Automating Variable Speed Limits Using Weather, Traffic and Friction Data

tech transfer summary

Aurora

working to advance road weather information systems technology

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RESEARCH PROJECT TITLE
Automating Variable Speed Limits Using Weather, Traffic and Friction Data

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The Aurora program is a partnership of highway agencies that collaborate on research, development, and deployment of road weather information to improve the efficiency, safety, and reliability of surface transportation. The program is administered by the Center for Weather Impacts on Mobility and Safety (CWIMS), which is housed under the Institute for Transportation at Iowa State University. The mission of Aurora and its members is to seek to implement advanced road weather information systems (RWIS) that fully integrate state-of-the-art roadway and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures.

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Variable speed limits offer a valuable tool for transportation agencies to proactively reduce crash risk and improve safety under a variety of adverse weather conditions.

Objective

The project's research objective was to investigate beneficial ways to recommend variable speed limits (VSLs) under a variety of adverse weather conditions.

Background

VSLs have the potential to enhance driver safety under adverse weather conditions and can reduce the number of crashes during the winter (Katz et al. 2012, 2017). VSLs are most suitable in locations subject to congestion, problematic weather conditions, incidents, and road construction.

Good driver compliance with VSLs can be obtained by setting speeds that are reasonable and neither too slow nor too fast for the underlying driving conditions. To achieve this balance during adverse weather conditions, the algorithm underlying the VSL must take the adverse conditions into account. With good compliance, VSLs can lead to improved safety, reduced travel time, reduced queue length, and fewer delays (Katz et al. 2012, Vrbanić et al. 2021).

While human-initiated VSLs are common and rules-based VSL models are utilized by multiple departments of transportation (DOTs), machine learning (ML) and physical models accounting for current weather conditions, roadway friction, or geometry are less prevalent. These latter models rely on road weather information system (RWIS) data to recommend VSLs autonomously.

https://www.udot.utah.gov/connect/2014/01/16/variable-speed-limit-signs-now-activated-on-i-80/

Variable speed limit sign

Problem Statement

A need exists to investigate methods to automatically recommend speeds for various weather conditions on roadway segments (straight or curved, downhill or uphill) that are good candidates for VSLs.

Research Description

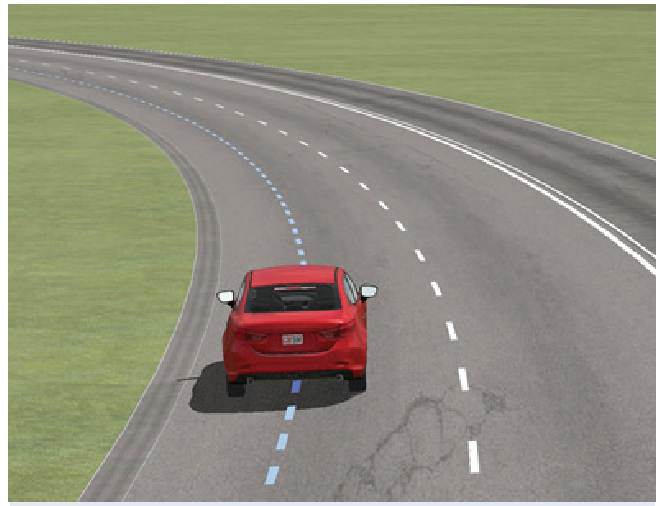
This research explored three key research areas: (1) VSL data analysis and ML model development, (2) VSL physical model development, and (3) a review of VSL requirements and state DOT rules of practice.

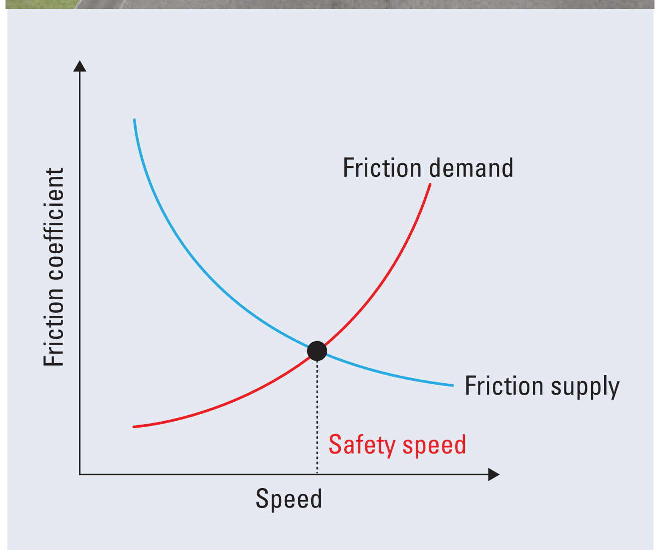
VSL Data Analysis and ML Model Development

Two distinct study areas were identified based on the availability of VSL signs with substantial winter histories and the availability of spatially and temporally available RWIS data:

- Parleys Canyon, Utah, located along I-80, which experiences high winter ski traffic that is frequently impacted by inclement weather posing safety and mobility concerns
- Multiple sites along I-80, I-25, I-90, and WYO789 in Wyoming, which wind through some of the harshest environmental conditions in the continental united States and are major shipping and cross county travel routes

Data were obtained from the Utah DOT (UDOT) and Wyoming DOT (WYDOT), and an extensive quality assurance (QA)/quality control (QC) process was performed on the RWIS data. Supervised ML modeling was then applied to the study areas for both regression (predicting continuous speed) and classification (predicting binary slowdown/no slowdown or binned speeds). Model performance was evaluated using root mean square error (RMSE) and mean absolute error (MAE) for regression and the F1 score for classification.





Physics-based method to determine VSLs: vehicle dynamics simulation on a horizontal curve (top), friction supply versus demand (bottom)

VSL Physical Model Development

A physics-based methodology was explored to determine the maximum safe speed of curves considering friction demand (the friction required by a vehicle to safely navigate a curve) and friction supply (the available friction on the road surface).

Friction demand was determined using two approaches: the traditional American Association of State Highway and Transportation Officials (AASHTO) point-mass model and a more sophisticated vehicle dynamics simulation. Friction supply was derived from real-time data collected by RWIS sensors. The maximum safe speed for a given curve and weather condition was identified as the intersection point where the escalating friction demand curve meets the declining friction supply curve.

A road segment on I-80 in Utah, a mountainous route with numerous curves and frequent adverse weather, was selected as a case study.

VSL Requirements and DOT Rules of Practice for VSL

A survey was used to identify state and local agencies that are using VSLs or variable speed advisories (VSAs) and to capture information on data used, triggers, who is responsible for managing the system, the extent and maturity of deployment, evaluations completed, and design specifications. Twenty-six responses were obtained, and further information was captured through additional or follow-up interviews.

Key Findings

VSL Data Analysis and ML Model Development

- For Parleys Canyon, Utah, the classification models achieved F1 scores of 0.84 (using meteorological predictors) and 0.82 (using road predictors) for binary slowdown/no slowdown cases. Classification models with F1 scores of 0.82 or above were also possible for binned speed models (e.g., 20 mph bins). Regression models demonstrated high performance, achieving an MAE and RMSE of less than 5 mph on average, with high R2 scores.

- The ML models for Wyoming exhibited reasonable skill, though their predictive ability was impacted by the absence of grip observations and the high proportion of slowdowns not directly tied to measurable weather or road conditions. The classification models achieved an F1 score of 0.71 with all predictors. However, for specific stations with fewer non-weather-related slowdowns, F1 scores exceeding 0.82 were possible for binary slowdown/no slowdown classification. Regression models for certain stations also achieved MAE errors of less than 5 mph, showing reasonable improvement over simply predicting the average speed.

VSL Physical Model Development

- Vehicle dynamics simulation provides a more realistic and critical assessment of friction demand than the point-mass model, especially at higher speeds.

- AASHTO design speeds, while adequate for normal conditions, are often unsafe during snow and ice events, underscoring the necessity of weather-responsive VSLs.

- To enable real-time application, correlation models were developed that directly link RWIS friction values to pre-calculated maximum safe speeds for specific curve geometries.

- A comparison with the existing VSL strategy on I-80 revealed that while the current system is generally conservative, the proposed model offers greater responsiveness to sudden drops in friction.

VSL Requirements and DOT Rules of Practice for VSL

- Of the 26 respondents, 16 indicated that they use VSLs or VSAs in their operations. The reported use of VSLs and VSAs are most commonly initiated due to roadway conditions, visibility issues, work zones or temporary traffic control scenarios, and traffic volume, with VSLs and VSAs initiated less commonly due to crashes, speed, precipitation, roadway grip, and temperature.

- For most agencies, VSLs are enforceable, but many agencies are using a combination of VSLs and/or VSAs.

- On average, responding agencies indicated that they have been using VSLs or VSAs for 7 years, with a few exceptions. Newer deployments have occurred in Montana and Wyoming, and future deployments are planned in Texas and Nebraska. Respondents provided the locations where VSLs and VSAs have been implemented; all deployments were on state or Interstate highways.

- Roadside changeable speed limit signs and roadside dynamic message signs (or variable message signs) are the most commonly used formats to convey messages to the public, followed by news outlets and, less commonly, social media.

- For most agencies, traffic management centers (TMC) or traffic operations centers (TOC) support the VSLs and VSAs, with the messages typically triggered manually by a person or by a data- or rules-based trigger. RWIS data, meteorological data, and camera images are the most commonly used data to support VSLs and VSAs. For most agencies, the data used to support VSLs and VSAs are retained.

- Just over half of responding agencies indicated that they have evaluated the effectiveness of their VSL/VSA program. Data used in the evaluations have included crash data, driver compliance data, crash severity data, personal experience by local supervisors and/or superintendents, and traffic speed sensor data.

Conclusions

- Statistical analysis showed that surface status and friction (grip) appear to be highly correlated with speed and may be important predictors for triggering VSLs.

- Weather variables, including relative humidity, visibility, precipitation type/intensity, solar radiance, and wind direction, are other important potential predictors for VSL models, as they are associated with winter storm events that lead to a buildup of snow or ice on the pavement and an associated reduction in friction (grip).

- A significant finding for both datasets (Utah and Wyoming) was that weather variables held an equal or slightly greater importance than non-weather surface variables in reliably predicting VSL speeds.

- Physical modeling successfully demonstrated a comprehensive and adaptive framework for VSL automation. By integrating real-time RWIS data with advanced vehicle dynamics, the proposed model can generate speed limits that are dynamically tailored to specific road geometries and weather conditions.

- VSLs and VSAs have been successfully applied in the United States, leading to reductions in speed and improved safety where applied.

Limitations and Recommendations for Future Development

- Future research should focus initially on observation data quality and analysis, as these are critical factors in developing high-performance ML models for reliably predicting VSLs.
- The eXtreme Gradient Boosting (XGBoost or XGB) algorithm in particular shows great promise for developing state-of-the-art ML models on tabular data such as VSL prediction.
- Reinforcement learning (RL) can be explored for speed automation in future research if reliable and dynamic or real-time observations become available at a larger scale.
- AASHTO design speeds may not be adequate for ensuring safety under severe weather conditions such as snow and ice.

Implementation Readiness and Benefits

Both ML and physical modeling approaches provide a significant enhancement over static speed limits and less-responsive VSL systems. These approaches offer a valuable tool for transportation agencies to proactively reduce crash risk and improve safety on horizontal curves and under a variety of adverse weather conditions found in extreme environments of the mountains and plains in the western United States.

References

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