plot. Interstate 435 and State Line Road forecast speeds, December 15, 2019.**

### *December 16, 2019, Weather and Road Conditions*

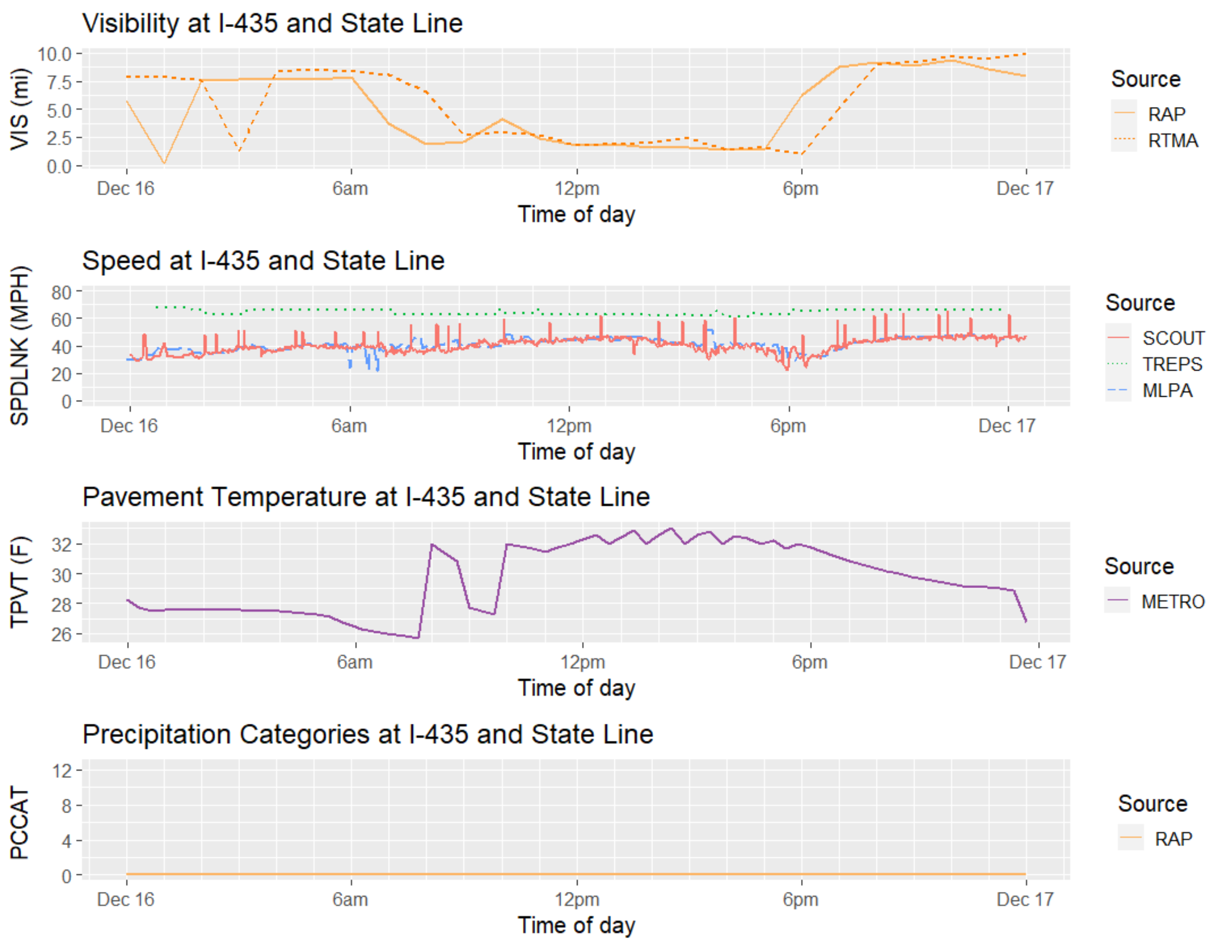
On December 16, 2019, the weather temperature was in the low 30s with no precipitation and a light wind (less than 10 mph) in the morning. There was light snow and some haze during the afternoon, and it was snowy during the evening. The road conditions were dry until noon, but had melting snow and some haze during the afternoon and ice and snow during the evening commute. The movement of EB traffic was affected by a construction work zone on I–435 at State Line Road. The construction in the area resulted in a lane shift and a reduced speed limit which, also affected traffic speeds.

### *December 16, 2019, Speed Predictions*

The plots in figure 12 display the historical data obtained for I–435 and State Line Road during December 16, 2019.

The plots show:

- There was a reduction in visibility starting in the morning, which remained low until about 6 p.m. according to RAP and RTMA sources.
- TrEPS speeds were higher than the detector throughout the day.
- MLP speeds tracked the detector speeds fairly closely for most of the day.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

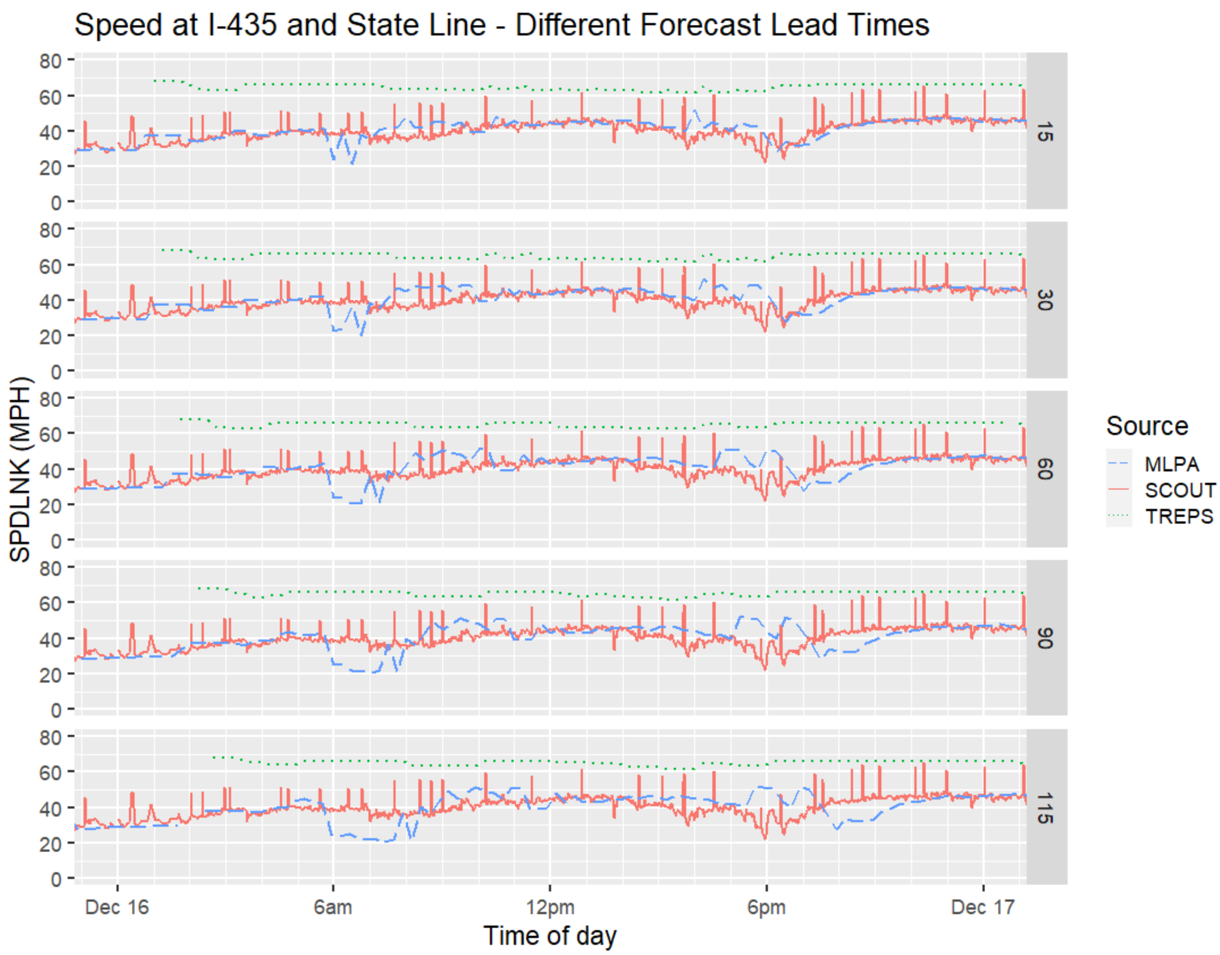
**Figure 12. Plot. Interstate 435 and State Line Road historical speeds, December 16, 2019.**

***December 16, 2019, Speed Forecasts***

The plots in figure 13 display the forecast speeds obtained for I–435 and State Line Road during December 16, 2019.

The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were consistently higher than the detector speeds.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 13. Plot. Interstate 435 and State Line Road forecast speeds, December 16, 2019.**

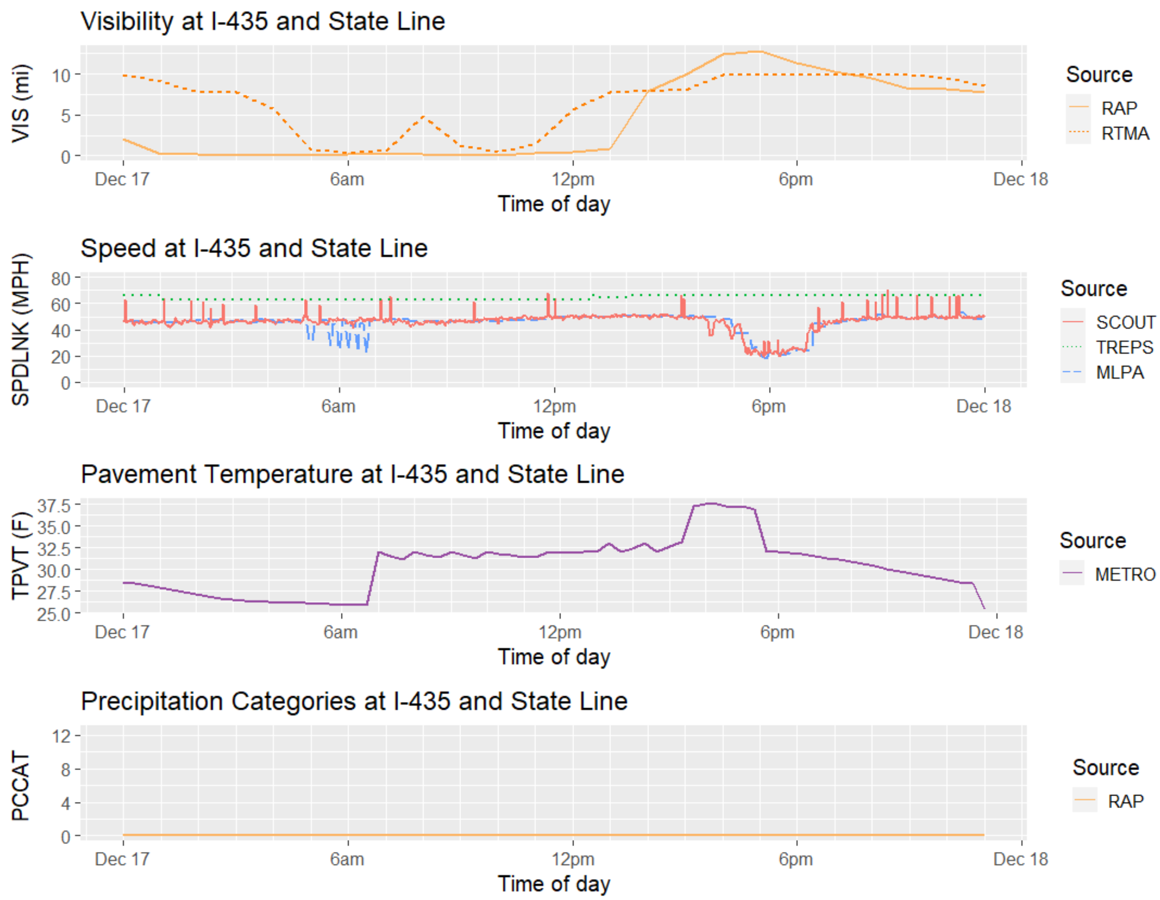
***December 17, 2019, Weather and Road Conditions***

On December 17, 2019, the weather temperature was in the mid- to upper 20s with no precipitation and a light wind (less than 10 mph) throughout the day and night. There was no precipitation during the day. The road conditions were dry during the morning, midday, and evening times. The movement of EB traffic was affected by a construction work zone on I–435 at State Line Road. The construction in the area resulted in a lane shift and a reduced speed limit, which also affected traffic speeds.

***December 17, 2019, Speed Predictions***

The plots in figure 14 display the historical data obtained for I–435 and State Line Road during December 17, 2019. For this day:

- There was a reduction in visibility from early morning to midafternoon, according to RAP and RTMA sources.
- TrEPS model speeds were not very accurate on this day and were consistently higher than the KC Scout detector speeds.
- MLP speeds tracked the detector speeds fairly closely for most of the day. However, between 5 and 7 a.m., there were periods when speeds were considerably lower than the detector speeds. The MLP speeds evening rush hour effect was captured well by the speed predictions from the MLP model.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.

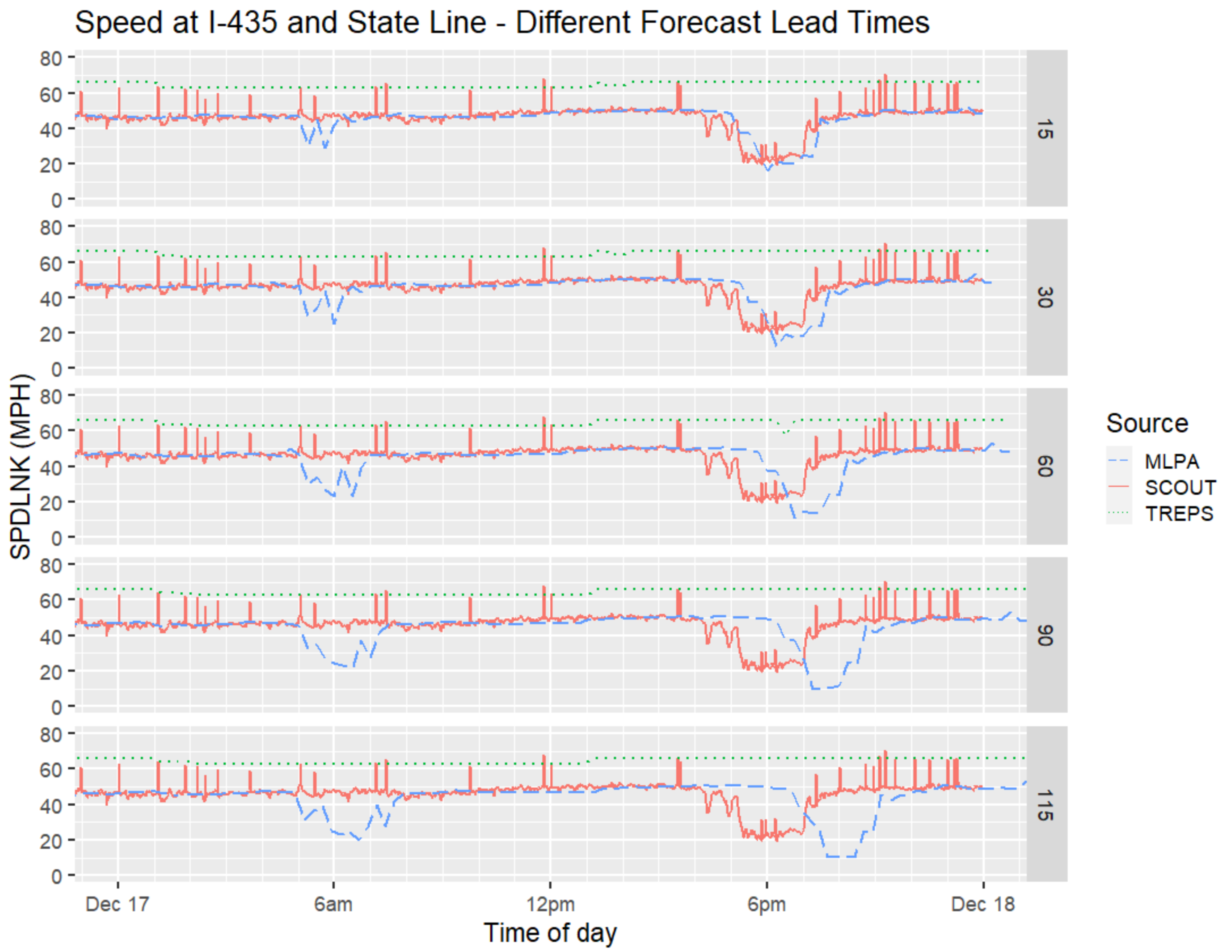
Source: Federal Highway Administration

**Figure 14. Plot. Interstate 435 and State Line Road historical speeds, December 17, 2019.**

### *December 17, 2019, Speed Forecasts*

The plots in figure 15 display the forecast speeds obtained for I–435 and State Line Road during December 17, 2019. The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were consistently higher than the detector speeds and do not reflect the decline in detected speeds from about 5 to 7 p.m.
- MLP speeds decrease similar to the the decline in detected speeds from about 5 to 7 p.m.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

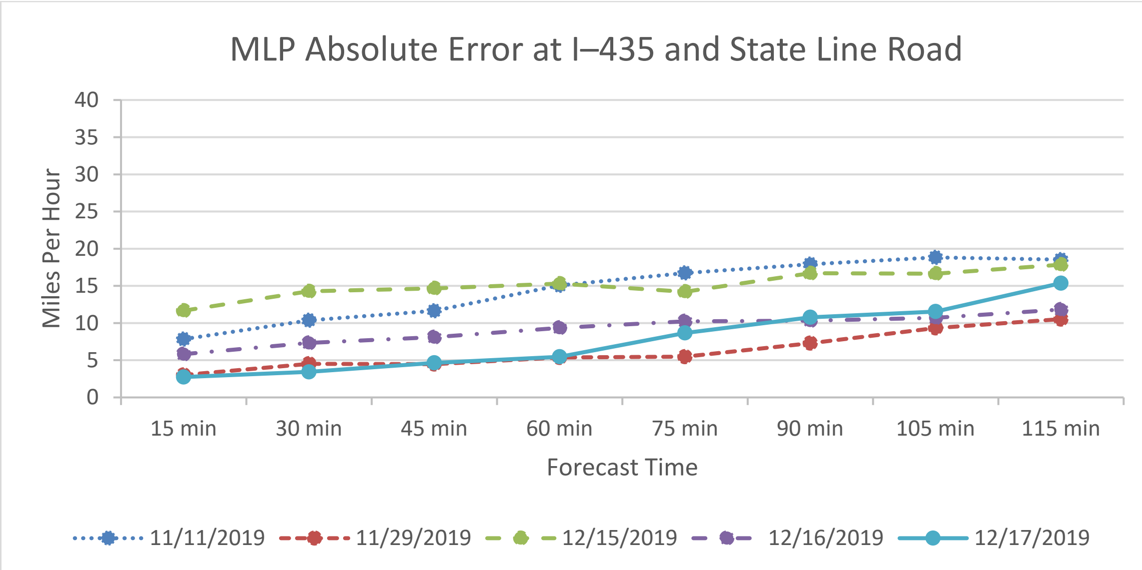
**Figure 15. Plot. Interstate 435 and State Line Road forecast speeds, December 17, 2019.**

### *Speed Forecast Error Analysis for Interstate 435 and State Line Road*

Figure 16 shows the MLP absolute error for the 15–115-min speed forecasts on November 11, 29, December 15, 16, and 17. Figure 17 shows the TrEPS absolute errors for the same forecast time periods. The plots show:

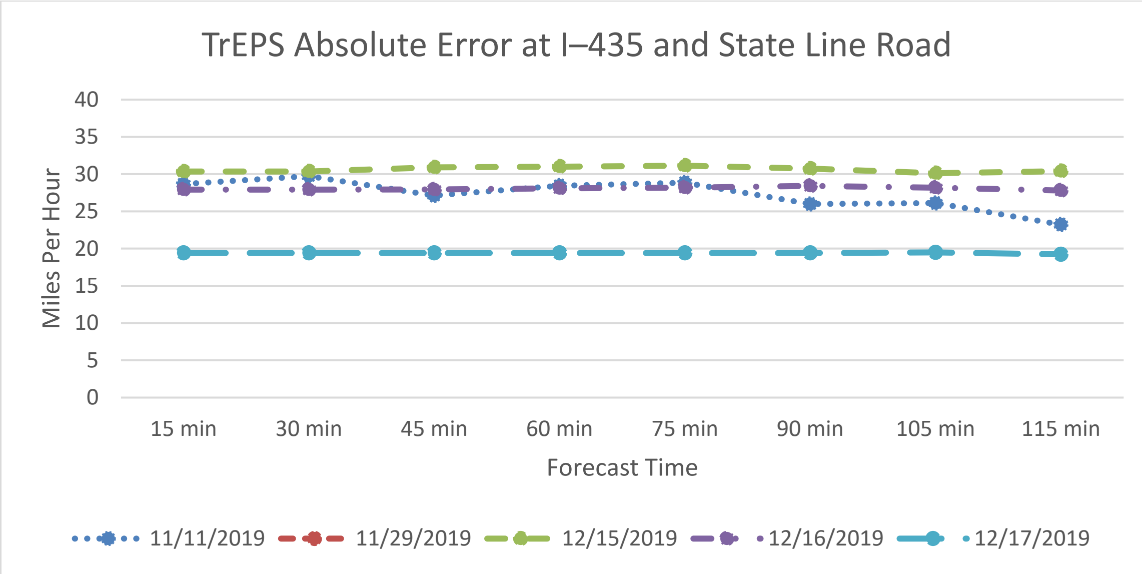
- For MLP, the absolute errors show that shorter-term forecasts tended to have smaller errors than longer-term forecasts. Consequently, the shorter-term forecasts tended to be more accurate. The average absolute error for the 15-min forecast was about 6.2 mph, whereas the 115-min forecast increased to about 14.8 mph.
- For TrEPS, the absolute errors were relatively consistent across all forecast times. The average absolute error was about 26 mph for all forecast times.

- Comparing the MLP to TrEPS absolute errors, the TrEPS errors tended to be larger than the MLP absolute errors. The average TrEPS error across all forecast times was about 26 mph versus about 10.6 mph for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 16. Graph. Machine learning-based prediction absolute error at Interstate 435 and State Line Road.**

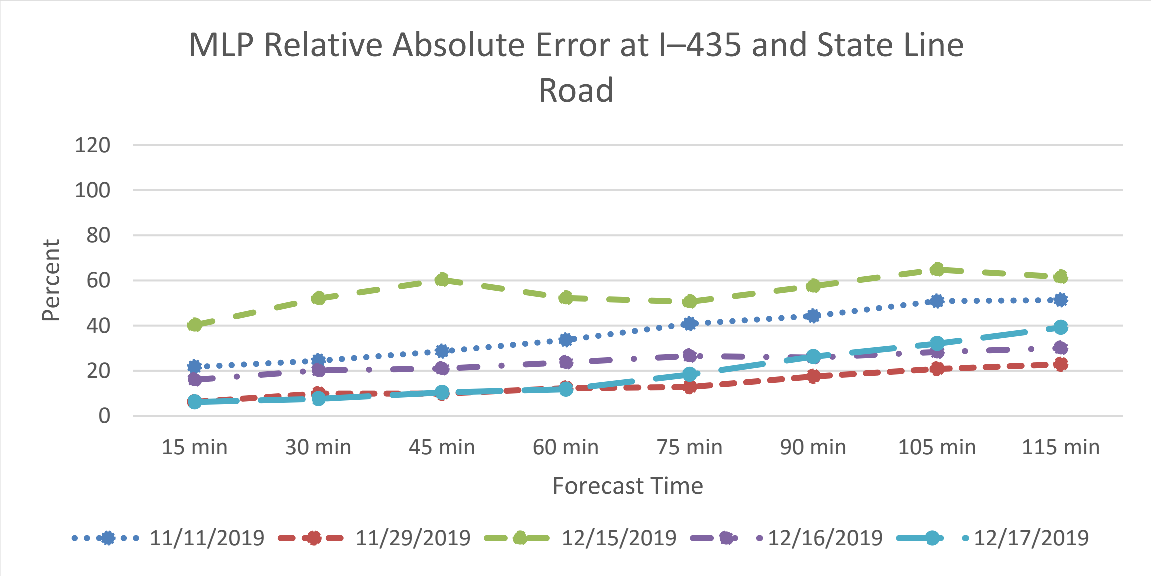



I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 17. Graph. Traffic Estimation and Prediction System absolute error at Interstate 435 and State Line Road.**

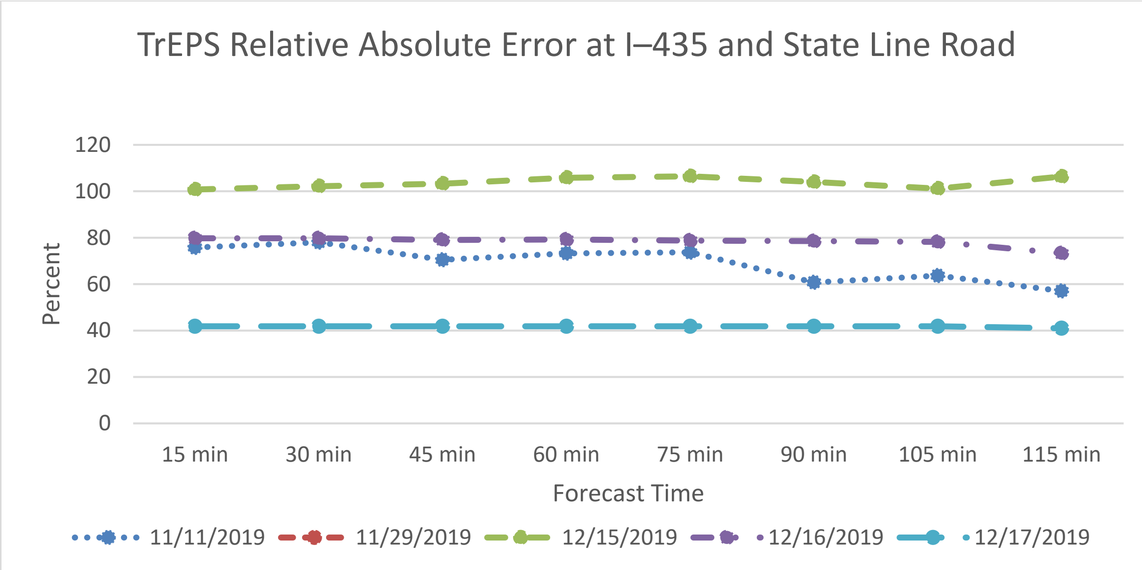
Figure 18 and figure 19 show the relative absolute errors for MLP and TrEPS at I–435 and State Line Road on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts. The relative absolute error measured the magnitude (in percent) of the absolute error as compared to the actual speed. The plots show:

- For MLP, the relative absolute error for shorter-term forecasts tended to be smaller than the errors for longer-term forecasts. In other words, the error as a percentage of the speed was smaller for shorter-term forecasts. The average relative absolute error for the 15-min forecast was about 18 percent, whereas the 115-min forecast increased to about 41 percent.
- For TrEPS, the relative absolute errors were relatively large (ranging from 40 to over 100 percent) and mostly consistent across all forecast times. The average relative absolute error was about 73 percent for all forecast times.
- Comparing the MLP to TrEPS relative absolute errors, the TrEPS errors tended to be larger than the MLP errors. The average TrEPS error across all forecast times was about 73 percent versus about 29 percent for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 18. Graph. Machine learning-based prediction relative absolute Error at Interstate 435 and State Line Road.**

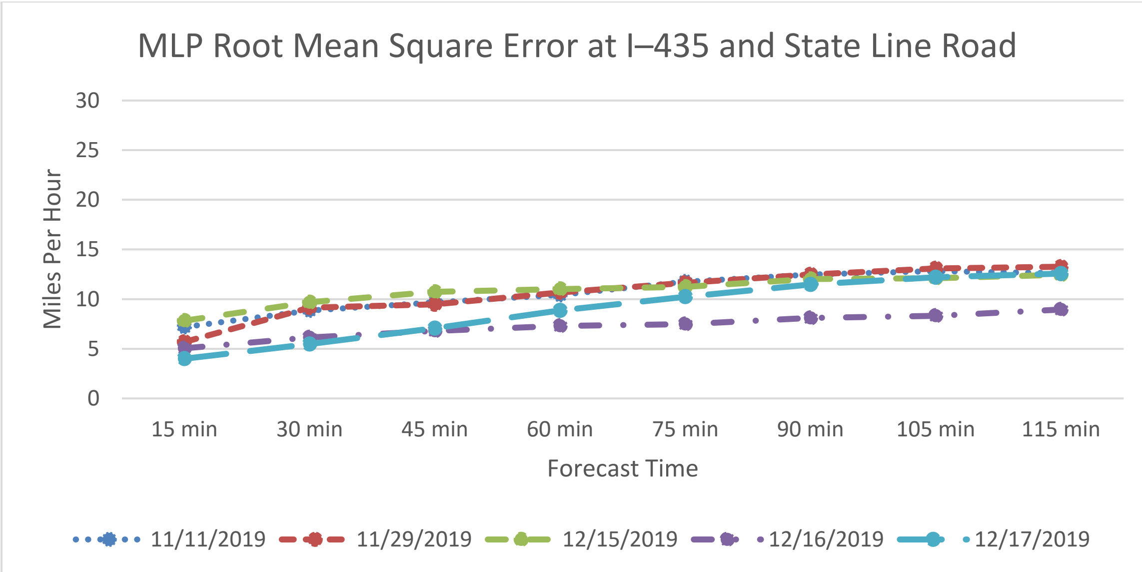



I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 19. Graph. Traffic Estimation and Prediction System relative absolute error at Interstate 435 and State Line Road.**

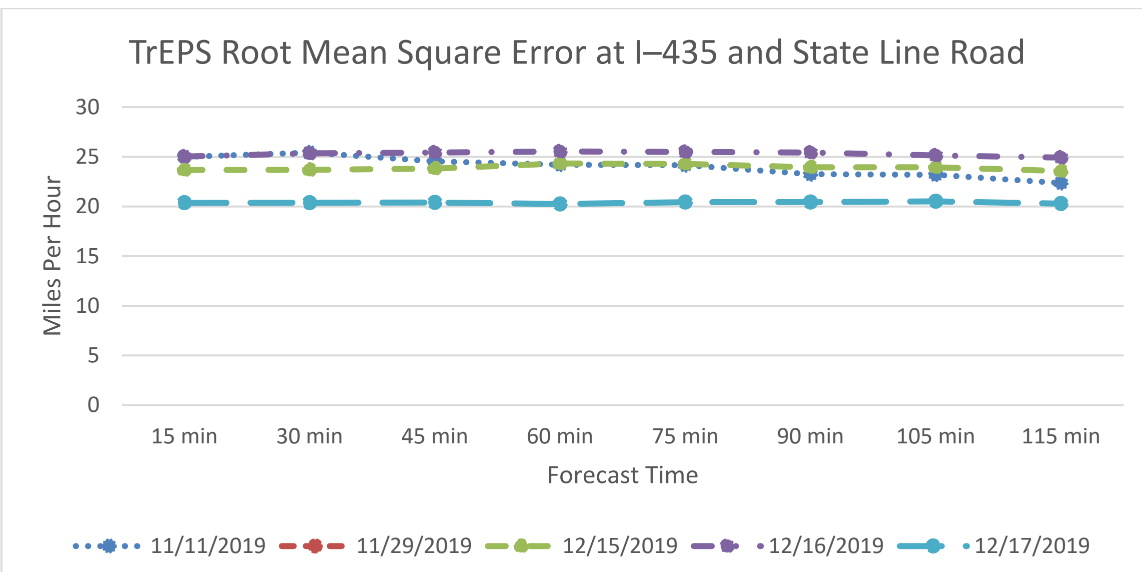
Figure 20 and figure 21 show the root mean square errors for MLP and TrEPS at I–435 and State Line Road on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts. The root mean square errors measure the deviation or spread of the forecast versus actual speeds. The plots show:

- For MLP, the root mean square error showed that the shorter-term forecasts errors tended to be smaller than longer-term forecasts. The average root mean square error for the 15-min forecast was about 6 mph versus about 12 mph for the 115-min forecast.
- For TrEPS, the root mean square errors were relatively consistent across all forecast times. The average root mean square error was about 23 mph for all forecast times.
- Comparing the MLP to TrEPS root mean square errors, the TrEPS errors were about twice as large as MLP. The average TrEPS error across all forecast times was about 23 mph versus about 10 mph for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 20. Graph. Machine learning-based prediction root mean square error at Interstate 435 and State Line Road.**




I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 21. Graph. Traffic Estimation and Prediction System root mean square error at Interstate 435 and State Line Road.**

### Interstate 435 Northbound at East Stadium Drive

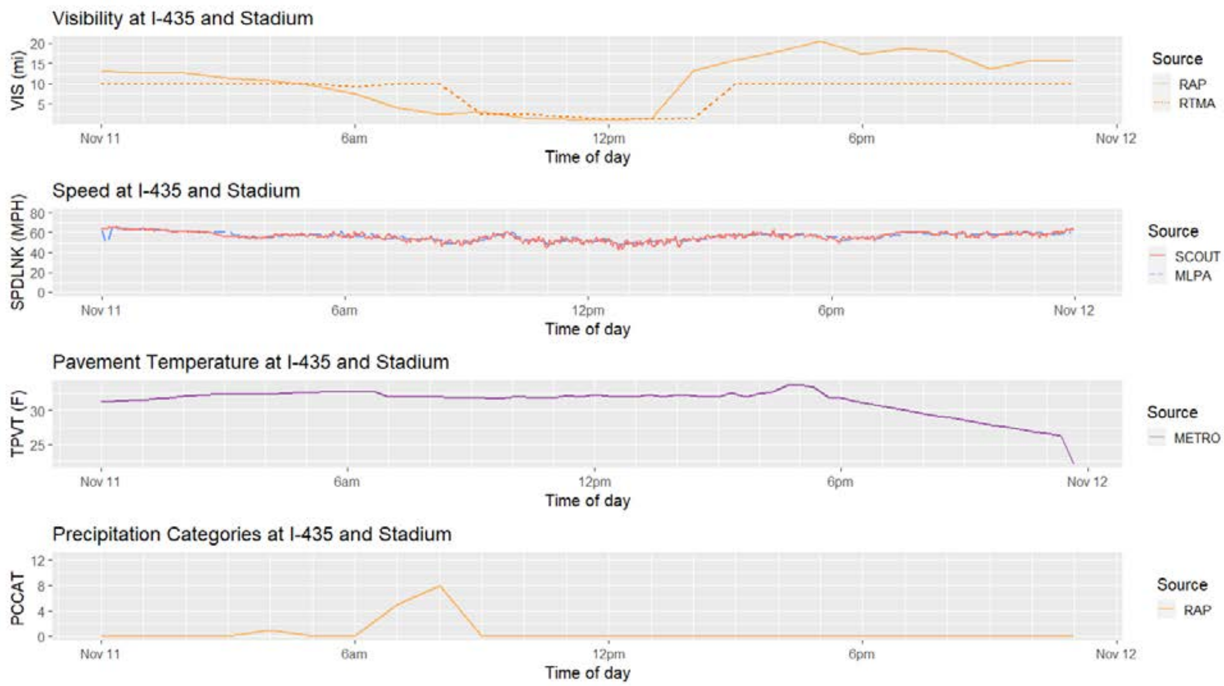
#### *November 11, 2019, Weather and Road Conditions*

On November 11, 2019, the weather temperature was in the low 30s and dropped throughout the day to about 12 °F by midnight, with periods of icing rain, light snow, and wind gusts up to 45 mph from 4 a.m. to 1 p.m. The road conditions had freezing rain during the morning and ice and snow at noon, and were dry in the afternoon and evening.

#### *November 11, 2019, Speed Predictions*

The plots in figure 22 display the historical data obtained for I–435 and East Stadium Drive for the seven days. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network. The plots show:

- There was a dip in visibility in the morning, according to both sources, and an increase in precipitation.
- MLP speed predictions were similar to the detector data throughout the entire day at this location. There was an incident between 7:44 a.m. and 2:09 p.m. on I–435 southbound upstream from the detector.



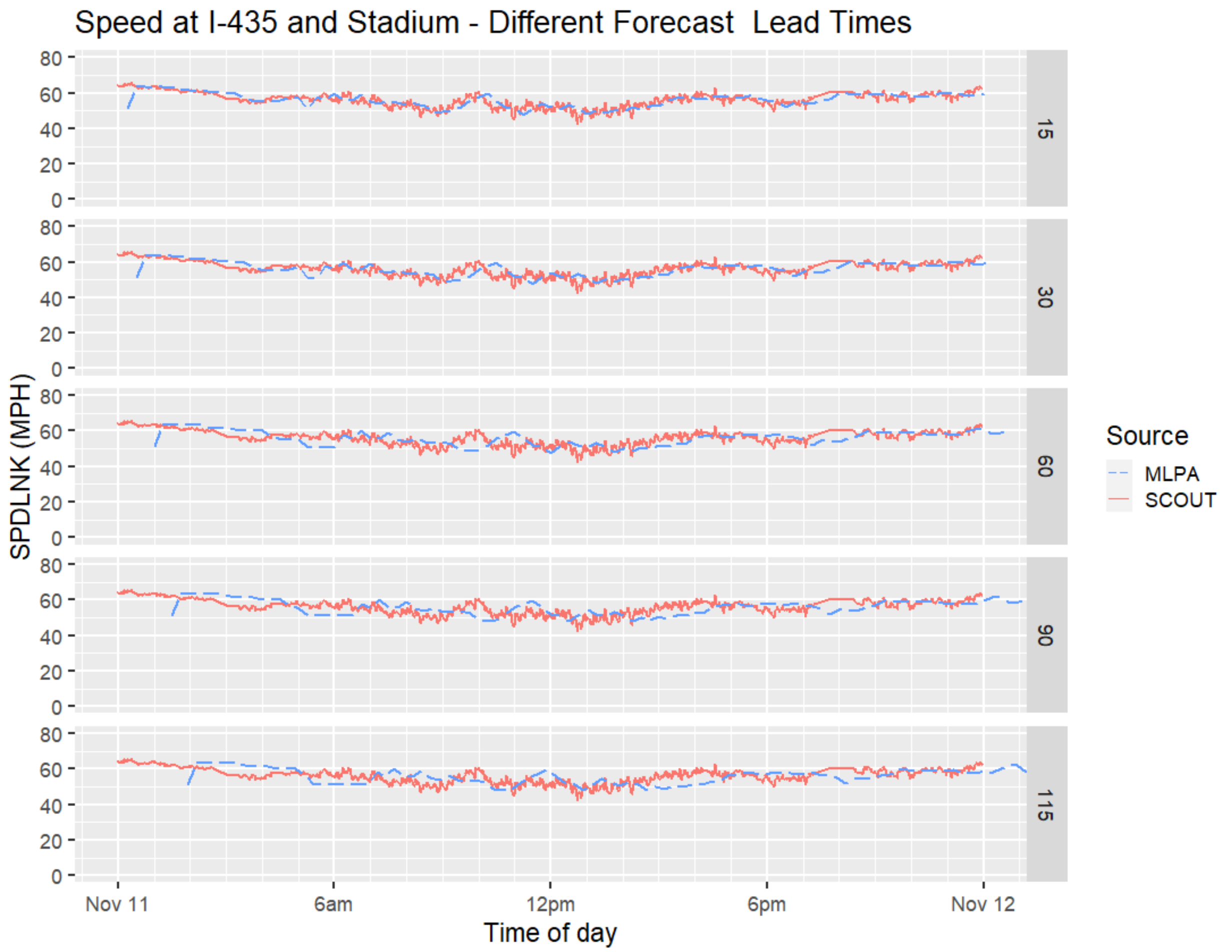

a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 22. Plot. Interstate 435 and East Stadium Drive historical speeds, November 11, 2019.**

### *November 11, 2019, Speed Forecasts*

The plots in figure 23 display the forecast speeds obtained for I–435 and East Stadium Drive during November 11, 2019. In the plots, speed forecasts for only MLP are available because this location is outside the TrEPS network. The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- MLP speed forecasts showed periods where the forecasts appeared to have small deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.

Source: Federal Highway Administration

**Figure 23. Plot. Interstate 435 and East Stadium Drive forecast speeds, November 11, 2019.**

### *November 29, 2019, Weather and Road Conditions*

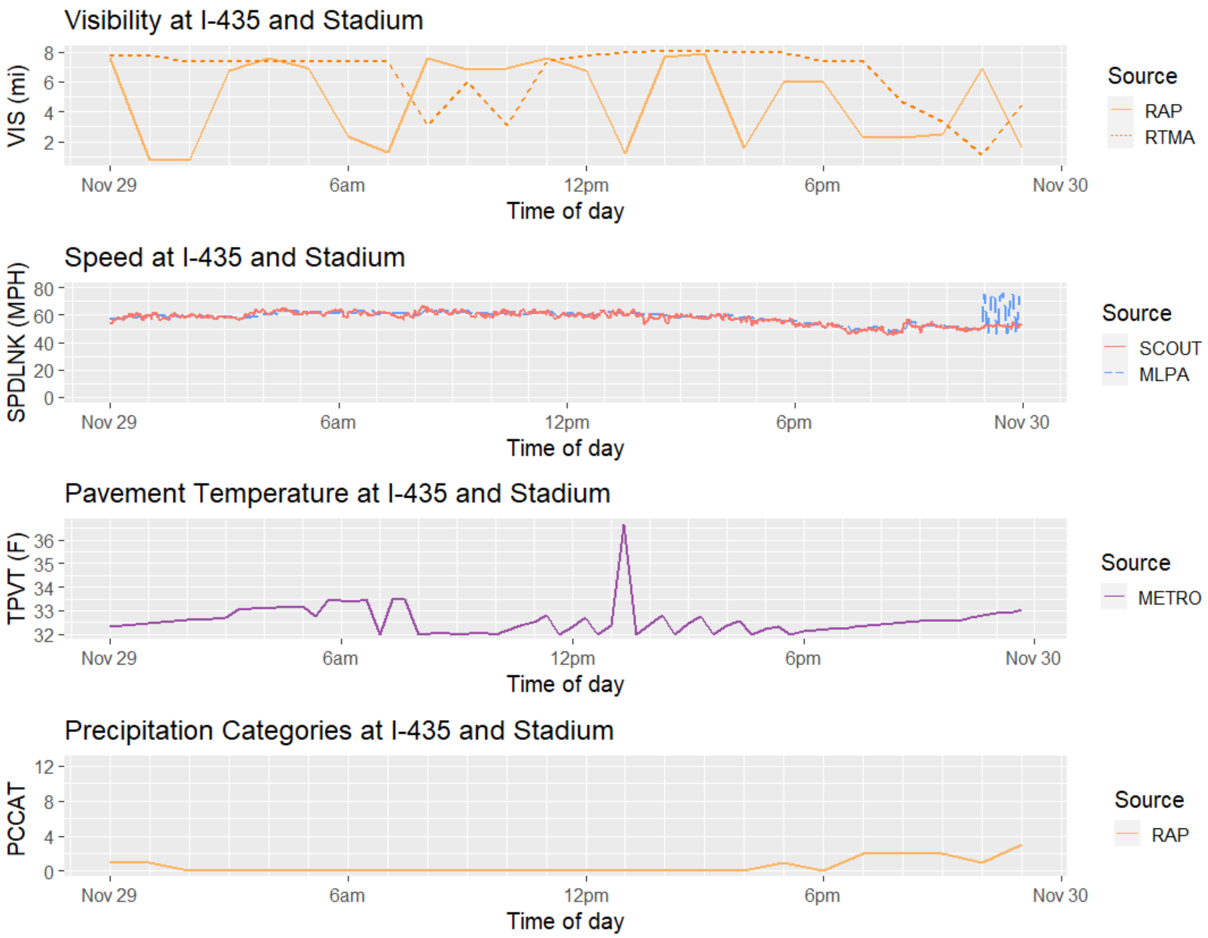
On November 29, 2019, the weather temperature was in the mid 30s, with dew and frost warnings and wind gusts up to 15 mph throughout the day and night. The road conditions were wet and frosty in the morning and wet during the afternoon and evening.

### *November 29, 2019, Speed Predictions*

The plots in figure 24 display the historical data obtained for I–435 and East Stadium Drive during November 29, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network.

The plots show:

- Both RAP and RTMA sources indicate visibility varied considerably throughout the day.
- The rush hour effect was less on this day, possibly due to being the Friday after Thanksgiving.
- Speed predictions by MLP were very similar to the detector speeds, even on an atypical Friday with a weather event and varied visibility at this location.



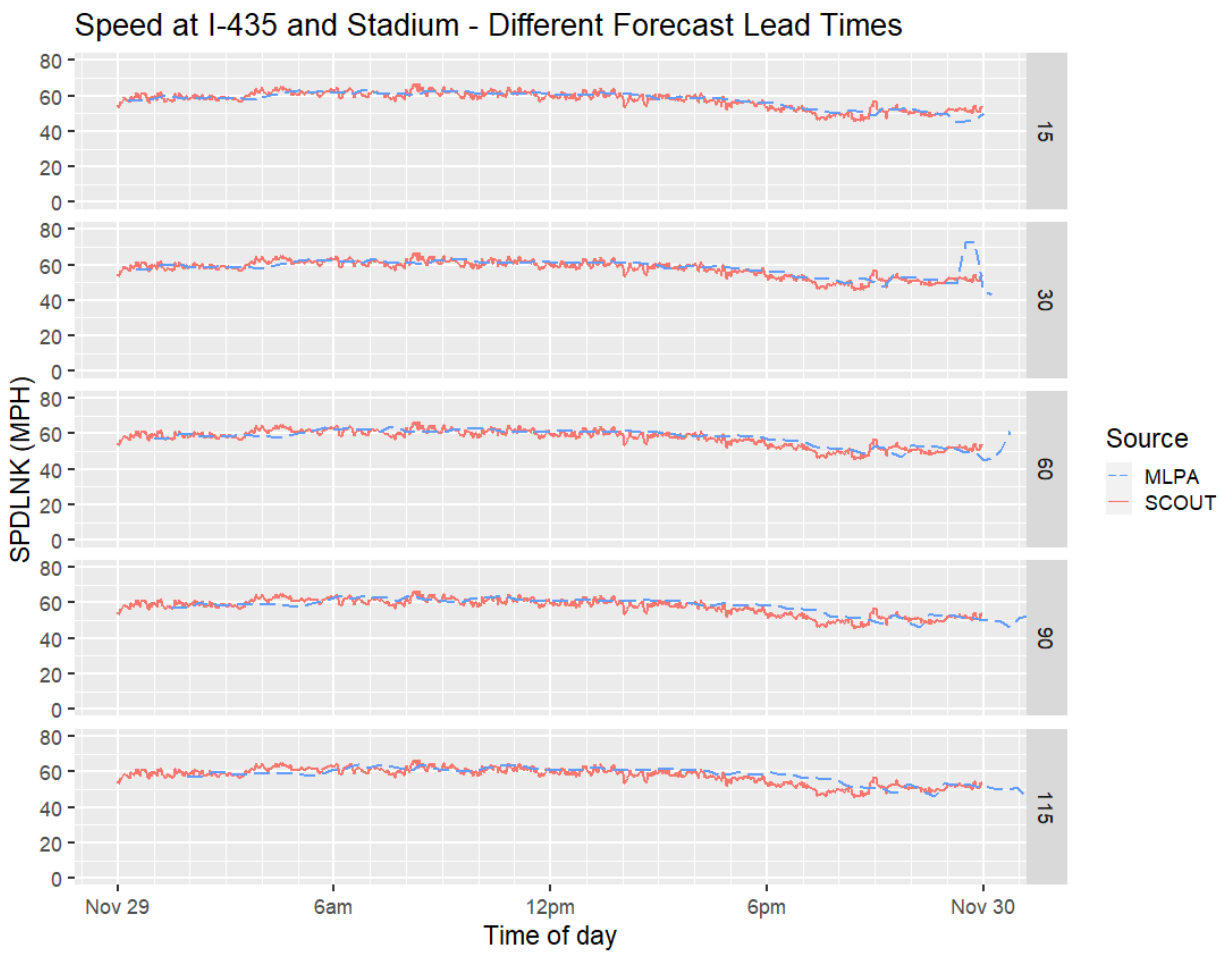

a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 24. Plot. Interstate 435 and East Stadium Drive historical speeds, November 29, 2019.**

***November 29, 2019, Speed Forecasts***

The plots in figure 25 display the forecast speeds obtained for I–435 and East Stadium Drive during November 29, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network. The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- MLP speed forecasts showed periods where the forecasts appeared to have small deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.

Source: Federal Highway Administration

**Figure 25. Plot. Interstate 435 and East Stadium Drive forecast speeds, November 29, 2019.**

### *December 15, 2019, Weather and Road Conditions*

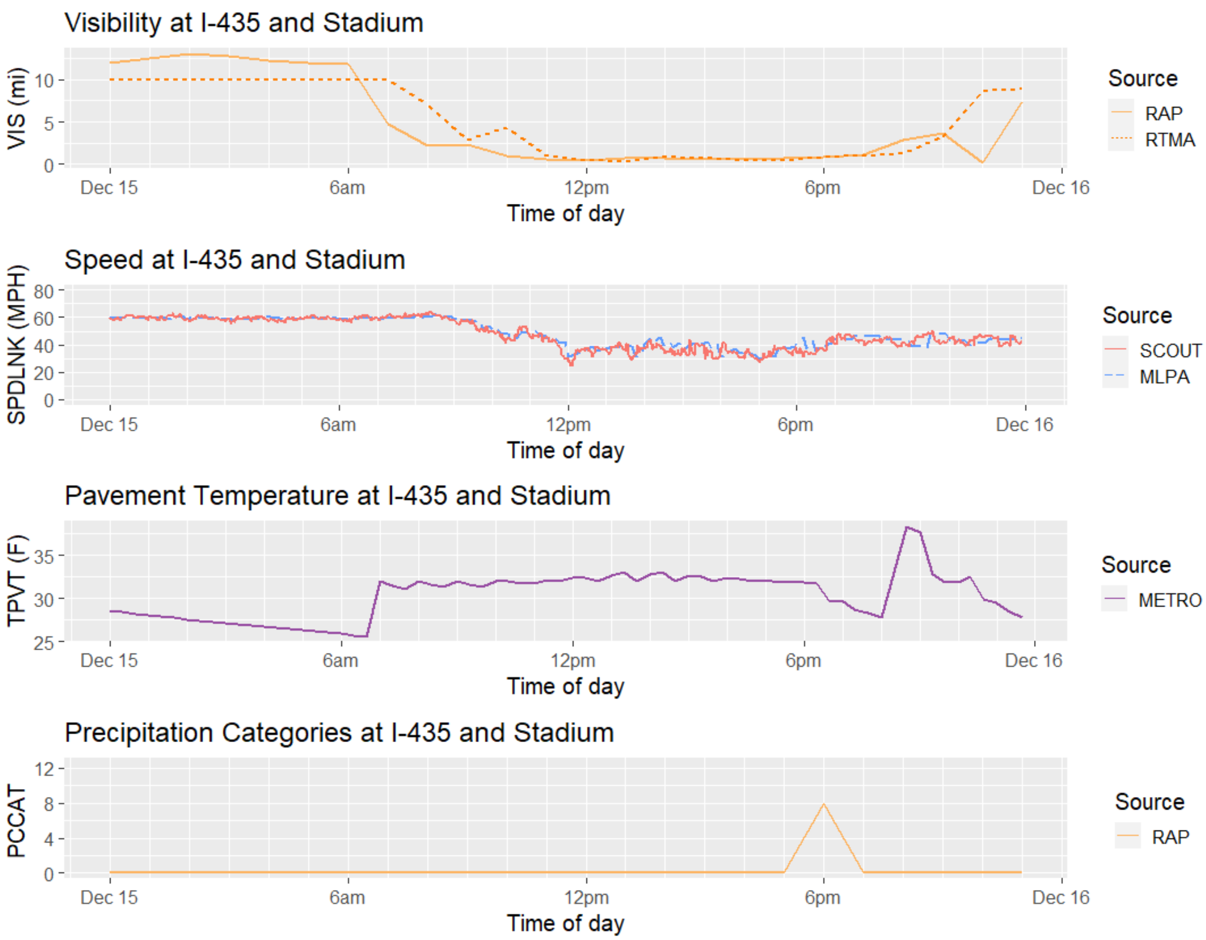
On December 15, 2019, the weather temperature was in the mid-20s with a light wind (less than 10 mph) in the morning. The road conditions were dry in the early morning but snowy by 9 a.m., slushy at noon, and icy and snowy during the evening commute. There was a downstream incident from 10:26 a.m. to 12:51 p.m.

### *December 15, 2019, Speed Predictions*

The plots in figure 26 display the historical data obtained for the first location, I–435 and East Stadium Drive, during December 15, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network.

The plots show:

- Both RAP and RTMA sources indicate that visibility decreased in the morning and remained low until slowly improving in the evening and night.
- Detector speeds recorded a slight decrease in speeds that corresponded to the reduced visibility from the morning and into the night.
- MLP speeds were similar to the detector speeds throughout the entire day at this location.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface.

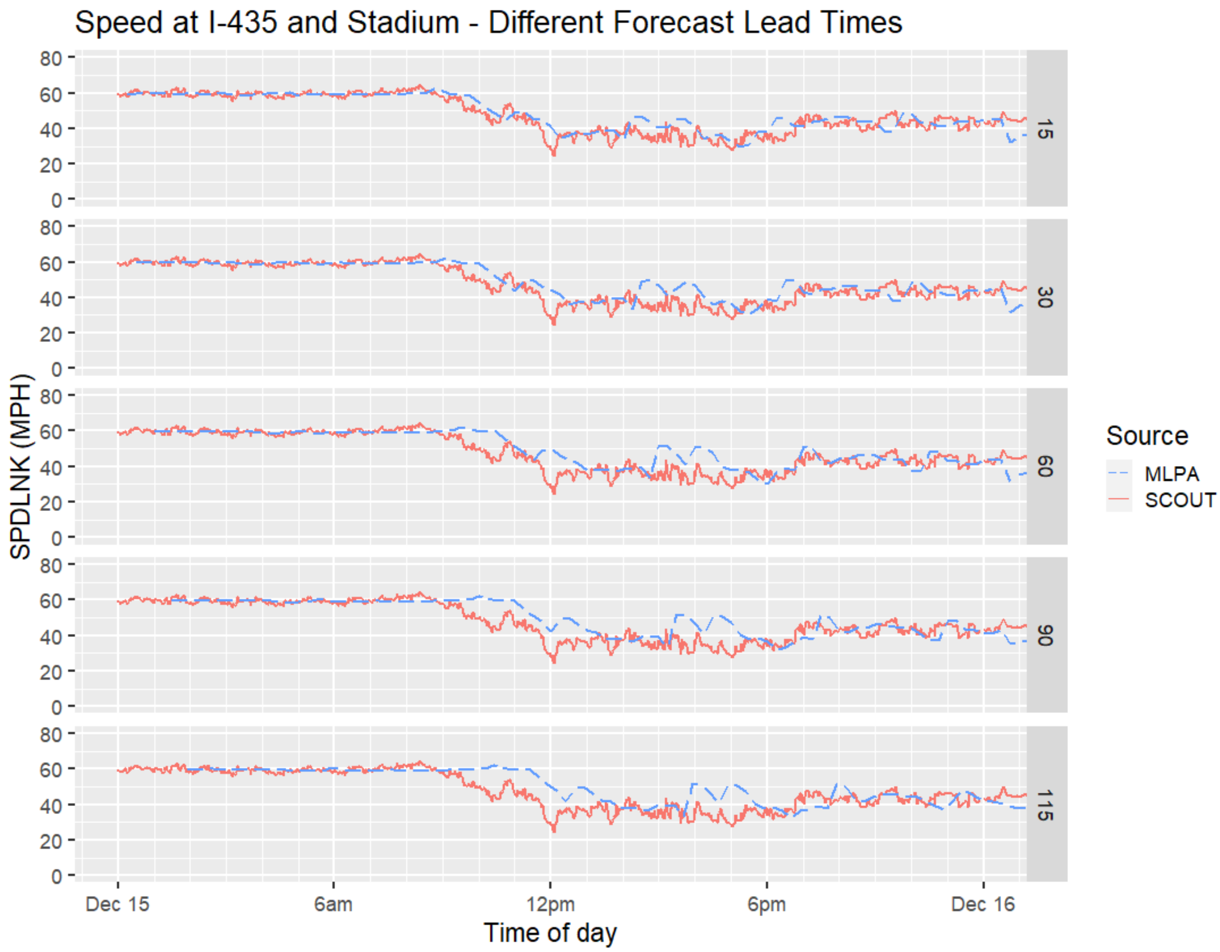
Source: Federal Highway Administration

**Figure 26. Plot. Interstate 435 and East Stadium Drive historical speeds, December 15, 2019.**

***December 15, 2019, Speed Forecasts***

The plots in figure 27 display the forecast speeds obtained for I–435 and East Stadium Drive during December 15, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network. The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- MLP speed forecasts showed periods where the forecasts appeared to have small deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.
Source: Federal Highway Administration

**Figure 27. Plot. Interstate 435 and East Stadium Drive forecast speeds, December 15, 2019.**

### *December 16, 2019, Weather and Road Conditions*

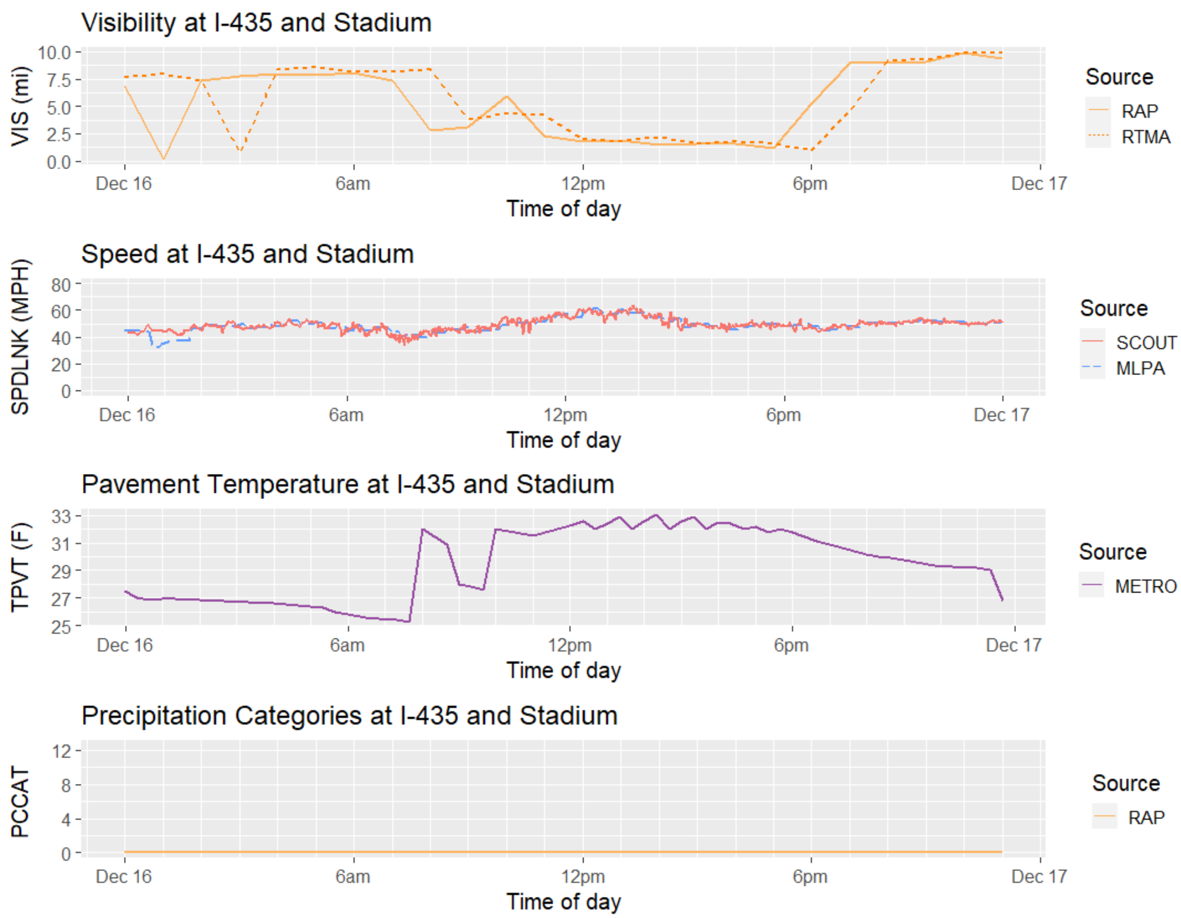
On December 16, 2019, the weather temperature was in the low 30s with no precipitation and a light wind (less than 10 mph) in the morning. There was light snow and some haze during the afternoon, and it was snowy during the evening. The road conditions were dry until noon, but had melting snow and some haze during the afternoon and were dry during the evening commute.

### *December 16, 2019, Speed Predictions*

The plots in figure 28 display the historical data obtained for I–435 and East Stadium Drive during December 16, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network.

The plots show:

- Both RAP and RTMA sources indicate that visibility decreased in the morning and remained low until slowly improving at about 6 p.m.
- MLP and detector speeds showed a slight increase from about 8 a.m. to about 2 p.m.
- The MLP speed predictions appeared to well match the detector speeds on this date.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface.
Source: Federal Highway Administration

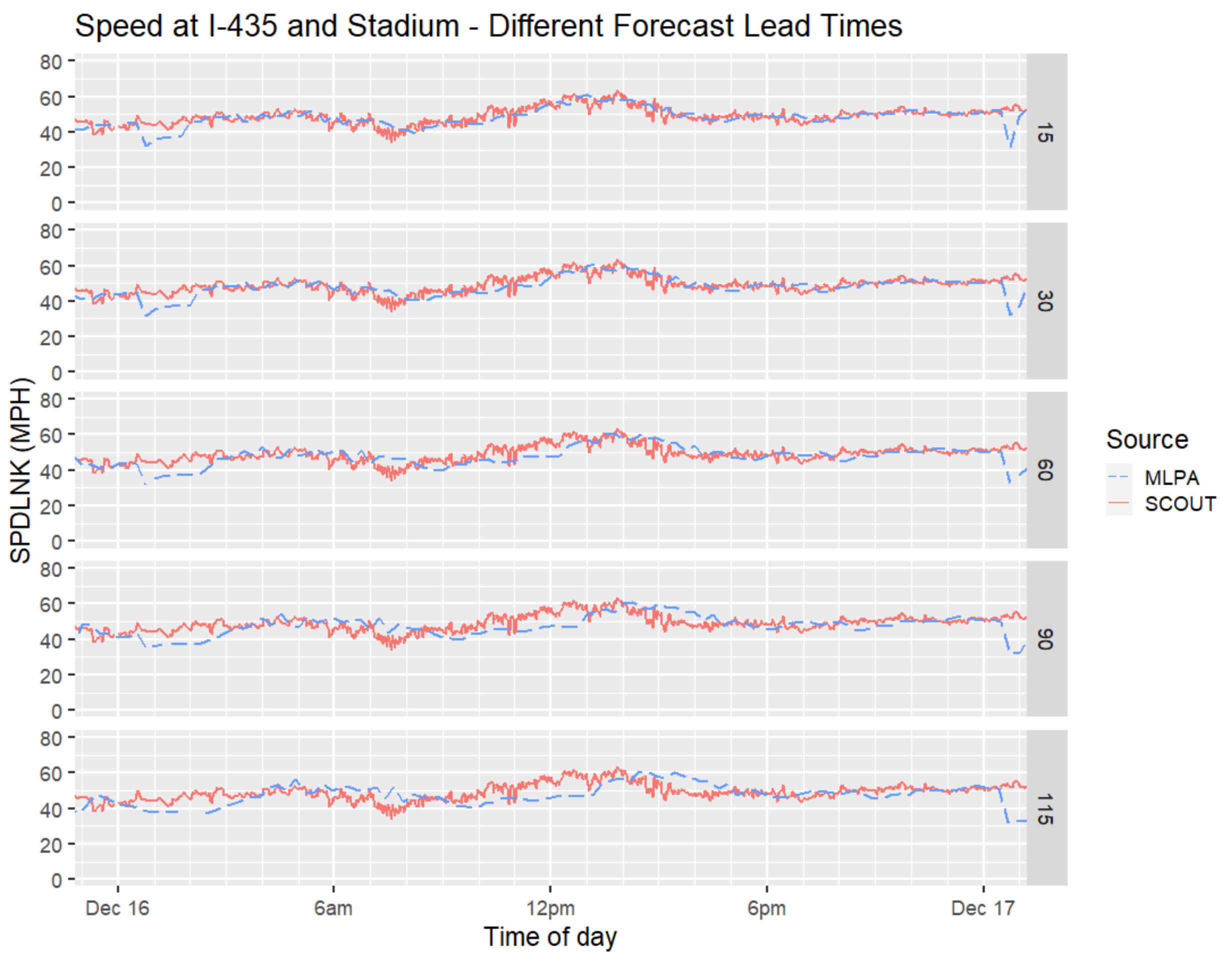
**Figure 28. Plot. Interstate 435 and East Stadium Drive historical speeds, December 16, 2019.**

### *December 16, 2019, Speed Forecasts*

The plots in figure 29 display the forecast speeds obtained for I–435 and East Stadium Drive during December 16, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network.

The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were not available at this location.
- MLP speed forecasts showed periods where the forecasts appeared to have small deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.
Source: Federal Highway Administration

**Figure 29. Plot. Interstate 435 and East Stadium Drive forecast speeds, December 16, 2019.**

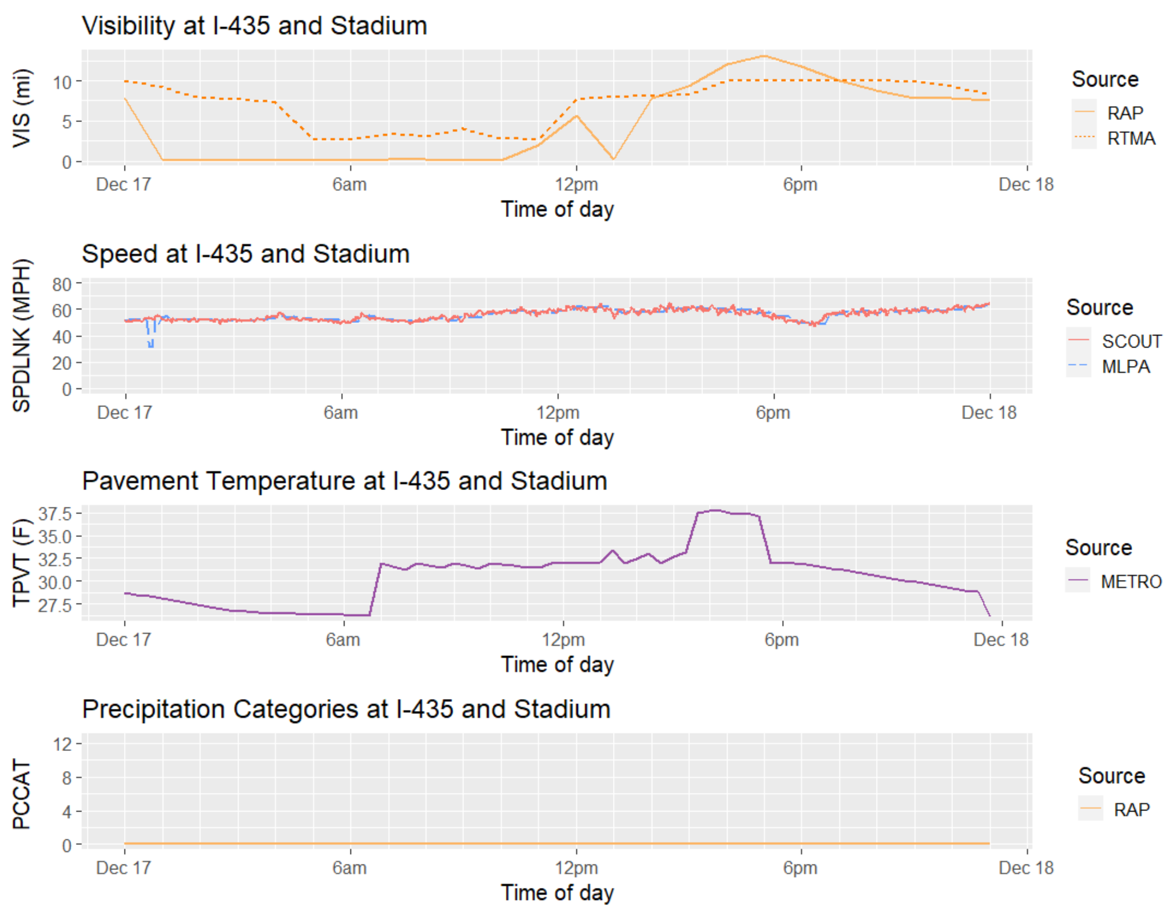
### *December 17, 2019, Weather and Road Conditions*

On December 17, 2019, the weather temperature was in the mid- to upper 20s, with no precipitation and a light wind (less than 10 mph) throughout the day and night. There was no precipitation during the day. The road conditions were dry during the morning, midday, and evening times.

*December 17, 2019, Speed Predictions*

The plots in figure 30 display the historical data obtained for I–435 and East Stadium Drive during December 17, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network. The plots show:

- RAP and RTMA sources indicate that visibility was low in the morning until slowly improving at about noon.
- MLP and detector speeds showed a slight increase in speeds at about 8 a.m.
- MLP speed predictions appeared to well match the detector speeds on this particular date.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface.

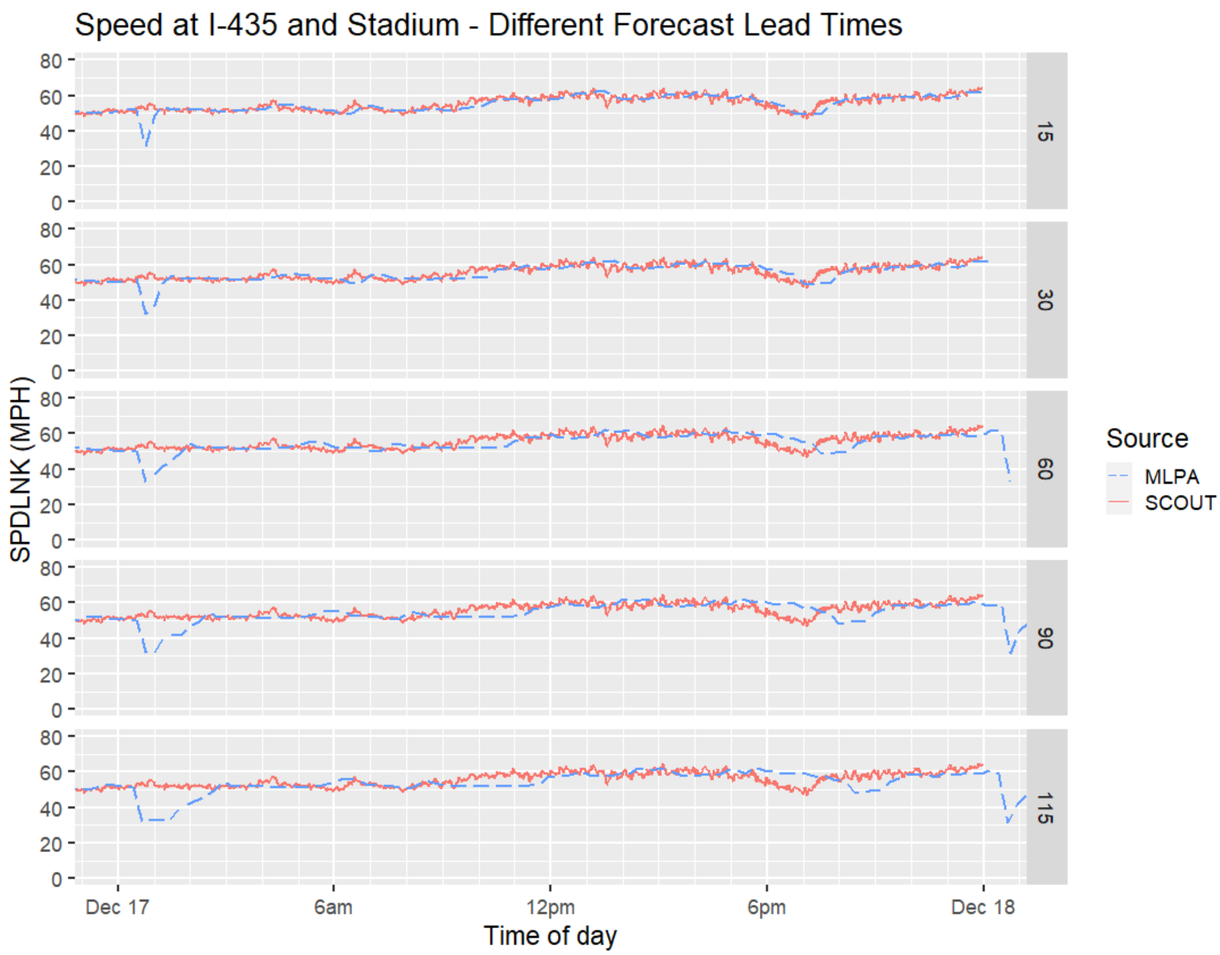
Source: Federal Highway Administration

**Figure 30. Plot. Interstate 435 and East Stadium Drive historical speeds, December 17, 2019.**

*December 17, 2019, Speed Forecasts*

The plots in figure 31 display the forecast speeds obtained for I–435 and East Stadium Drive during December 17, 2019. In the plots, speeds for only KC Scout and MLP are available because this location is outside the TrEPS network. The plots show:

- Detector and MLP speeds fluctuated throughout the day for all forecast times.
- MLP speed forecasts showed periods where the forecasts appeared to have small deviations above and below the detector speeds. The MLP speed deviations appeared to grow larger with longer forecasts.



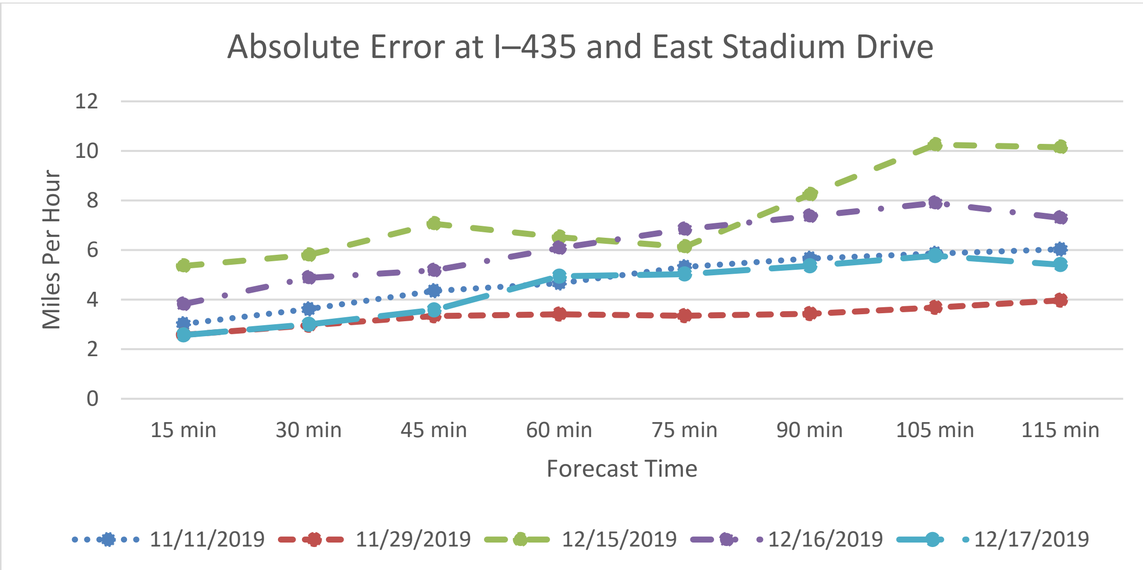

a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link.
Source: Federal Highway Administration

**Figure 31. Plot. Interstate 435 and East Stadium Drive forecast speeds, December 17, 2019.**

*Speed Forecast Error Analysis for Interstate 435 and East Stadium Drive*

Figure 32 shows the MLP absolute error for the 15–115-min speed forecasts on November 11, 29, December 15, 16, and 17. The plots show:

- The absolute errors show that shorter-term forecasts tended to have smaller errors than longer-term forecasts.
- The shorter-term forecasts tended to be more accurate.
- The average absolute error for the 15-min forecast was about 3.5 mph versus about 6.5 mph for the 115-min forecast.

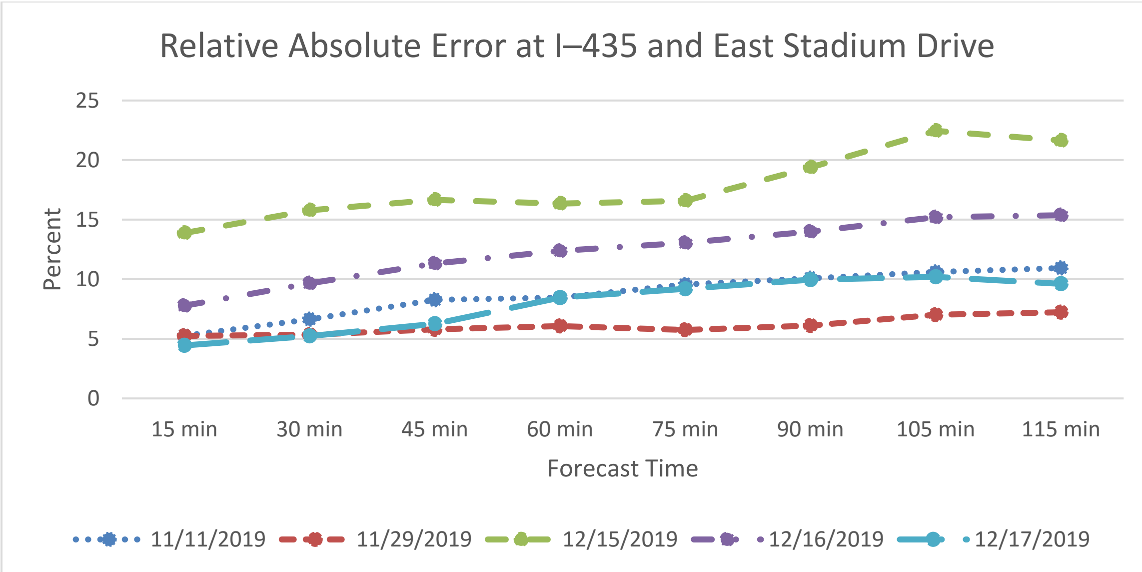



I–435 = Interstate 435. min = minute.
Source: Federal Highway Administration

**Figure 32. Graph. Machine learning-based prediction absolute error at Interstate 435 and East Stadium Drive.**

Figure 33 shows the relative absolute errors for MLP at I–435 and East Stadium Drive on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts. The plots show:

- The relative absolute error for the MLP shorter-term forecasts tended to be smaller than the errors for longer-term forecasts. In other words, the error as a percentage of the speed was smaller for shorter-term forecasts.
- The relative absolute error shows the shorter-term forecasts tended to be more accurate.
- The average relative absolute error for the 15-min forecast was about 7 percent versus about 13 percent for the 115-min forecast.



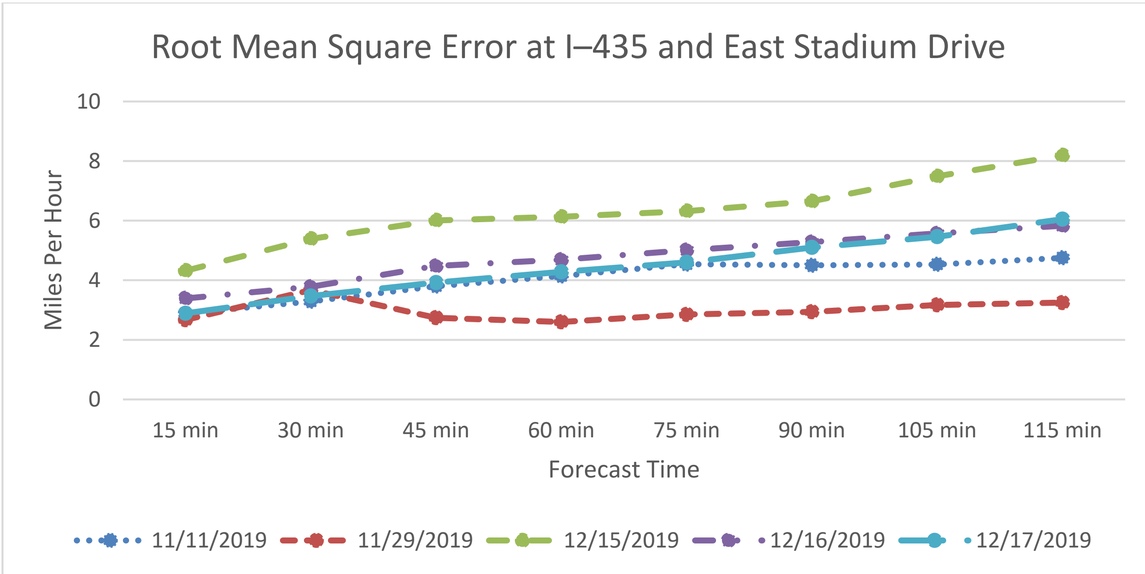

I–435 = Interstate 435. min = minute.

Source: Federal Highway Administration

**Figure 33. Graph. Machine learning-based prediction relative absolute error at Interstate 435 and East Stadium Drive.**

Figure 34 shows the root mean square errors for MLP at I–435 and East Stadium Drive on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts. The plots show:

- The root mean square error showed that shorter-term forecasts errors tended to be smaller than longer-term forecasts.
- The root mean square error showed that the shorter-term forecasts tended to be more accurate.
- The average root mean square error for the 15-min forecast was about 3 mph versus about 5 mph for the 115-min forecast.




I–435 = Interstate 435. min = minute.

Source: Federal Highway Administration

**Figure 34. Graph. Machine learning-based prediction root mean square error at Interstate 435 and East Stadium Drive.**

## Interstate 435 Eastbound at East Antioch Road

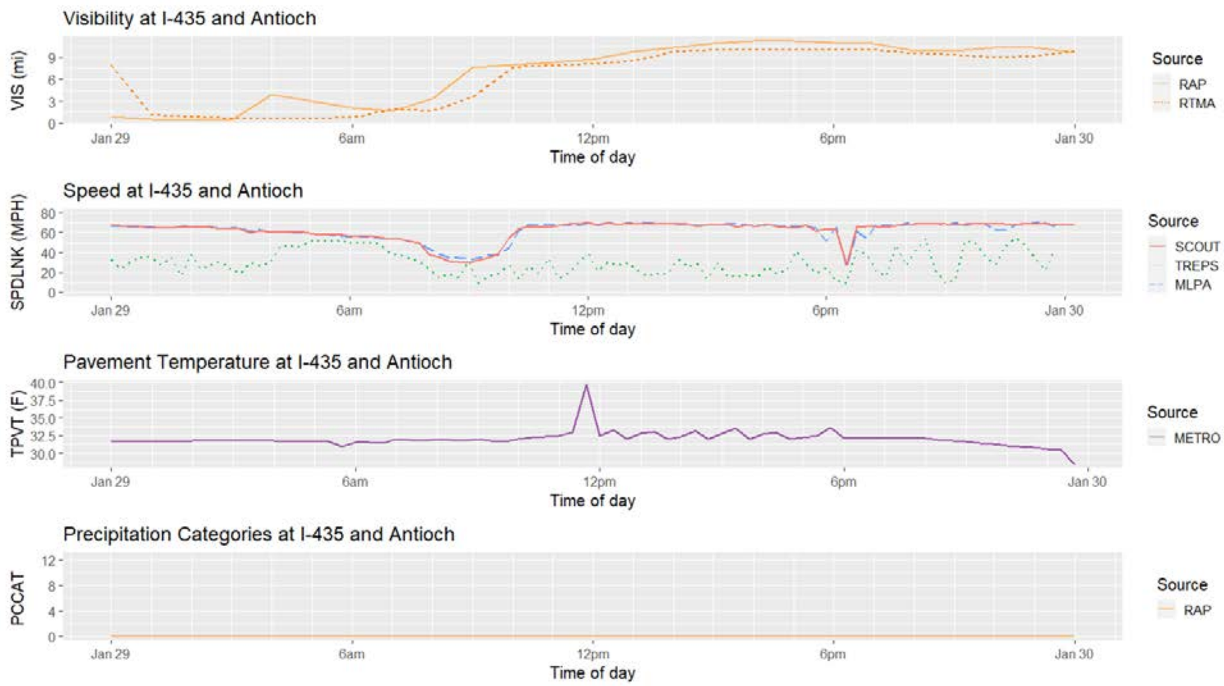
### *January 29, 2020, Weather and Road Conditions*

On January 29, 2020, the weather temperature was in the upper 20s to low 30s with early morning snow. The road conditions had snow until about 9 a.m. and were dry afterwards. There were two incidents—both involving a stalled vehicle—between 5:42 and 6:07 p.m. and then again between 9:37 and 10:02 p.m.

### *January 29, 2020, Speed Predictions*

The plots in figure 35 display the historical data obtained for I–435 and East Antioch Road during January 29, 2020. The speed plot shows the reported speeds from KC Scout roadway detectors, TrEPS, and MLP, and shows the fluctuation and deviations during the day. The plots show:

- RAP and RTMA sources indicate that visibility was low in the morning and until slowly improving at about 8 a.m.
- MLP and detector speeds showed speeds decreasing until about 9 a.m., then increasing until about 11 a.m. and, with an exception at about 6:30 p.m., remained consistent thereafter.
- MLP speed predictions appeared to match the detector speeds well on this particular date, and appeared to show speeds decreasing at about the time of the stalled-vehicle incidents between 5:42 and 6:07 p.m. and 9:37 and 10:02 p.m.
- TrEPS speeds were consistently much lower than KC Scout and MLP for most of the day.




a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.

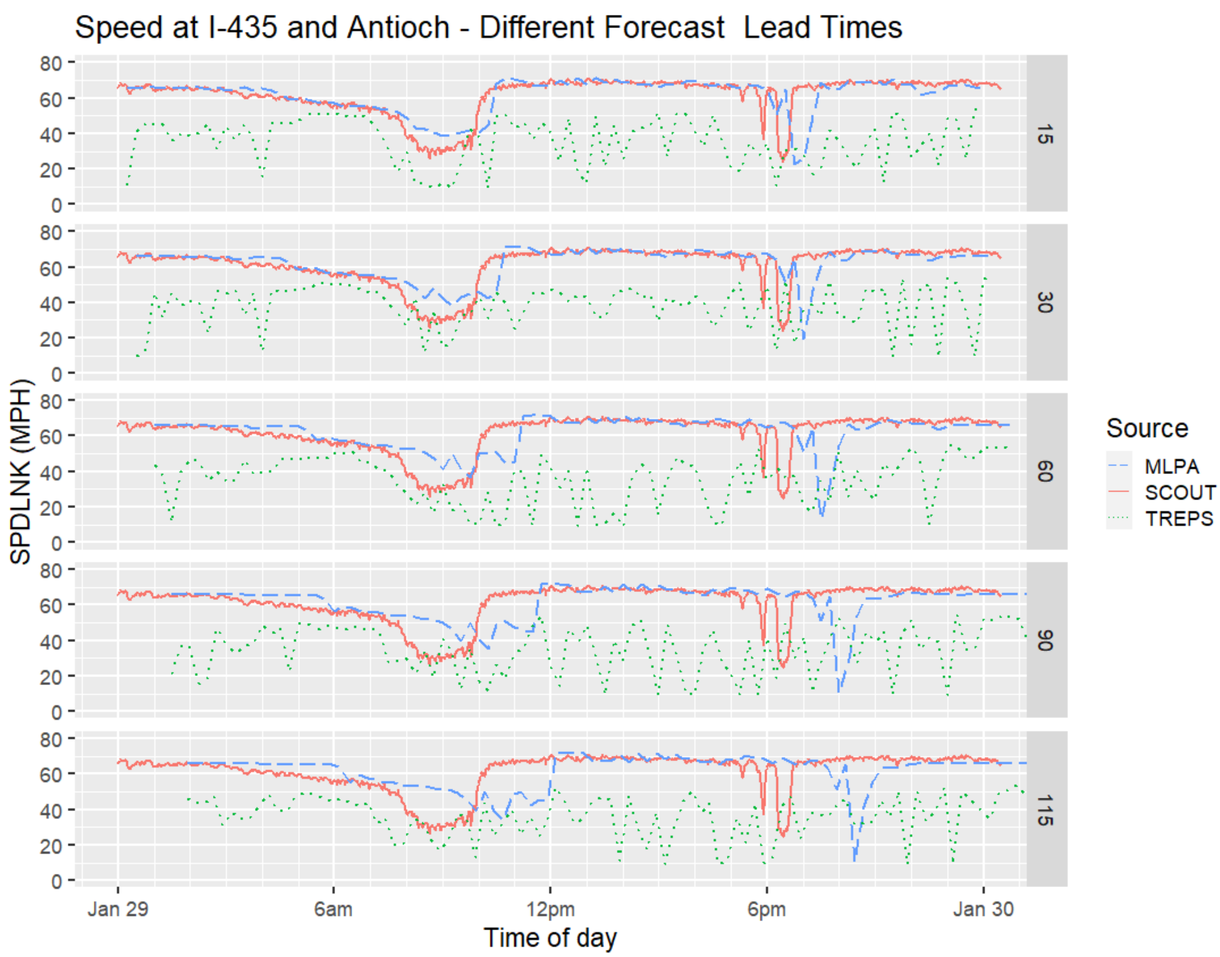
Source: Federal Highway Administration

**Figure 35. Plot. Interstate 435 and East Antioch Road historical speeds, January 29, 2020.**

### *January 29, 2020, Speed Forecasts*

The plots in figure 36 display the MLP and TrEPS forecast speeds obtained for I–435 and East Antioch Road during January 29, 2020. The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were consistently lower than the detector speeds and do not reflect the decline in detected speeds from about 5 to 7 p.m.
- TrEPS and MLP speeds decreased similar to the the decline in detected speeds from about 8 to 10 a.m.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations below the detector speeds. Both TrEPS and MLP speed deviations appeared to grow larger with longer forecasts.




a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.

Source: Federal Highway Administration

**Figure 36. Plot. Interstate 435 and East Antioch Road forecast speeds, January 29, 2020.**

### *February 12, 2020, Weather and Road Conditions*

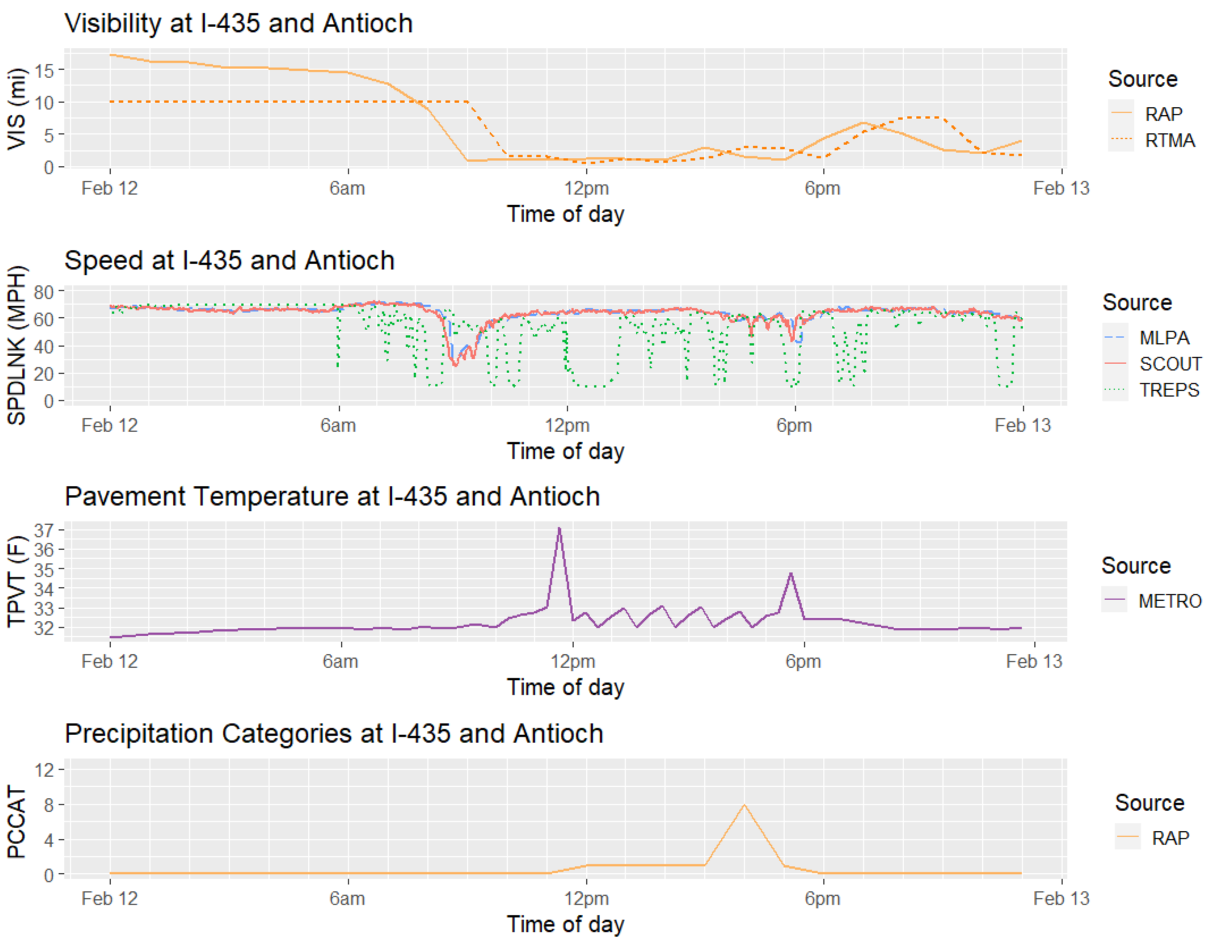
On February 12, 2020, the weather temperature was about 32 degrees throughout the day with periods of light snow, with snow from about 9 a.m. to midnight. The road conditions were dry until about 9 a.m., then became wet until and through midnight.

### *February 12, 2020, Speed Predictions*

The plots in figure 37 display the historical data obtained for the first location, I–435 and East Antioch Road, during February 12, 2020. On this date, there were multiple incidents between 7:30 a.m. and 2 p.m. near to and downstream from this detector.

The plots show:

- RAP and RTMA sources indicate that visibility decreased at about 9 a.m. until slowly improving at about 7 p.m.
- MLP and detector speeds showed speeds decreased from about 9 to 10 a.m., then returned to normal until from about 3 to 6 p.m. when precipitation was indicated by PCCAT.
- MLP speed predictions appeared to pretty well match the detector speeds on this particular date, and appeared to show decreasing speeds between 9 and 10 a.m. and increasing variability from 3 to 6 p.m.
- TrEPS speeds deviated considerately and had frequent periods that were much lower than KC Scout.



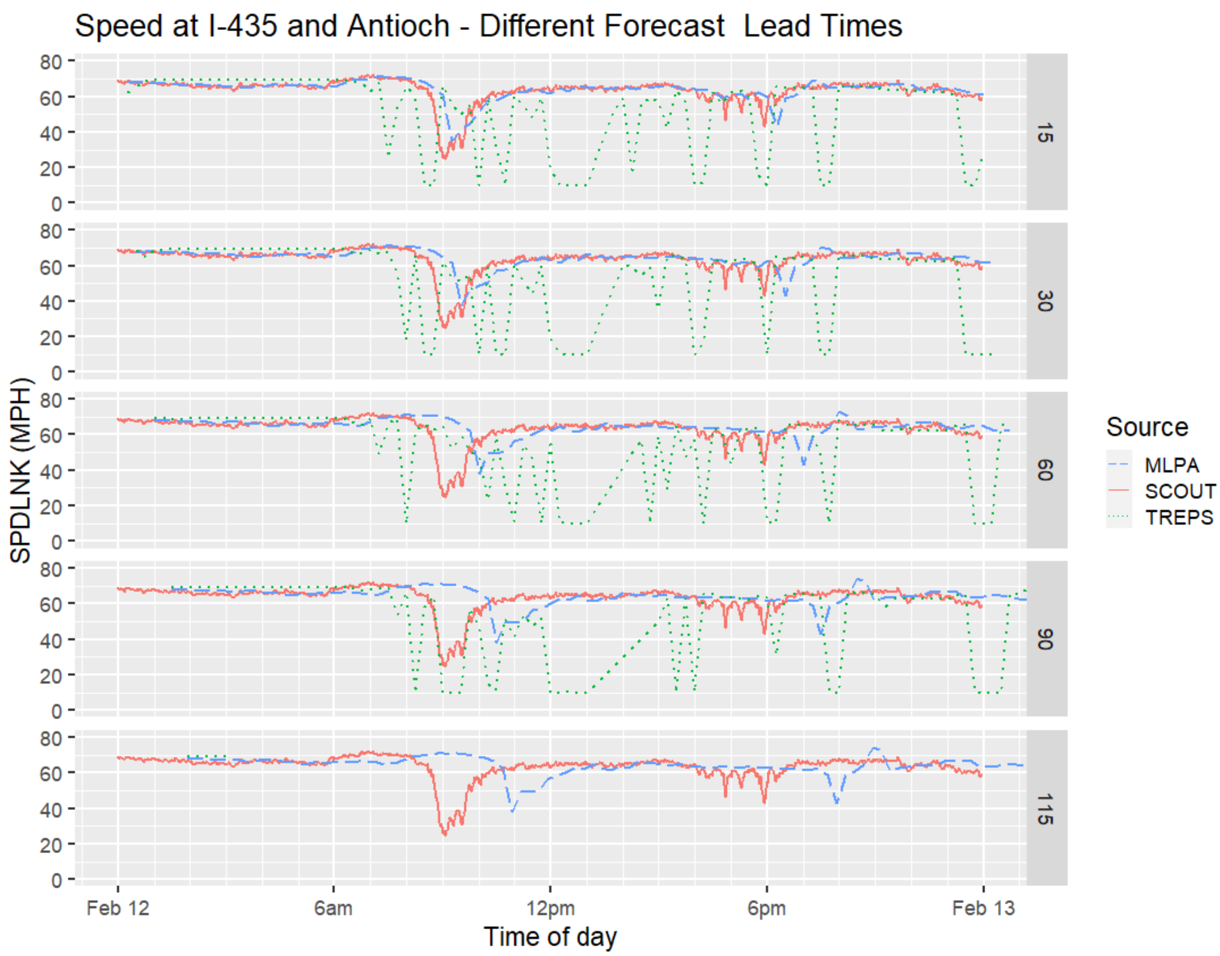

a.m. = ante meridiem. F = Fahrenheit. I–435 = Interstate 435. METRo = Model of the Environment and Temperature of Roads. mi = mile. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. PCCAT = precipitation category. RAP = Rapid Refresh. RTMA = Real-Time Mesoscale Analysis. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TPVT = temperature of pavement. VIS = visibility of surface. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 37. Plot. Interstate 435 and East Antioch Road historical speeds, February 12, 2020.**

***February 12, 2020, Speed Forecasts***

The plots in figure 38 display the forecast speeds obtained for I–435 and East Antioch Road during February 12, 2020. The plots show:

- Detector, MLP, and TrEPS speeds fluctuated throughout the day for all forecast times.
- TrEPS speeds were consistent until about 7 a.m., then fluxuated lower than the detector speeds until about 8 p.m.
- MLP speeds for the 15-min forecast decreased similar to the the decline in detected speeds from about 9 to 10 a.m., then had deviations that grew larger with longer-term forecasts.
- MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations from the detector speeds. Both TrEPS and MLP speed deviations appeared to grow larger with longer forecasts.



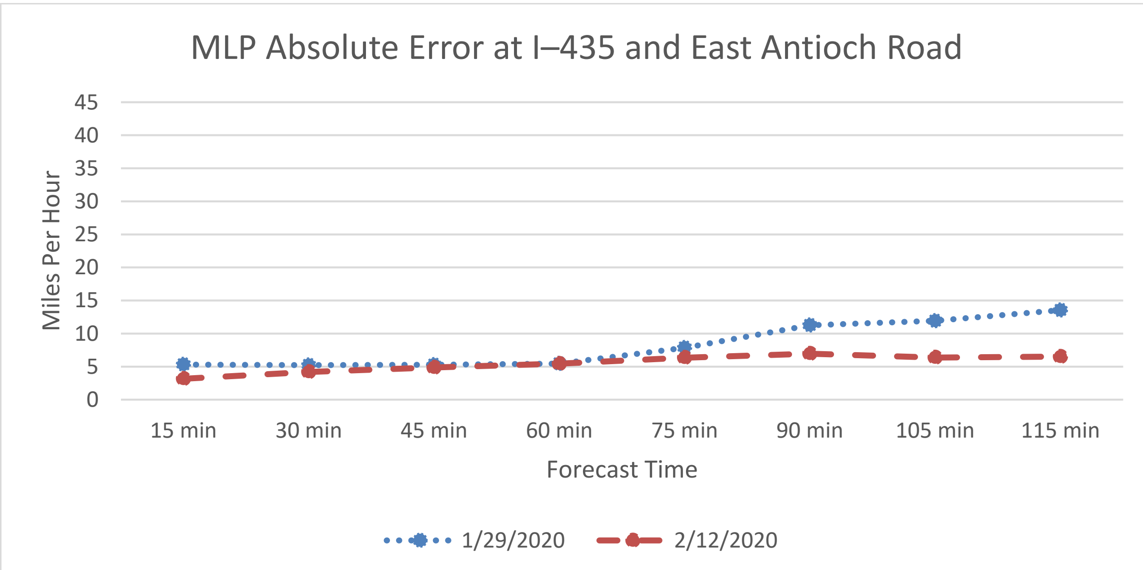

a.m. = ante meridiem. I–435 = Interstate 435. MLPA = machine learning-based prediction model A. mph = mile per hour. p.m. = post meridiem. SCOUT = Kansas City Scout. SPDLNK = average speed of vehicles on each link. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 38. Plot. Interstate 435 and East Antioch Road forecast speeds, February 12, 2020.**

### *Speed Forecast Error Analysis for Interstate 435 and East Antioch Road*

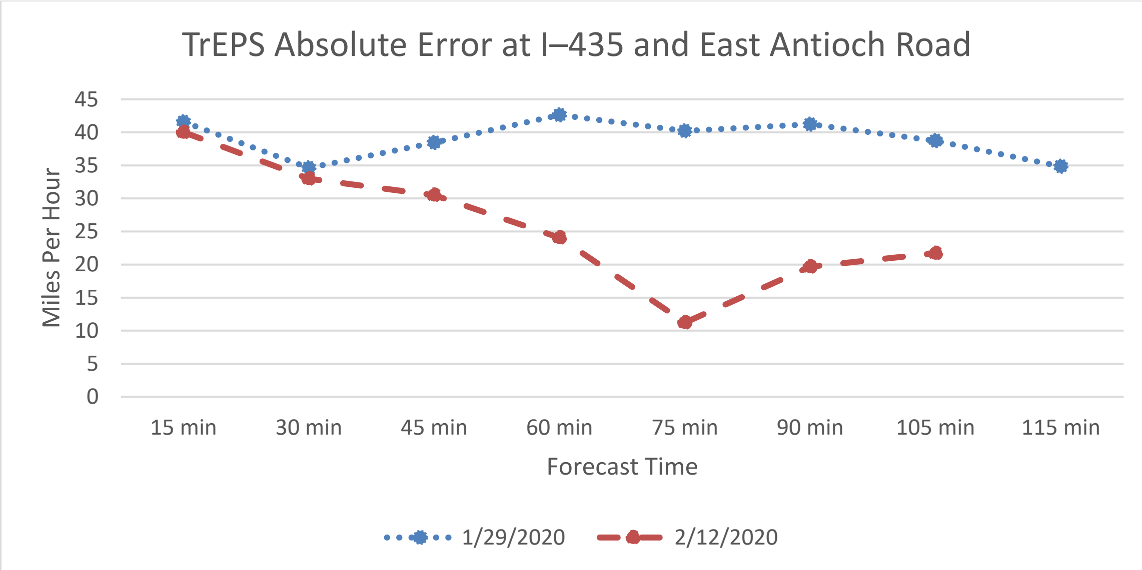
Figure 39 shows the MLP absolute error for the 15–115-min speed forecasts on November 11, 29, December 15, 16, and 17. Figure 40 shows the TrEPS absolute errors for the same forecast time periods. The plots show:

- For MLP, the absolute errors show that shorter-term forecasts tended to have smaller errors than longer-term forecasts. Consequently, the shorter-term forecasts tended to be more accurate. The average absolute error for the 15-min forecast was about 4 mph, whereas the 115-min forecast increased to about 10 mph.
- For TrEPS, the absolute errors were relatively mixed across all forecast times. On January 29, 2020, the absolute error was relatively consistent and ranged from about 35 to 42 mph. On February 12, 2020, the absolute error was about 40 mph for the 15-min forecast, steadily decreased to about 11 mph for the 75-min forecast, then increased to about 21 mph for the 105-min forecast.
- Comparing the MLP to TrEPS absolute errors, the TrEPS errors tended to be larger than the MLP absolute errors. The average TrEPS error across all forecast times was about 33 mph versus about 7 mph for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 39. Graph. Machine learning-based prediction absolute error at Interstate 435 and East Antioch Road.**

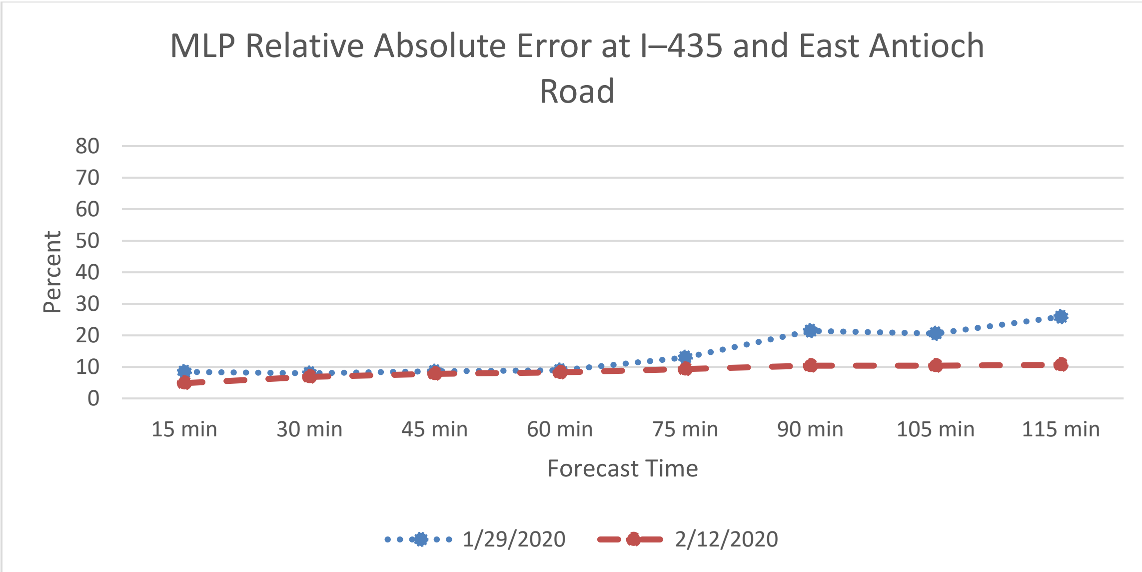



I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 40. Graph. Traffic Estimation and Prediction System absolute error at Interstate 435 and East Antioch Road.**

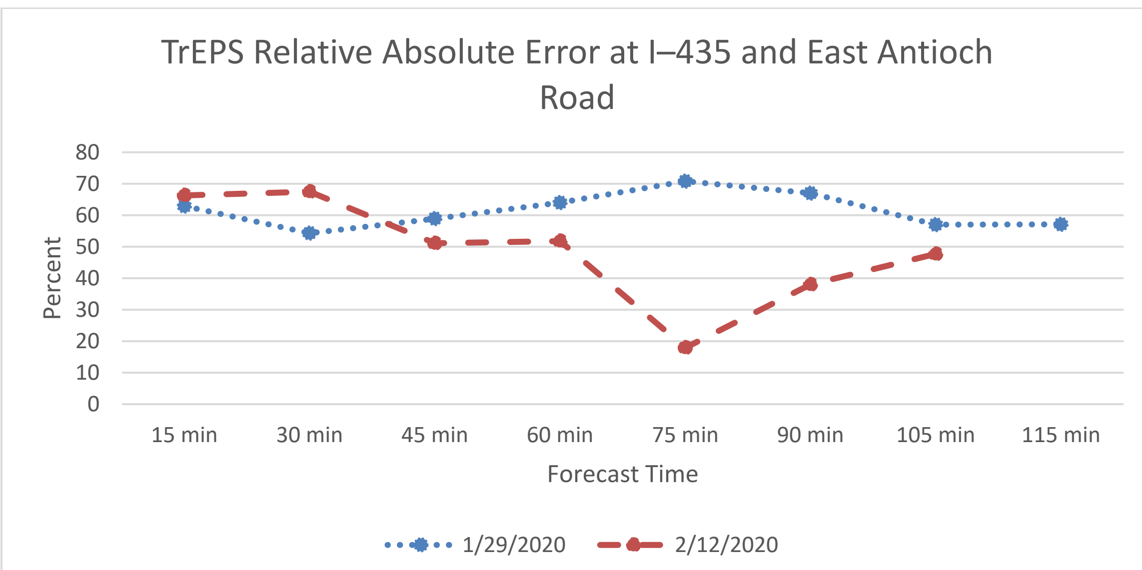
Figure 41 and figure 42 show the relative absolute errors for MLP and TrEPS at I–435 and East Antioch Road on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts. The plots show:

- For MLP, the relative absolute error for shorter-term forecasts tended to be smaller than the errors for longer-term forecasts with the error as a percentage of the speed smaller for shorter-term forecasts. The average relative absolute error for the 15-min forecast was about 7 percent, whereas the 115-min forecast increased to about 18 percent.
- For TrEPS, the relative absolute errors were relatively mixed across all forecast times. On January 29, 2020, the absolute error was relatively consistent and ranged from about 54 to 71 percent. On February 12, 2020, the relative absolute error was about 66 percent for the 15-min forecast, steadily decreased to about 18 percent for the 75-min forecast, then increased to about 48 percent for the 105-min forecast.
- Comparing the MLP to TrEPS relative absolute errors, the TrEPS errors tended to be larger than the MLP errors. The average TrEPS error across all forecast times was about 56 percent versus about 12 percent for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 41. Graph. Machine learning-based prediction relative absolute error at Interstate 435 and East Antioch Road.**



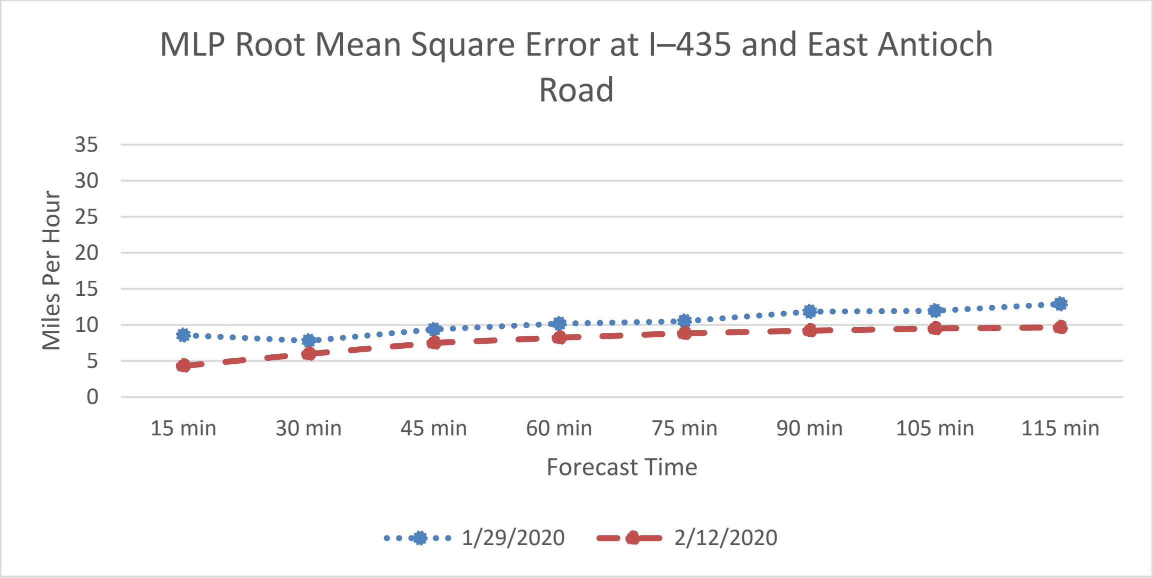

I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 42. Graph. Traffic Estimation and Prediction System relative absolute error at Interstate 435 and East Antioch Road.**

Figure 43 and figure 44 show the root mean square errors for MLP and TrEPS at I–435 and East Antioch Road on November 11, 29, December 15, 16, and 17, 2019, for 15–115-min forecasts.

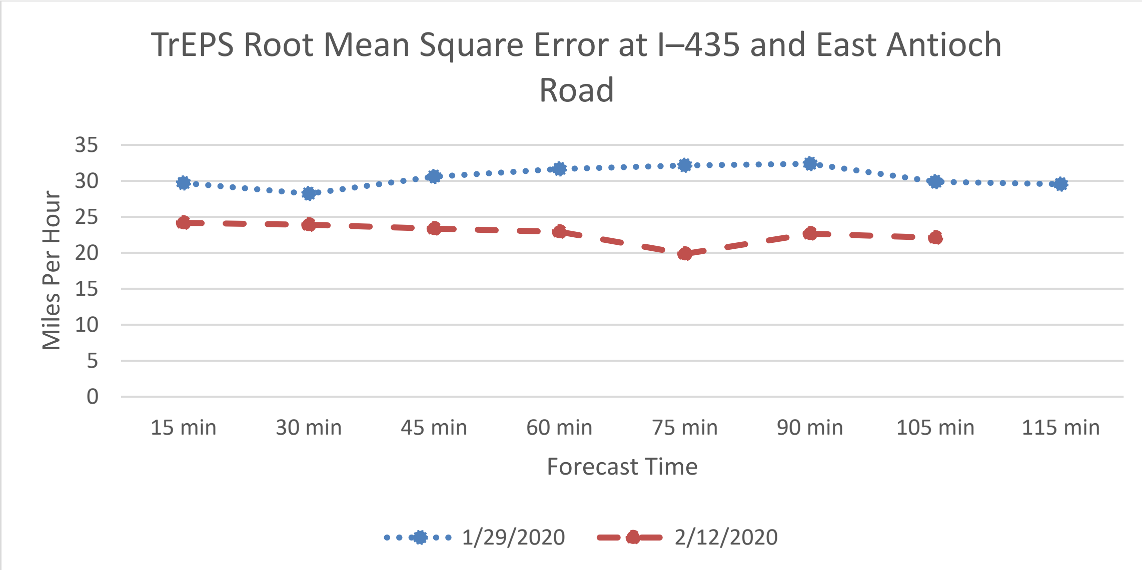
The root mean square errors which measure the deviation or spread of the forecast versus actual speeds. The plots show:

- For MLP, the root mean square error showed that the shorter-term forecasts errors tended to be smaller than longer-term forecasts. The average root mean square error for the 15-min forecast was about 6 mph versus about 11 mph for the 115-min forecast.
- For TrEPS, the root mean square errors were relatively consistent across all forecast times. The root mean square error ranged from 19 mph to 32 mph.
- Comparing the MLP to TrEPS root mean square errors, the TrEPS errors were about three times larger than MLP. The average TrEPS error across all forecast times was about 27 mph versus about 9 mph for MLP.




I–435 = Interstate 435. min = minute. MLP = machine learning-based prediction.
Source: Federal Highway Administration

**Figure 43. Graph. Machine learning-based prediction root mean square error at Interstate 435 and East Antioch Road.**




I–435 = Interstate 435. min = minute. TREPS = Traffic Estimation and Prediction System.
Source: Federal Highway Administration

**Figure 44. Graph. Traffic Estimation and Prediction System root mean square error at Interstate 435 and East Antioch Road.**

## USEFULNESS STUDY

The usefulness study investigated staff perceptions, attitudes, and behaviors. The goals of the interviews and discussions with KC Scout operators and supervisors were to learn about the users' experiences and perceptions relating to:

- Usage of IMRCP prior to, during, and/or after weather events.
- Accuracy of IMRCP information and forecasts.
- Integration of IMRCP into processes.
- Perspectives of IMRCP, overall (benefits, limitations, and lessons learned).

The operators reported primarily using IMRCP prior to a weather event. This included both rain and winter weather, but more often when winter weather was expected. The operators used it less during heavy rain or flooding events. In general, the operators did not use the traffic predictions capability. The operators said they liked the precipitation/weather predictions and the pavement status predictions because they can provide some insight into what locations to monitor more closely as the weather moves in. The operators used this feature to find areas with potential issues affected by the incoming weather. They reported it helped them prioritize and focus attention on particular roadway sections or areas, which in turn may improve their communication and decisions relating to motorist assist deployments. One user reported that IMRCP has been informally used to help inform transportation management center (TMC) staffing decisions during a weather event (e.g., should additional staff be called in, or can staff be sent home?).

The operators reported using IMRCP during the weather event in a more limited capacity. They are often busy during the weather events performing priority duties and responsibilities, such as entering, monitoring, and updating incidents into their system.

The operators typically do not use IMRCP to assess an event that has already passed; however, they acknowledge it may be helpful for data analysis and evaluation to determine lessons learned. One user believed there was a benefit to using IMRCP capabilities and its weather event data to look back and assess winter maintenance response efforts and emergency operation staffing decisions. Insight gained could potentially help save the agency staffing and monetary resources.

Overall, the users reported a fair confidence in the weather-related prediction components of IMRCP. As mentioned earlier, the operators did not use the traffic prediction components. The operators also indicated that periods of IMRCP downtime negatively affected the usage of IMRCP in their daily routines, especially in the 2019–2020 winter season. The operators' responses from the interviews seemed to indicate a more frequent use of IMRCP in the 2018–2019 winter season.

# CHAPTER 4. FINDINGS

The purpose of the evaluation is to explore whether Integrated Modeling for Road Condition Prediction (IMRCP) had an impact on the Kansas City Scout (KC Scout) operations and to assess whether the information was useful to the KC Scout operators and supervisors. The key questions guiding the evaluation data collection and analyses are: (1) Did IMRCP have an operational impact? and (2) Did the users consider the IMRCP information useful? To explore whether IMRCP had an impact, the evaluation investigated the accuracy of IMRCP speeds and speed forecasts. To investigate whether IMRCP information was useful, KC Scout operators and supervisors were interviewed to obtain their insights and perspectives. The findings in this section describe the outcomes of investigating speed and speed forecast accuracy and operator and supervisor perceptions of IMRCP's operational impact and usefulness.

## DID INTEGRATED MODELING FOR ROAD CONDITION PREDICTION HAVE AN OPERATIONAL IMPACT?

This evaluation found that IMRCP had minimal operational impact during the 2018–2019 and 2019–2020 winter driving seasons. However, operators did report that they often referred to IMRCP for weather forecast information prior to weather events. They stated that during normal day operations, they relied on existing KC Scout tools, applications, and information sources to monitor real-time traffic operations. Consequently, IMRCP speeds and speed forecasts were basically unused by the operators.

Analysis of the Traffic Estimation and Prediction System (TrEPS) and machine learning-based prediction (MLP) speeds and speed forecasts at three locations during seven winter days revealed that the two IMRCP models produced speeds and speed forecasts of varying accuracy. Three types of analyses for each location and date were completed:

- Analysis of historical predicted speeds.
- Analysis of forecast speeds for 15-, 30-, 45-, 60-, 75-, 90-, 105-, and 115-minute (min) predictions.
- Analysis of speed forecast errors (absolute, relative absolute, and root mean square errors).

Looking at the accuracy of historical predicted speeds, TrEPS speed data were found to be problematic on several dates, sometimes with several hours of predicted speeds considerably different (over 20 miles per hour [mph]) from the detector speeds. The TrEPS model predicts speeds using several input parameters, such as changes to posted speed limit, roadway construction (or blockage) information, and detector data. If any of these inputs are inaccurate or missing, it may affect TrEPS ability to predict accurate speeds. For example, it appeared that speeds reported by TrEPS at Interstate 435 (I–435) eastbound (EB) at State Line Road were affected by a construction work zone that was not reported by KC Scout. The MLP speed data often appeared to be within about 5 mph of the detector speeds and were much less affected by the I–435 at State Line Road construction work zone changes, but occasionally had periods with large deviations (up to 20 mph) above or below the detector speeds.

Analysis of forecast speeds found that MLP and TrEPS speed forecasts both showed periods where the forecasts appeared to have large deviations (up to 20 mph) above and below the detector speeds. The deviations appeared to grow larger and for longer periods of time with longer-term forecasts. The MLP forecast speeds tended to more closely match the detector speeds than the TrEPS forecasts and the errors were examined in the forecast speed error analysis.

The analysis of speed forecast errors used three formulas to calculate and compare the speed forecast errors: absolute, relative absolute, and root mean square error.

The absolute error analysis measured the difference between the forecast speed and the actual detector speed. In general, when examining the 15–115-min speed forecasts:

- The MLP absolute error showed that shorter-term forecasts tended to be more accurate than longer-term forecasts. The results at the three detector locations (I–435 at State Line Road, I–435 at East Stadium Drive, and I–435 at East Antioch Road) showed the 15-min forecasts were from 3 to 8 mph more accurate than the 115-min forecasts.
- The TrEPS absolute errors showed mixed results for speed forecasts. At I–435 and State Line Road, the absolute errors were relatively consistent across all forecast times. On January 29, 2020, the absolute error was relatively consistent, ranging from about 35 to 42 mph. However, on February 12, 2020, the absolute error was about 40 mph for the 15-min forecast, decreased to about 11 mph for the 75-min forecast, then increased to about 21 mph for the 105-min forecast.
- The TrEPS absolute errors for speed forecasts tended to be larger than the MLP absolute errors. At I–435 and State Line Road, the average TrEPS error across all forecast times was about 26 mph versus about 10.6 mph for MLP. At I–435 at East Antioch Road, the average TrEPS error across all forecast times was about 33 mph versus about 7 mph for MLP.

The relative absolute error measured how large the absolute error was compared to the actual speed and provided the percent size of the error. In general, when examining the 15–115-min speed forecasts:

- The MLP relative absolute error also showed that shorter-term forecasts tended to be more accurate than longer-term forecasts, in that the error as a percentage of the speed was smaller for shorter-term forecasts. The results at the three detector locations showed the 15-min forecasts were from 7 to 18 percent versus 13 to 41 percent for the 115-min forecasts.
- The TrEPS relative absolute errors generally showed mixed results. At I–435 and State Line Road, the relative absolute errors were relatively large (ranging from 40 to over 100 percent) and mostly consistent across all forecast times. The average relative absolute error was about 73 percent for all forecast times. On January 29, 2020, the relative absolute error was about 66 percent for the 15-min forecast, steadily decreased to about 18 percent for the 75-minute forecast, then increased to about 48 percent for the 105-min forecast.

- Comparing TrEPS to MLP, the TrEPS relative absolute errors were generally larger. At I–435 and State Line Road, the average TrEPS error across all forecast times was about 73 percent versus about 29 percent for MLP. At I–435 at East Antioch Road, the average TrEPS error across all forecast times was about 56 percent versus about 12 percent for MLP.

The root mean square error measured the spread (or concentration) between forecasts and actual speeds. In general, when examining the 15–115-min forecasts:

- The MLP root mean square error showed that shorter-term forecasts errors tended to be smaller than longer-term forecasts. The root mean square error ranged from 3 to 12 mph.
- For TrEPS, the root mean square errors were relatively consistent across all forecast times. The root mean square error ranged from 19 to 32 mph.
- Comparing the root mean square errors of TrEPS to MLP, the TrEPS root mean square errors were found to be two to three times larger than the MLP root mean square errors. At I–435 and East Antioch Road, the average TrEPS error across all forecast times was about 27 mph versus about 9 mph for MLP.

## DID USERS CONSIDER IMRCP INFORMATION AS USEFUL?

This evaluation found that KC Scout operators and supervisors liked the weather-related prediction components of IMRCP, but preferred to use existing tools for obtaining information about real-time traffic conditions and incidents. Although road and weather information were sometimes helpful, the operators did not rely on IMRCP to select more relevant operational strategies. A KC Scout representative stated that IMRCP might be a helpful tool for planning and assessing winter maintenance response efforts and emergency operation staffing decisions.

The operators stated they accessed IMRCP when weather events were approaching, and found the weather information helpful. They mentioned that IMRCP was useful for both rain and winter weather, but more so for when winter weather was expected. The operators used it less during heavy rain or flooding events. Otherwise, the operators tended to not use IMRCP as part of their normal daily routines.

# CHAPTER 5. CONCLUSION

This evaluation has resulted in a better understanding of the impact the Integrated Modeling for Road Condition Prediction (IMRCP) Phase 3 had on Kansas City Scout (KC Scout) operations, the accuracy of the speed predictions and forecasts, and the usefulness of the information to KC Scout operators and supervisors.

Accuracy and reliability of the IMRCP traffic speeds can affect the operator's confidence in and the use of IMRCP's traffic-predictive applications. The Traffic Estimation and Prediction System (TrEPS) predicted speeds were inaccurate on several of the observed dates. This model was found to be sensitive to missing or erroneous input parameters, such as changes to posted speed limits, roadway construction (or blockages), and erroneous or missing detector data. The machine learning-based prediction (MLP) speeds was often found to be accurate and within about 5 miles per hour (mph) of the detector speeds. MLP was less affected by the construction work zone changes at Interstate 435 (I–435) at State Line Road, but occasionally had periods with large deviations (up to 20 mph) above or below the detector speeds. Forecast speeds for MLP and TrEPS showed periods where the forecasts appeared to have large deviations (up to 20 mph) above and below the detector speeds. With MLP speed forecasts, the shorter-term forecasts tended to be more accurate than the longer-term forecasts.

Operators reported not using the traffic predictions capability, because they preferred to use existing tools for obtaining information about real-time traffic conditions and incidents. Based on the project experience, traffic management center staff were focused on current traffic events and conditions, monitoring known problem areas and incidents. They often did not have the time or means to address the overall network conditions and assess the IMRCP traffic predictions. There seemed to be a preference from the operators to have IMRCP outputs integrated into existing TMC interfaces.

Although IMRCP traffic speed predictions had minimal operational impact during the 2018–2019 and 2019–2020 winter driving seasons, operators reported that they often referred to IMRCP for weather forecast information prior to weather events. Interviews and discussions with KC Scout operators and supervisors revealed that operators liked the weather-related prediction components of IMRCP and primarily assessed it prior to a winter weather event. The operators said they liked the precipitation/weather predictions and the pavement status predictions, because they can provide some insight into what locations to monitor more closely as the weather moves in. The operators used this feature to find areas with potential issues affected by the incoming weather. They reported it helped them prioritize and focus attention on particular roadway sections or areas, which in turn may improve their communication and decisions relating to motorist assist deployments.

The findings from this evaluation may be helpful to inform future improvements to the IMRCP application and any new deployments. Additional information can be found in the *Integrated Modeling for Road Condition Prediction Phase 3 Project Report* which summarizes the lessons learned from the evaluation and the KC Scout demonstration, as well as potential applications for IMRCP and recommendations for further study.

## APPENDIX A. SPEED FORECAST ERROR DATA

**Table 4. Absolute error 80 percent quantiles (in miles per hour) at Interstate 435 and State Line Road.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 7.84 | 3.02 | 11.67 | 5.82 | 2.743 |
| MLP | 30 min | 10.37 | 4.52 | 14.27 | 7.33 | 3.43 |
| MLP | 45 min | 11.65 | 4.48 | 14.67 | 8.1 | 4.65 |
| MLP | 60 min | 15.07 | 5.37 | 15.3 | 9.36 | 5.47 |
| MLP | 75 min | 16.73 | 5.48 | 14.22 | 10.24 | 8.67 |
| MLP | 90 min | 17.91 | 7.29 | 16.7 | 10.32 | 10.78 |
| MLP | 105 min | 18.83 | 9.34 | 16.65 | 10.71 | 11.55 |
| MLP | 115 min | 18.53 | 10.53 | 17.85 | 11.82 | 15.37 |
| MLP | All | 15.84 | 5.89 | 15.15 | 9.25 | 6.04 |
| TrEPS | 15 min | 28.67 | N/A | 30.35 | 27.93 | 19.41 |
| TrEPS | 30 min | 29.73 | N/A | 30.36 | 27.93 | 19.41 |
| TrEPS | 45 min | 27.12 | N/A | 30.9 | 27.94 | 19.41 |
| TrEPS | 60 min | 28.44 | N/A | 31 | 28.1 | 19.41 |
| TrEPS | 75 min | 28.85 | N/A | 31.13 | 28.18 | 19.41 |
| TrEPS | 90 min | 25.98 | N/A | 30.73 | 28.42 | 19.41 |
| TrEPS | 105 min | 26.11 | N/A | 30.12 | 28.17 | 19.49 |
| TrEPS | 115 min | 23.22 | N/A | 30.4 | 27.8 | 19.23 |
| TrEPS | All | 27.74 | N/A | 30.64 | 28.1 | 19.49 |

min = minute. MLP = machine learning-based prediction. TrEPS = Traffic Estimation and Prediction System. N/A = not applicable.

**Table 5. Relative absolute error 80 percent quantiles (percent) at Interstate 435 and State Line Road.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 21.68 | 6.19 | 40.21 | 15.99 | 6.14 |
| MLP | 30 min | 24.42 | 9.85 | 51.99 | 20.13 | 7.56 |
| MLP | 45 min | 28.62 | 9.88 | 60.21 | 20.96 | 10.34 |
| MLP | 60 min | 33.6 | 12.31 | 52.2 | 23.67 | 11.77 |
| MLP | 75 min | 40.75 | 12.8 | 50.55 | 26.56 | 18.32 |
| MLP | 90 min | 44.23 | 17.47 | 57.51 | 25.82 | 26.22 |
| MLP | 105 min | 50.82 | 20.82 | 64.8 | 28.27 | 32 |
| MLP | 115 min | 51.28 | 22.82 | 61.55 | 30.03 | 39.16 |
| MLP | All | 41.11 | 13.21 | 53.72 | 23.92 | 13.85 |
| TrEPS | 15 min | 75.75 | N/A | 100.77 | 79.75 | 41.81 |
| TrEPS | 30 min | 77.99 | N/A | 102.18 | 79.75 | 41.81 |
| TrEPS | 45 min | 70.45 | N/A | 103.28 | 79.04 | 41.81 |
| TrEPS | 60 min | 73.24 | N/A | 105.83 | 79.22 | 41.81 |
| TrEPS | 75 min | 73.69 | N/A | 106.44 | 78.76 | 41.81 |
| TrEPS | 90 min | 60.72 | N/A | 104.02 | 78.52 | 41.81 |
| TrEPS | 105 min | 63.65 | N/A | 101.16 | 78.19 | 41.83 |
| TrEPS | 115 min | 57.02 | N/A | 106.36 | 73.3 | 40.97 |
| TrEPS | All | 71.48 | N/A | 104.32 | 78.58 | 41.83 |

min = minute. MLP = machine learning-based prediction. N/A = not applicable. TrEPS = Traffic Estimation and Prediction System.

**Table 6. Root mean square error (in miles per hour) at Interstate 435 and State Line Road.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 7.19 | 5.69 | 7.83 | 5.05 | 4 |
| MLP | 30 min | 8.85 | 9.14 | 9.68 | 6.14 | 5.47 |
| MLP | 45 min | 9.67 | 9.47 | 10.73 | 6.8 | 7.07 |
| MLP | 60 min | 10.42 | 10.67 | 11.01 | 7.3 | 8.86 |
| MLP | 75 min | 11.75 | 11.64 | 11.24 | 7.48 | 10.24 |
| MLP | 90 min | 12.47 | 12.48 | 12.02 | 8.1 | 11.47 |
| MLP | 105 min | 12.82 | 13.09 | 12.11 | 8.32 | 12.2 |
| MLP | 115 min | 12.61 | 13.26 | 12.45 | 8.95 | 12.57 |
| MLP | All | 10.85 | 10.85 | 10.92 | 7.31 | 9.44 |
| TrEPS | 15 min | 25 | N/A | 23.67 | 25.02 | 20.37 |
| TrEPS | 30 min | 25.42 | N/A | 23.68 | 25.34 | 20.38 |
| TrEPS | 45 min | 24.54 | N/A | 23.82 | 25.43 | 20.4 |
| TrEPS | 60 min | 24.21 | N/A | 24.33 | 25.54 | 20.25 |
| TrEPS | 75 min | 24.16 | N/A | 24.29 | 25.49 | 20.43 |
| TrEPS | 90 min | 23.25 | N/A | 23.95 | 25.42 | 20.44 |
| TrEPS | 105 min | 23.19 | N/A | 23.95 | 25.13 | 20.51 |
| TrEPS | 115 min | 22.36 | N/A | 23.57 | 24.92 | 20.29 |
| TrEPS | All | 24.08 | N/A | 23.91 | 25.32 | 20.38 |

min = minute. MLP = machine learning-based prediction. N/A = not applicable. TrEPS = Traffic Estimation and Prediction System.

**Table 7. Absolute error 80 percent quantiles (in miles per hour) at Interstate 435 and East Stadium Drive.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 3.02 | 2.58 | 5.36 | 3.82 | 2.57 |
| MLP | 30 min | 3.62 | 2.96 | 5.8 | 4.88 | 3 |
| MLP | 45 min | 4.35 | 3.34 | 7.06 | 5.18 | 3.58 |
| MLP | 60 min | 4.66 | 3.41 | 6.52 | 6.08 | 4.94 |
| MLP | 75 min | 5.32 | 3.35 | 6.13 | 6.84 | 5.03 |
| MLP | 90 min | 5.66 | 3.43 | 8.24 | 7.37 | 5.36 |
| MLP | 105 min | 5.86 | 3.68 | 10.25 | 7.9 | 5.77 |
| MLP | 115 min | 6.03 | 3.97 | 10.15 | 7.3 | 5.41 |
| MLP | All | 6.04 | 7.21 | 7.21 | 6.04 | 4.62 |

min = minute. MLP = machine learning-based prediction.

**Table 8. Relative absolute error 80 percent quantiles (in miles per hour) at Interstate 435 and East Stadium Drive.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 5.26 | 5.25 | 13.88 | 7.78 | 4.45 |
| MLP | 30 min | 6.64 | 5.34 | 15.79 | 9.66 | 5.24 |
| MLP | 45 min | 8.27 | 5.8 | 16.66 | 11.33 | 6.26 |
| MLP | 60 min | 8.46 | 6.07 | 16.35 | 12.38 | 8.46 |
| MLP | 75 min | 9.56 | 5.75 | 16.58 | 13.05 | 9.2 |
| MLP | 90 min | 10.08 | 6.11 | 19.39 | 14 | 9.96 |
| MLP | 105 min | 10.61 | 7.02 | 22.45 | 15.2 | 10.2 |
| MLP | 115 min | 10.94 | 7.23 | 21.64 | 15.37 | 9.62 |
| MLP | All | 9.31 | 6.13 | 18.61 | 12.59 | 7.96 |

min = minute. MLP = machine learning-based prediction.

**Table 9. RMS error 80 percent quantiles (in miles per hour) at Interstate 435 and East Stadium Drive.**

| Source | Forecast Lead Time | 11/11/ 2019 | 11/29/ 2019 | 12/15/ 2019 | 12/16/ 2019 | 12/17/ 2019 |
|---|---|---|---|---|---|---|
| MLP | 15 min | 2.89 | 2.67 | 4.32 | 3.39 | 2.89 |
| MLP | 30 min | 3.29 | 3.67 | 5.39 | 3.78 | 3.47 |
| MLP | 45 min | 3.8 | 2.74 | 6.01 | 4.48 | 3.92 |
| MLP | 60 min | 4.14 | 2.6 | 6.13 | 4.69 | 4.28 |
| MLP | 75 min | 4.54 | 2.85 | 6.32 | 5.01 | 4.6 |
| MLP | 90 min | 4.5 | 2.94 | 6.65 | 5.28 | 5.1 |
| MLP | 105 min | 4.53 | 3.17 | 7.49 | 5.57 | 5.46 |
| MLP | 115 min | 4.75 | 3.25 | 8.19 | 5.83 | 6.05 |
| MLP | All | 4.09 | 3 | 6.36 | 4.78 | 4.57 |

min = minute. MLP = machine learning-based prediction.

**Table 10. Absolute error 80 percent quantiles (in miles per hour) at Interstate 435 and East Antioch Road.**

| Source | Forecast Lead Time | 1/29/2020 | 2/12/2020 |
|---|---|---|---|
| MLP | 15 min | 5.31 | 3.16 |
| MLP | 30 min | 5.22 | 4.2 |
| MLP | 45 min | 5.27 | 4.86 |
| MLP | 60 min | 5.45 | 5.44 |
| MLP | 75 min | 7.85 | 6.35 |
| MLP | 90 min | 11.26 | 6.95 |
| MLP | 105 min | 11.92 | 6.37 |
| MLP | 115 min | 13.54 | 6.51 |
| MLP | All | 7.09 | 5.6 |

min = minute. MLP = machine learning-based prediction.

**Table 11. Relative absolute error 80 percent quantiles (percent) at Interstate 435 and East Antioch Road.**

| Source | Forecast Lead Time | 1/29/2020 | 2/12/2020 |
|---|---|---|---|
| MLP | 15 min | 8.42 | 4.86 |
| MLP | 30 min | 7.98 | 6.86 |
| MLP | 45 min | 8.6 | 7.82 |
| MLP | 60 min | 8.93 | 8.26 |
| MLP | 75 min | 12.99 | 9.32 |
| MLP | 90 min | 21.43 | 10.38 |
| MLP | 105 min | 20.62 | 10.37 |
| MLP | 115 min | 25.87 | 10.65 |
| MLP | All | 12.71 | 8.5 |
| TrEPS | 15 min | 62.9 | 66.32 |
| TrEPS | 30 min | 54.3 | 67.48 |
| TrEPS | 45 min | 58.9 | 51.12 |
| TrEPS | 60 min | 64 | 51.8 |
| TrEPS | 75 min | 70.8 | 17.92 |
| TrEPS | 90 min | 67 | 38.01 |
| TrEPS | 105 min | 57 | 47.72 |
| TrEPS | 115 min | 57.1 | N/A |
| TrEPS | All | 61.5 | 51.75 |

min = minute. MLP = machine learning-based prediction. N/A = not applicable.
TrEPS = Traffic Estimation and Prediction System.

**Table 12. Root mean square error (in miles per hour) at Interstate 435 and East Antioch Road.**

| Source | Forecast Lead Time | 1/29/2020 | 2/12/2020 |
|---|---|---|---|
| MLP | 15 min | 8.58 | 4.33 |
| MLP | 30 min | 7.8 | 5.98 |
| MLP | 45 min | 9.38 | 7.51 |
| MLP | 60 min | 10.18 | 8.22 |
| MLP | 75 min | 10.52 | 8.85 |
| MLP | 90 min | 11.86 | 9.21 |
| MLP | 105 min | 11.96 | 9.51 |
| MLP | 115 min | 12.91 | 9.67 |
| MLP | All | 10.49 | 8.07 |
| TrEPS | 15 min | 29.69 | 24.16 |
| TrEPS | 30 min | 28.21 | 23.89 |
| TrEPS | 45 min | 30.58 | 23.36 |
| TrEPS | 60 min | 31.64 | 22.91 |
| TrEPS | 75 min | 32.14 | 19.85 |
| TrEPS | 90 min | 32.37 | 22.66 |
| TrEPS | 105 min | 29.86 | 22.09 |
| TrEPS | 115 min | 29.53 | N/A |
| TrEPS | All | 30.52 | 22.68 |

min = minute. MLP = machine learning-based prediction. N/A = not applicable.
TrEPS = Traffic Estimation and Prediction System.

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