



Examining Potential Southern California High Winds Adaptation Strategies

Requested by

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List of Abbreviations and Acronyms

| | |
|----------|--|
| AASHTO | American Association of State Highway and Transportation Officials |
| CA | California |
| Caltrans | California Department of Transportation |
| CFD | computational fluid dynamics |
| CV | connected vehicle |
| CVOP | Commercial Vehicle Operator Portal (Wyoming) |
| DMS | dynamic message signs |
| DOT | department of transportation |
| ESS | Environmental Sensor Station |
| I-15 | Interstate 15 |
| ILMA | Lombada Forest Intervention Region (Portugal) |
| NARR | North American Regional Reanalysis |
| ODOT | Oregon Department of Transportation |
| OR | Oregon |
| PSPS | public safety power shutoff |
| PWIS | portable weather instrument station |
| RANS | Reynolds-average Navier–Stokes |
| RoS | rate of spread |
| RWIS | road weather information system |
| UW | University of Wyoming |
| V2I | vehicle to infrastructure |
| V2V | vehicle to vehicle |
| WA | Washington |
| WRF | Weather Research and Forecasting |
| WSDOT | Washington State Department of Transportation |
| WYDOT | Wyoming Department of Transportation |

Executive Summary

Background

Southern California's Interstate 15 corridor, a major commercial and commuter corridor, is increasingly vulnerable to extreme Santa Ana winds, particularly through the Cajon Pass. When coupled with high temperatures and dry vegetation, Santa Ana winds significantly heighten the risk of fast-spreading wildfires and infrastructure disruption.

The current lack of integrated wind-resilient features in transportation infrastructure results in more frequent road closures and detours, increasing overhead and capital costs. Understanding both the state of scientific knowledge and real-world implementation practices is vital to building an adaptable, cost-effective resilience framework that can be supported by both decision-makers and the community.

To gather information that will aid Caltrans' investigation, CTC & Associates surveyed state departments of transportation (DOTs) to examine alternatives for, and the success of, wind-resilient adaptation strategies that can inform implementation of regionally appropriate practices across California. A review of in-progress and completed domestic and international research regarding high wind adaptation strategies supplemented survey findings.

Summary of Findings

Survey of Practice

An online survey distributed to state DOT members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Security and Resilience and selected California contacts identified by the project panel sought information about high wind adaptation strategies. Five agencies responded to the survey:

- Caltrans District 9
- Idaho Transportation Department
- San Bernardino County Transportation Authority
- South Dakota DOT
- Wyoming DOT

Survey findings are summarized below in two topic areas:

- Agency experience with high wind adaptation strategies
- Agencies not employing high wind adaptation strategies

Agency Experience with High Wind Adaptation Strategies

Wyoming DOT is the only responding agency to describe experience with a formalized high wind adaptation strategy.

Wyoming Department of Transportation: Weight-Based Wind Closure System

Background

In Wyoming, severe wind events tend to occur during the winter months, when wind speeds can reach 30 to 40 mph over extended periods with wind gust speeds up to 50 to 60 mph. Beginning in 2020 through 2022, the state experienced an average of 167 vehicle blow overs per year. After implementing a

new weight-based wind closure system in October 2023, blow overs were reduced by at least half in 2023 and 2024.

Genesis of the System

While Wyoming DOT has been closing portions of the state's highways to light, high-profile vehicles since 2011, the volume of out-of-state vehicles using Wyoming highways, coupled with the significant winds experienced across the state, prompted the agency to better define *light, high-profile vehicles* and provide clear messaging for commercial and noncommercial drivers that specifies the vehicle weights subject to high wind advisories.

System Deployment

The weight-based wind closure system deploys in locations with wind gusts greater than 50 mph under any road conditions, provided there is adequate signage to inform the traveling public. Deployment of the system produces a *Blow-Over Risk* advisory for a road closure to vehicles at or below a specific gross vehicle weight. Drivers are advised not to travel when a *Blow-Over Risk* advisory is posted.

The public is notified of *Blow-Over Risk* advisories through three primary sources:

- *Pre-trip information systems*: Wyoming DOT website, WYDOT Commercial Vehicle Operator Portal, 511 phone system, text and email alerts, mobile app, YouTube video forecasts and Wyoming DOT Public Affairs Office social media.
- *Roadside information systems*: dynamic message signs, variable speed limits, highway advisory radios and road weather information systems.
- *In-vehicle information systems*: Shared road condition information with third-party providers such as Google, TomTom, SiriusXM and others.

Recent legislation that addresses the failure to comply with road closures may encourage compliance with the closure system. On July 1, 2024, a new law went into effect that provides for penalties associated with closures to light and high-profile vehicles and other weight-based road closures.

System Assessment

Wyoming DOT tracks the number and frequency of blow overs to assess the success of the weight-based wind closure system. The agency has identified a statistically significant reduction in blow-over crashes since adoption of the new closure system despite an increase in severe wind events.

The most significant challenges to date have been ensuring that Wyoming DOT and Wyoming Highway Patrol staff are informed of new processes and establishing a process for providing additional information when reporting on blow-over crashes. When asked to provide a lesson learned or best practice, the survey respondent noted that “[u]sing research has greatly added to the credibility of what we are doing.”

High Wind Research

The **Detailed Findings** section of this report presents more information about the primary findings of Wyoming DOT research that provided the basis for the agency's high wind closure system:

- *Estimating the Relationship Between Measured Wind Speed and Overturning Truck Crashes Using a Binary Logit Model* (2007). Correlates data from Wyoming's overturned freight vehicle crash records to wind speeds measured at nearby weather stations.

- *High Wind Warning System for Bordeaux, Wyoming* (2010). Correlates the likelihood of overturning trucks and weather conditions to develop a three-level warning system.
- *Connected Vehicle Pilot: Final System Performance Measurement and Evaluation — WYDOT CV Pilot* (2022). Adds a blow-over algorithm to Pikalert that uses wind gust speed and other variables to provide a blow-over risk rating.
- *Historical Winter Weather Assessment for Snow Fence Design Using a Numerical Weather Model* (2017). Develops a dataset with continuous weather data in areas where wind and precipitation data are hard to obtain.
- *Characterization of Blow Over Risk in the Wyoming Highway System* (2021). Develops a model to quantify blow-over crash risk in real time using a range of variables. Provides the foundation for the October 2023 launch of the agency’s weight-based wind closure system.

In research now underway, Wyoming DOT is investigating a physical means to mitigate high winds with *Evaluation of Blow-Over Risk Reduction by Wind Fences Using Wind Profile Measurements*. This project is expected to conclude in June 2027.

Other Wyoming DOT high wind resources include a website about the weight-based wind closure system and a two-page illustrated brochure from the Public Affairs Office that describes the system and provides images of the truck types prone — and not prone — to blowing over.

Agencies Not Employing High Wind Adaptation Strategies

Four of the five responding agencies are not currently employing high wind adaptation strategies:

- Caltrans District 9
- Idaho Transportation Department
- San Bernardino County Transportation Authority
- South Dakota DOT

Described below are South Dakota DOT’s efforts toward a future implementation.

South Dakota DOT’s High Wind Warning Initiative

The South Dakota DOT respondent identified truck blow overs and widespread sign damage resulting from the state’s high-speed straight-line winds as prompting the agency’s interest in high wind warning systems. The agency is assembling a project team that will include representatives from the National Weather Service, South Dakota Highway Patrol and the South Dakota Trucking Association with an eye toward system installation in the next five years.

The project team seeks to “create a system like Wyoming’s to issue specific warnings and closures for light, high-profile vehicles during high wind events.” The future system will use real-time sensors to monitor wind speed, wind direction and road geometry to identify risks for commercial trucks with light loads. Message boards, social media and 511 will be used to communicate warnings and closures to the public. A review of current state law will assess the need for additional legislative authority for the proposed system to restrict the travel of high-profile vehicles.

Other Responding Agencies’ High Wind Environments

Idaho Transportation Department is not considering implementing a high wind adaptation strategy, with the respondent noting that the issue is not a priority relative to other hazards and the risk is low. The

remaining two agencies reported interest in developing adaptation strategies but no formal plans to do so. Selected elements of these agencies' high wind environments are described below:

- *Caltrans District 9*. Rather than a formalized notification system, the district uses word of mouth from maintenance crews or law enforcement triggers road closures for high-profile vehicles. Barriers to a future implementation include funding, IT system deficiencies, maintenance capacity and permitting.
- *San Bernardino County Transportation Authority*. Wildfire due to high wind is the most relevant hazard for San Bernardino County's transportation and energy assets. Stress and physical damage to the system cause other wildfire and flooding events. Operational measures of interest are those that can reduce the number of public safety power shutoff days, especially for critical infrastructure.

Related Research and Resources

A sampling of domestic and international research supplements the research sponsored by Wyoming DOT and the public-facing materials the agency produced to support implementation of the weight-based wind closure system. Highlighted below are selected publications, other than those sponsored by Wyoming DOT, cited in **Detailed Findings**.

High wind guidance and strategies are highlighted in a 10-step plan developed by Transport Scotland, which offers guidelines for high wind management that include defining high wind level thresholds, developing the levels of restriction, determining enforcement and disseminating information about the guidance. A United Kingdom study offers adaptation measures for roadway threats associated with high winds, and identifies risk results with and without adaptation and estimated costs.

High winds and wildfires are considered in an article about the West Coast's 2020 Labor Day Wildfires that described the interplay of wind and fire:

While these large-scale wildfires are associated with dry, easterly winds and concurrent drought, the regionally distinct patterns of wind, fuel, fire size and drought in the 2020 event point to a more complex mechanism than the mere coincidence of wind and drought. A more complex 'recipe' for major westside flames than just wind and drought happening at the same time includes the presence of mountainous areas and valley margins that appear to have affected fire growth and spread. The variation in fire size appears to be partially explained by geographic patterns of wind speed and drought.

A 2024 Portugal study noted that "agricultural/pasture areas could be used as fuel breaks in fires dominated by high winds but moderate humidity levels, and have in fact been used to assist in fire management operations." United Kingdom researchers considered the effect of vegetation height and bulk density on wildfire propagation, noting that "grass-cutting is observed to effectively curb fire propagation, although it may be less effective under specific conditions such as high winds, as vegetation characteristics and propagation modes significantly affect fire dynamics."

Wind fences are examined in a series of articles by international research teams. Two studies consider the efficacy of a deflector-porous fence as compared to traditional wind fencing and the limitations of wind tunnel testing in determining the efficiency of fences as a windbreak. A research effort that "focused on truck aerodynamic analysis under crosswind conditions by means of numerical modeling" analyzed "the effect of both height and porosity of wind fence models on the aerodynamic

coefficients acting on [the] truck with respect to separation distance between the truck and the wind fence.”

Gaps in Findings

The survey received very few responses. Of the five respondents, only Wyoming DOT reported on an implemented high wind adaptation measure. Another respondent, from South Dakota DOT, offered information about that agency’s nascent effort to develop a high wind warning system similar to Wyoming DOT’s. The South Dakota DOT effort will require follow-up to assess its progress.

An examination of relevant literature did not identify well-documented, formalized high wind adaptation strategies, other than the recently implemented system in Wyoming, that can inform the development of other agencies’ high wind monitoring systems or physical measures to address high wind corridors on transportation networks. However, a research project expected to conclude in June 2027 is assessing the efficacy of the application of wind fences in Wyoming.

Next Steps

Moving forward, Caltrans could consider:

- Engaging with the Wyoming DOT respondent to learn more about the development, implementation and continuing assessment of the agency’s weight-based wind closure system.
- Checking in with the South Dakota DOT respondent to inquire about the agency’s progress on developing a high wind warning system.
- Reviewing the Transport Scotland 10-step guideline to identify elements of this practice that may apply to Caltrans’ high wind corridors:
 - Diversion route planning, monitoring, high wind level thresholds, levels of restriction, enforcement and information dissemination.
 - Modeling that identifies the comparative mean wind speeds and gust speeds for the trunk road network and certain local roadways using historical wind data.
 - High wind strategy forum of law enforcement and others in impacted areas.
 - Roles, responsibilities and procedures for:
 - Trunk road maintenance organizations (operating companies).
 - Traffic control centers.
 - Police forces.
 - Local authorities.
- Tracking ongoing Wyoming DOT research that is assessing the efficacy of wind fences as a physical high wind adaptation strategy.

Detailed Findings

Background

Southern California's Interstate 15 (I-15) corridor, a major commercial and commuter corridor, is increasingly vulnerable to extreme Santa Ana winds, particularly through the Cajon Pass. When coupled with high temperatures and dry vegetation, Santa Ana winds significantly heighten the risk of fast-spreading wildfires and infrastructure disruption.

Events such as the 2015 North Fire and 2016 Blue Cut Fire threaten public and tourist safety, disrupt cargo logistics, lead to costly emergency road repairs, and overload alternate local roads that are not designed for heavy traffic. Despite these recurring impacts, comprehensive adaptation strategies that combine engineering, ecological and operational solutions remain underdeveloped. The current lack of integrated wind-resilient features in transportation infrastructure results in more frequent road closures and detours, increasing overhead and capital costs.

While some studies have explored structural interventions (e.g., wind fairings, fences) and nature-based solutions (e.g., vegetative windbreaks) to address high winds, the California Department of Transportation (Caltrans) is unaware of an effort to synthesize these approaches into a regionally applicable strategy for the I-15 corridor. Understanding both the science and real-world implementation practices is vital to building an adaptable, cost-effective resilience framework that can be supported by both decision-makers and the community.

Below is a presentation of information gathered about these issues. The materials and experience discussed in this investigation were gathered through a survey of state departments of transportation (DOTs) and a review of in-progress and completed domestic and international research.

Survey of Practice

An online survey distributed to state DOT members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Security and Resilience and selected California contacts identified by the project panel sought information about respondents' experience with high wind adaptation strategies. Five agencies responded to the survey:

- Caltrans District 9
- Idaho Transportation Department
- San Bernardino County Transportation Authority
- South Dakota DOT
- Wyoming DOT

Survey questions are provided in [Appendix A](#). Survey findings are summarized below in two topic areas:

- Agency experience with high wind adaptation strategies
- Agencies not employing high wind adaptation strategies

Agency Experience with High Wind Adaptation Strategies

Of the five respondents, only the Wyoming DOT respondent reported experience with a high wind adaptation strategy.

Wyoming Department of Transportation

Background

Since 2011, Wyoming DOT has closed sections of highway to light, high-profile vehicles to limit blow-over crashes caused by high winds and strong crosswinds. In Wyoming, severe wind events tend to occur during the winter months, when wind speeds can reach 30 to 40 mph over extended periods with wind gust speeds up to 50 to 60 mph.

In recent years, Wyoming has had roughly 20 to 30 more windy days than in the 1980s. An April 2025 annual report on traffic crashes in Wyoming noted that “there are occasional hurricane force wind gusts, or wind gusts in excess of 74 mph, with some wind gusts that would be classified as a Category 2 (96 to 100 mph).”

An August 2023 presentation provided to the Wyoming State Legislature, [High Wind Blow Over Briefing](#), sought to address why high wind blow overs are increasing in the state and offered data on the preceding five years of blow-over crashes:

- 2018: 87
- 2019: 83
- 2020: 167
- 2021: 178
- 2022: 157

Beginning in 2020 through 2022, the state averaged 167 blow-over crashes per year. The two most recent Wyoming DOT annual reports of traffic crashes reflected lower numbers of blow-over crashes for these years:

- 2023: 67
- 2024: 83

The survey respondent noted that these lower crash numbers were recorded after the October 2023 implementation of a targeted strategy to address blow-over crashes. This strategy — a weight-based wind closure system — and the research that informed it are discussed below.

Table 1 provides information provided by the survey respondent on the nature of the high wind challenges in Wyoming and how the agency is addressing them.

Table 1. High Wind Environment (Wyoming DOT)

| <u>Topic</u> | <u>Description</u> |
|---|--|
| Assets Most Impacted by High Winds | Wyoming DOT and Wyoming Highway Patrol have identified “a large impact from wind-related blow-over crashes.” |
| Most Relevant Hazards | Wind gusts exceeding 60 mph are common during winter months in Wyoming. |

| <u>Topic</u> | <u>Description</u> |
|--|--|
| Operational Triggers | The agency has developed research-based algorithms to restrict travel of high-profile vehicles based on their weight and blow-over risk during high wind events. |
| Observed Impacts in Last Five Years | Between 2020 and 2022, the state experienced an average of more than 160 vehicle blow overs per year. After implementing the strategy described in Table 2, blow overs were reduced by more than half. |
| Structural Measures | Wyoming DOT uses a large number of snow fences and began testing snow fence as a means to provide a wind barrier. See page 19 for more about this ongoing research. |
| Vegetative Windbreaks | Living snow fence has been employed as a vegetation barrier. |
| Operational Measures | The agency closes roadways to certain vehicles based on their profile and vehicle weight, which has proved to be effective in reducing blow-over crashes. |
| Monitoring and Prediction | Road weather information systems are key to the agency's algorithms. |
| Traveler Information | Wind alerts are posted beginning at 40 mph. |

Weight-Based Wind Closure System

Weight-based wind closures for light, high-profile vehicles are used to address high winds occurring across the state. (Several known problem areas are related to topography.) Table 2 presents the survey respondent's description of the new system. Following the table are additional system details drawn from publicly available sources.

Table 2. Weight-Based Wind Closure System (Wyoming DOT)

| <u>Topic</u> | <u>Description</u> |
|--|---|
| Installation Date | October 2023 |
| Monitoring Practice | Every reported vehicle blow over is monitored and reviewed. |
| Information Dissemination | Dynamic message signs (DMS) and various public information systems are used to inform the traveling public. |
| Impact on Emergency Response | The wind closure strategy has reduced the number of emergency responses; fewer crashes result in fewer callouts. |
| Safety Issues | None |
| Cost and Maintenance Requirements | Some algorithm development costs and modifications to software were required, but the cost to implement this strategy was minimal. |
| Identifying Other High Wind Locations | The agency has used GIS to analyze all routes in the state for vehicle blow-over potential. Road closures are implemented only in locations that have adequate DMS. |

Topic

Description

Assessment

The agency tracks the number and frequency of blow overs to assess the success of this strategy. The agency has identified a statistically significant reduction in blow-over crashes despite an increase in severe wind events.

The most significant challenges to date have been ensuring that Wyoming DOT and Wyoming Highway Patrol staff are informed of new processes and establishing a process for reporting blow-over crashes with additional detail. When asked to provide a lesson learned or best practice, the respondent commented, "Using research has greatly added to the credibility of what we are doing."

Genesis of the System

Wyoming DOT has been closing portions of the state’s highways to light, high-profile vehicles since 2011. But as the speaker’s notes for a 2023 presentation to the Wyoming Legislature noted, “[Wyoming DOT] has historically closed roads to light, high-profile vehicles. This definition was ambiguous and difficult to enforce.”

The volume of out-of-state vehicles using Wyoming highways, coupled with the significant winds experienced across the state, prompted the agency to better define *light, high-profile vehicles* and provide clear messaging for commercial and noncommercial drivers that specifies the vehicle weights subject to high wind advisories.

Figure 1, which illustrates the physics of a blow over, is taken from the research report that informed development of Wyoming DOT’s weight-based wind closure system.

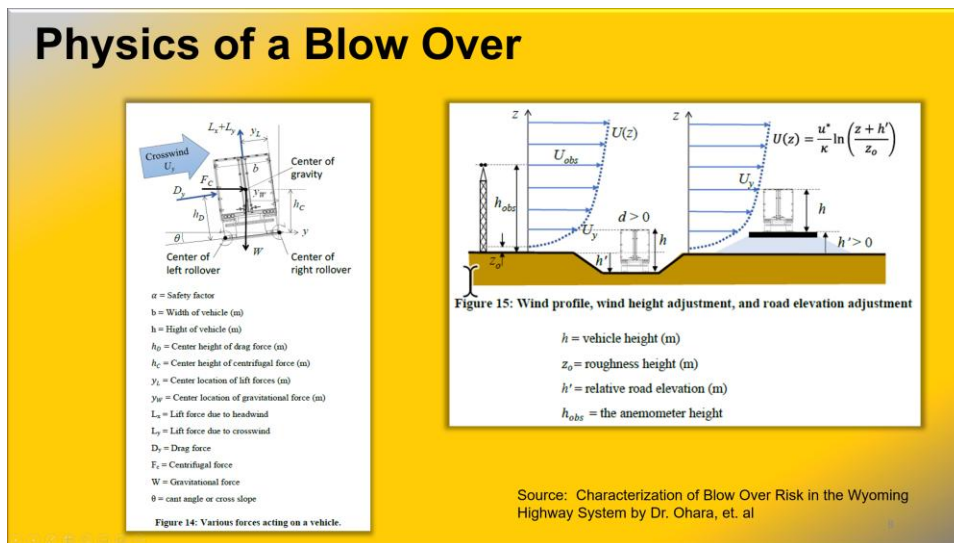


Figure 1. Illustration of the Physics of a Blow Over
(Source: Reducing Blow Over Crashes.)

System Deployment

The system is deployed in locations with extreme wind gusts (greater than 50 mph) under any road conditions, provided there is adequate signage to inform the traveling public. Deployment of the system produces a *Blow-Over Risk* advisory for a road closure to vehicles at or below a specific gross vehicle weight (GVW). GVW is the total weight of a truck and its payload, which includes all people in the vehicle and all contents of a tractor and trailer. Drivers are advised not to travel when a *Blow-Over Risk* advisory is posted.

Closures may be partial, when a road is closed to some but not all vehicles or closed in only one direction. In areas along Interstate 80 with small towns that may offer limited resources, a long-duration closure may be shifted to the next town to avoid stranding travelers in a location lacking necessary services. Roads may also permit local traffic only. A *No Unnecessary Travel* advisory means “the road is open but travel is not recommended due to hazardous driving conditions.” Examples of conditions that would generate such an advisory include extremely icy conditions and limited visibility due to blowing snow.

Differentiating Vehicle Types

A September 2025 Wyoming DOT Public Affairs Office publication ([Blow Over Hazards: Weight-Based Closures, Advisories and Definitions](#)) differentiates truck types as those prone and not prone to blowing over:

Prone to Blowing Over

- Semi-truck with enclosed trailer (single or tandem)
- Recreational vehicles (single unit with or without pull-behind)
- Recreational vehicle (single unit, truck-mounted or pull-behind)
- 5th wheel recreational vehicles and toy haulers
- Box trucks or moving vans
- Horse/livestock or box/cargo trailers

Not Prone to Blowing Over

- Tanker truck or belly dump
- Empty flatbed truck
- School bus
- Flatbed truck carrying odd-shaped load

A [travel website addressing Wyoming wind](#) describes Wyoming DOT’s experience, which indicates that “enclosed trailers (e.g., 53-foot box trailers and doubles) are most susceptible to being blown over. Tankers and flatbed trailers that are unloaded or are not hauling a high-profile load, such as cargo containers, are also less risky and typically not included in the weight-based wind restrictions.”

Informing the Public

The public is notified of *Blow-Over Risk* advisories through three primary sources:

- *Pre-trip information systems*: Wyoming DOT website, [WYDOT Commercial Vehicle Operator Portal \(CVOP\)](#), 511 phone system, text and email alerts, mobile app, YouTube video forecasts and Wyoming DOT’s Public Affairs Office social media.

Note: Wyoming DOT’s CVOP “provides visibility, wind and surface condition forecasts for interstate highways in Wyoming.” Access is limited to professional truckers and trucking companies.

- *Roadside information systems*: DMS, variable speed limits, highway advisory radios and road weather information systems.
- *In-vehicle information systems*: Shared road condition information with third-party providers such as Google, TomTom, SiriusXM and others.

Failure to comply with a *Blow-Over Risk* advisory may result in penalties, described below.

Supporting Legislation

New penalties for failure to comply with road closures may encourage compliance with the closure system. On July 1, 2024, a new law went into effect (see [SF0113 - Light and high profile vehicle closures](#) for the bill text) that provides for penalties associated with closures to light and high-profile vehicles and other weight-based closures.

The Wyoming Legislature provides a summary of major elements of this act that “[creates] an offense and penalties for willfully failing to observe signs for closure to light and high profile vehicles or other weight based road closures”:

Summary/Major Elements:

- This act establishes a misdemeanor criminal offense for any person who willfully fails to observe any sign, warning or notice (among other things) placed or given for road closure to light and high profile vehicles or for other weight based road closures.
- For a first offense, a person failing to observe a light and high profile or weight based road closure is subject to a fine of one thousand dollars (\$1,000.00) and may be subject to imprisonment for up to thirty (30) days.
- For a second or subsequent offense within three (3) years of the first offense, the person must pay a fine of two thousand five hundred dollars (\$2,500.00) and may be subject to imprisonment for up to thirty (30) days. A second or subsequent offense is deemed to be reckless driving for purposes of any driver licensing action.
- The act requires any person who is guilty of this offense to pay the required fine.

Note: The summary above is provided with the following disclaimer:

The above summary is not an official publication of the Wyoming Legislature and is not an official statement of legislative intent. While the Legislative Service Office endeavored to provide accurate information in this summary, it should not be relied upon as a comprehensive abstract of the bill.

Characterizing the Research Informing the New System

The 2021 Wyoming DOT research study, [Characterization of Blow Over Risk in the Wyoming Highway System](#), laid the groundwork for implementation of the weight-based wind closure system. As an [August 2023 presentation](#) noted, the researcher:

- Provided the ability to extrapolate wind data to other locations.
- Provided risk levels for tractor/trailer combinations (flatbeds and tankers are less prone to blowing over).
- Included the cross slope of a curve as a contributing factor.

- Noted that a slight head-wind is more dangerous than a direct broadside gust for a heavy vehicle; light trucks can blow over from almost any wind direction.

Research findings identified five steps to develop an operational system that produces a blow-over risk warning:

- Identify roadway features
- Develop tables for each weather station
- Link real-time wind speed and direction to developed tables. The research team determined critical wind speed based on vehicle weight and superelevation in 5,000-pound increments and identified that risk increases as wind speed and superelevation increases.
- Provide the weight restriction to Wyoming DOT’s traffic management center
- Make information available at the roadside

In the abstract for a January 2023 *Transportation Research Record* article, the research team described the model calibration and results that informed development of the new wind closure system:

Data about blow-over crashes from 2012 to 2020 were used to calibrate a new statewide model, and this model was leveraged to observe the evolution of blow-over risk during high wind periods from past blow-over crash events. The results from this model show that blow-over crashes occur in specific zones with elevated risk variables. The model was also especially precise at predicting crash locations within 10 km of nearby weather stations.

An October 2025 presentation to the National Society of Professional Engineers (see page 25 of this report for a citation) highlighted areas where the agency is continuing to improve its high wind adaptation efforts:

- **Communication:** Seeking to provide targeted information for better roadside messaging and enforcement and identify an approach to inform drivers upstream.
- **Vehicle assessment:** Evaluating smaller vehicles such as camping trailers and horse trailers and other commercial vehicle configurations (see Figure 2). The midsize camper trailer and 28-foot tractor trailer combination appear to be particularly prone to a blow over. The agency has been informed by troopers that these risks model very well with real-world situations.

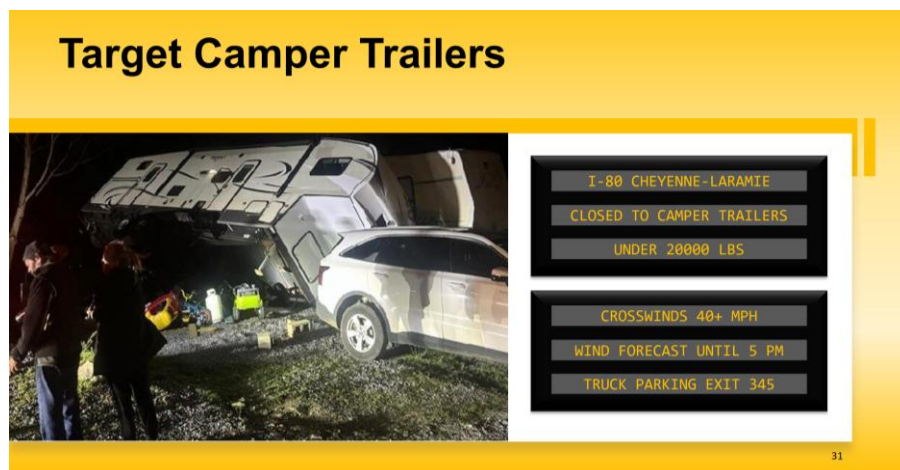


Figure 2. Roadside Information for Camper Trailer Closure

(Source: Reducing Blow Over Crashes.)

Wyoming DOT's High Wind Research

Wyoming DOT's use of technology to address high wind blow-over hazards includes the agency's participation in a U.S. DOT Intelligent Transportation Systems Joint Program Office Connected Vehicle Pilot Project that launched in September 2015. More recent research led to development of the weight-based wind closure system launched in October 2023. Research in progress, expected to conclude in June 2027, seeks to provide "the information needed to design wind fences for blow-over risk mitigation for high-profile lightweight vehicles under different high wind conditions." Below are details of selected research efforts that are more formally cited in the **Related Resources** section of this report (see page 24).

Foundational Research

Highlighted below are selected research efforts that informed more recent research seeking to manage the blow-over risk for vulnerable, high-profile and other vehicles traveling the state's highways.

Quantitative Model Predicts Probability of Overturned Trucks

Background: Researchers used a database of more than 14,000 truck crashes from 1994 to 2003 and wind speed and gust information from 21 weather stations to determine whether "measured wind speed at a remote weather station is an adequate predictor of the crash occurrence." If such a correlation can be made, a model can be developed to predict the probability of trucks being overturned using data collected at nearby weather stations.

Research Results: The authors commented that their development of a quantitative model that correlates data from Wyoming's overturned freight vehicle crash records to wind speeds measured by nearby weather stations is notable for two reasons:

- Wind variables such as wind speed and the difference between measured wind gust speed and average wind speed were found to be significant in the estimated models.
- As the authors noted, before this research, "It was believed by some that wind conditions were too localized for weather station data."

Source: [*Estimating the Relationship Between Measured Wind Speed and Overturning Truck Crashes Using a Binary Logit Model*](#) (2007)

Early High Wind Warning System Applies Statistical Model

Background: Severe wind conditions in the southeast corner of Wyoming along Interstate 80 and Interstate 25 prompted this project that sought to develop an experimental high wind warning system. A review of historical crashes over a 15-year period led researchers to identify a hazardous section of Interstate 25 for deployment of the proposed system.

Research Results: A statistical model that revealed the correlation between the likelihood of overturning trucks and weather conditions was used to develop a warning system that employed three operation levels:

- Level 1: Wind speeds and road surface variable thresholds for advisory warning messages on DMS.
- Level 2: Wind speed, road surface variable, vehicle type and vehicle weight thresholds to determine road closure for all high-profile, lightweight vehicles.
- Level 3: Wind speed, road surface variable and vehicle type variable thresholds to determine road closure for all high-profile vehicles.

Recommended thresholds for each operation level are provided in the final report.

Source: [High Wind Warning System for Bordeaux, Wyoming](#) (2010)

Pilot Project Applies Blow-Over Risk Algorithm

Background: This multiyear effort launched in 2015 to develop connected vehicle (CV) applications sought “to reduce the impact of adverse weather on truck travel in the I-80 corridor.” The Pikalert system, developed by the National Center for Atmospheric Research to generate in-vehicle warnings for users, lacked a wind algorithm needed to generate high wind warnings.

Research Results: The blow-over algorithm added to Pikalert applies a fuzzy logic algorithm that uses wind gust speed, the difference between the wind gust speed and sustained wind speed, orientation of the wind direction relative to the roadway, and pavement slickness to provide a blow-over risk rating of 0 to 1 for four vehicle categories: pickups with trailers, light high-profile, heavy high-profile and a generic all vehicles category. Vehicles with on-board units equipped with Dedicated Short-Range Communications participating in the pilot received the high wind warnings.

Source: [Connected Vehicle Pilot: Final System Performance Measurement and Evaluation — WYDOT CV Pilot](#) (2022)

Model-Simulated Wind Field Identifies Hot Spots

Background: The research team updated data (Tabler data) used for snow fence design that include prevailing wind direction and snow precipitation for the period 1980 to 2014 using the Weather Research and Forecasting (WRF) model with North American Regional Reanalysis data input.

Notes: Throughout the research report, the research team uses and makes reference to **Tabler data**, which they describe as “existing manually observed wind data.”

The **WRF model** is described by its developer, the National Science Foundation’s National Center for Atmospheric Research, as “[a] state of the art mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications.”

Research Results: A dataset was developed with continuous weather data in areas where wind and precipitation data are hard to obtain. Simulated wind fields were successfully validated using observed data from selected airport sites and the Tabler data. Reconstructed wind fields that provide complete spatial coverage in Wyoming can be used to assess travel risks under adverse weather conditions, including high winds.

Source: [Historical Winter Weather Assessment for Snow Fence Design Using a Numerical Weather Model](#) (2017)

Informing Development of a Weight-Based Wind Closure System

The research described below led to development of the weight-based wind closure system Wyoming DOT implemented in October 2023.

Research Team Quantifies Blow-Over Risk

Background: Blow-over crash risk was quantified using variables such as road geometry, wind fields, vehicle types and vehicle speeds to develop a model capable of calculating risk in real time. Researchers considered how their findings could be integrated into Wyoming DOT’s existing road weather management system to provide information to impacted vehicles regarding current and forecasted high wind events.

Figure 3 is an illustration taken from the proposal for the research project described above that identifies elements of the research effort. Figure 4 illustrates critical elements of the research that informed development of the operational high wind closure system.

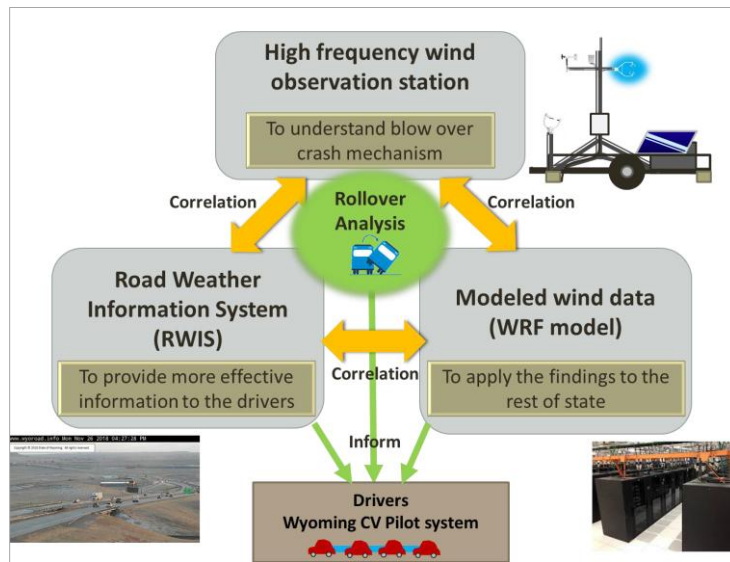


Figure 3. Diagram of Proposed Research Activities

(Source: Proposal: Characterization of Blowover Risk in the Wyoming Highway System (2019).)



Figure 4. Variables Impacting the Weight-Based Wind Closure System

(Source: Reducing Blow Over Crashes.)

Research Results: Research began with installation of a high-frequency wind monitoring system at a known hazard area along Interstate 25 in southeast Wyoming that characterized “blow over-inducing wind gusts.” Using data from this and other sources in conjunction with a static vehicle stability model, researchers “statistically modeled by distribution fitting” the critical vehicle speed for the blow-over condition, and produced blow-over hazard maps using the WRF model. Research findings were expected to “provide significant additional information to traveler information systems and roadway agencies managing roads with frequent high wind conditions,” and informed development of Wyoming DOT’s weight-based wind closure system.

Source: [Characterization of Blow Over Risk in the Wyoming Highway System](#) (2021)

Research in Progress

Wyoming DOT’s examination of strategies to mitigate high winds on the state’s highways continues with research in progress that considers the use of wind fences as a physical high wind adaptation strategy. The fence system under consideration is similar to a jet blast deflector that seeks to minimize or mitigate the impacts of high winds in isolated areas.

Quantifying the Reduction in Blow-Over Probability When Using a Wind Fence

Background: While Wyoming has implemented a weight-based wind closure system that notifies drivers of road closures using DMS and other sources, the state has not yet implemented physical adaptation measures in connection with blow-over crashes. The research proposal for this project noted that while wind fences have been reported to be effective in certain situations, “[t]here are still key discrepancies between real-world implementations and the idealized conditions present in computational fluid [dynamics] (CFD) simulations and wind tunnel experiments.”

Anticipated Results: The research team proposes to use an existing “blow-over risk model based on the force balance action on a vehicle” to evaluate the efficiency of different wind fence designs. Researchers plan to use a comprehensive wind profile measurement system in the median of a portion of Interstate 80 to “evaluate the effect of wind modification by the existing wind/snow fence.”

Preliminary Results: An October 2025 presentation to the National Society of Professional Engineers described how the research team “instrumented an existing snow fence located between Cheyenne and Laramie with [four] tripods, each with [three] wind-detecting sensors. One of the tripods is located 36 feet upstream of the snow fence and three are located downstream of the snow fence at 18 feet, 60 feet and 120 feet behind the snow fence. While the research is still in process, the preliminary results are very interesting.”

Source: [Research in Progress: Evaluation of Blow-Over Risk Reduction by Wind Fences Using Wind Profile Measurements](#) (expected completion date: June 2027)

Agencies Not Employing High Wind Adaptation Strategies

Four of the five responding agencies are not currently employing high wind adaptation strategies. Idaho Transportation Department is not considering implementing these practices, with the respondent noting that the issue is not a priority relative to other hazards and the risk is low.

Respondents from the remaining three agencies — Caltrans District 9, San Bernardino County Transportation Authority and South Dakota DOT — reported interest in developing high wind adaptation

strategies. The tables below describe each agency’s current environment and plans or expectations for future implementation.

Caltrans District 9

Rather than a formalized notification system, the district uses word of mouth from maintenance crews or law enforcement triggers road closures for high-profile vehicles. Barriers to future implementation of a formalized high wind adaptation strategy include funding, IT system deficiencies, maintenance capacity and permitting. Table 3 briefly describes the high wind environment in the district and the adaptation strategies in use or of interest.

Table 3. High Wind Environment (Caltrans District 9)

| <u>Topic</u> | <u>Description</u> |
|---|---|
| Assets Most Impacted by High Winds | Signs; impacts to roadway from toppled semis |
| Most Relevant Hazards | Flying debris, poor visibility, dangerous driving conditions |
| Operational Triggers | Word of mouth from maintenance crews or California Highway Patrol staff issue high-profile vehicle road closures |
| Observed Impacts in Last Five Years | Many overturned semis, road closures and roadway debris |
| Structural Measures of Interest | Wind fence is used to block blowing snow in mountainous regions. |
| Vegetative Windbreaks of Interest | The respondent mentioned the Olancho-Cartago 4-Lane Project , which is converting a two-lane conventional highway into a four-lane expressway, as “closer to the mountains, so higher wind speeds.” |
| Monitoring and Prediction | None, but would be helpful for the southern area of District 9. |
| Traveler Information | Currently use quick maps for closures. |
| Needed to Begin Implementing Solutions | <ul style="list-style-type: none"> • Case studies • Design guidance • Funding • Measured cost–benefit results |
| Barriers to Implementation | <ul style="list-style-type: none"> • Funding • IT system deficiencies • Maintenance capacity • Permitting |
| Timeline for Implementation | Not known; if there is a strong need, sooner rather than later. |

San Bernardino County Transportation Authority

Wildfire due to high wind is the most relevant hazard for San Bernardino County’s transportation and energy assets. Stress and physical damage to the system cause other wildfire and flooding events. Operational measures of interest are those that can reduce the number of public safety power shutoff days, especially for critical infrastructure. Table 4 briefly describes the high wind environment in the county and the adaptation strategies of interest.

Table 4. High Wind Environment (San Bernardino County Transportation Authority)

| <u>Topic</u> | <u>Description</u> |
|---|---|
| Assets Most Impacted by High Winds | Transportation and energy assets throughout the county |
| Most Relevant Hazards | Wildfire due to high wind scenarios |
| Operational Triggers | Public safety power shutoff (PSPS) during high wind events |
| Observed Impacts in Last Five Years | Stress on the system and physical damage to the system causing other wildfire and flooding events |
| Structural Measures of Interest | Electricity resources and reliability; utility infrastructures are often co-located with roadway infrastructure |
| Operational Measures of Interest | Reduce PSPS days; backup power for redundancy, especially for critical infrastructures |
| Traveler Information | The respondent commented that this would be helpful. |
| Other Potential Strategy | Communicate with utility companies |
| Needed to Begin Implementing Solutions | <ul style="list-style-type: none"> • Case studies • Funding • Measured cost–benefit results • Threshold or operational playbooks |
| Barriers to Implementation | <ul style="list-style-type: none"> • Funding • Interagency alignment • IT system deficiencies • Maintenance capacity • Staffing • Standards uncertainty |
| Timeline for Implementation | Not applicable |

South Dakota Department of Transportation

The South Dakota DOT respondent identified truck blow overs and widespread sign damage resulting from the state’s high-speed straight-line winds as prompting the agency’s interest in high wind warning systems, with installation anticipated in the next five years. In a follow-up communication, the survey respondent provided additional information about the agency’s high wind warning initiative:

South Dakota DOT is assembling a project team that will include representatives from the National Weather Service, South Dakota Highway Patrol and the South Dakota Trucking Association to “create a system like Wyoming’s to issue specific warnings and closures for light, high-profile vehicles during high wind events.”

The anticipated system will use real-time sensors to monitor wind speed, wind direction and road geometry to identify risks for commercial trucks with light loads. Message boards, social media and 511 will be used to communicate with the public regarding warnings and closures. A review of current state law will assess the need for additional legislative authority for the proposed system to restrict the travel of high-profile vehicles.

Table 5 briefly describes the high wind environment on South Dakota roadways and the adaptation strategies used or of interest.

Table 5. High Wind Environment (South Dakota DOT)

| <u>Topic</u> | <u>Description</u> |
|---|---|
| Assets Most Impacted by High Winds | Operational assets; truck blow overs are the biggest impact |
| Most Relevant Hazards | High-speed straight-line winds |
| Operational Triggers | Forecasted or current wind speeds of 40 to 50 mph or higher |
| Observed Impacts in Last Five Years | Truck blow overs; widespread damage to signs, salt sheds and other infrastructure from May 2022 Derecho |
| Operational Measures of Interest | Reviewing high wind warning systems |
| Traveler Information | DMS messaging |
| Needed to Begin Implementing Solutions | <ul style="list-style-type: none"> • Equipment specifications • Funding • Threshold or operational playbooks |
| Barriers to Implementation | Maintenance capacity |
| Timeline for Implementation | Hopefully within the next five years |

Related Research and Resources

A review of domestic and international published and in-progress research and related resources identified a sampling of resources related to high wind adaptation strategies or related topics. Findings are organized into five categories:

- High Wind Alerts
- High Wind Guidance and Strategies
- High Wind Warning Systems
- High Winds and Wildfire
- Wind and Snow Fences

Resources may be further categorized by state, region or country.

High Wind Alerts

Wyoming

Connected Vehicle Pilot: Final System Performance Measurement and Evaluation – WYDOT Connected Vehicle Pilot, Vince Garcia, Nayel Ureña Serulle, Kaveh Bakhsh Kelarestaghi, Rhonda Young, Deepak Gopalakrishna, Tony English, Shane Zumpf, Mohamed Ahmed, Mike McQueen and Amanda Anderson, ITS-Joint Program Office, U.S. Department of Transportation, July 2022.

<https://rosap.ntl.bts.gov/view/dot/64854>

From the abstract: The Wyoming Department of Transportation’s (WYDOT) Connected Vehicle (CV) Pilot Deployment Program is intended to develop a suite of applications that utilize vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication technology to reduce the impact of adverse weather on truck travel in the I-80 corridor. These applications support a flexible range of services from advisories, roadside alerts, parking notifications and dynamic travel guidance. Information from these applications is made available directly to the equipped fleets or through data connections to fleet management centers (who will then communicate it to their trucks using their own systems).

Excerpt from Research and Testing accomplishments identified in Table 1. Summary of Pilot's Accomplishments (see page 4 of the report, page 20 of the PDF):

| | Accomplishments | Impact |
|----|--|---|
| 7. | The creation of a testbed for new technologies and software. | Wyoming I-80 can now serve as a testbed, enabling early testing and deployment of systems such as Pikalert. The deployment also yielded robust test plans and templates for sharing test results, usable information for other future implementations. |
| 8. | Help move forward the hardware, firmware and software. | The pilot also helped Pikalert identify areas of improvement. One of these was transitioning to the cloud, which allows for more straightforward and consistent deployment on other road segments and/or regions. The pilot also supported the development of a new high wind blow over risk algorithm that adds a new capability to the system that other regions using Pikalert have implemented. |

Related Resource:

“Generating Weather Alerts Including High Wind Blower Hazards Using Pikalert for the Wyoming Connected Vehicle Pilot Project,” Rhonda K. Young, Brittany M. Welch and Amanda R. Siems-Anderson, *Transportation Research Board 98th Annual Meeting*, Paper #19-02065, 2019. Citation at <https://trid.trb.org/View/1572700>

From the abstract: The 402-mile corridor on Interstate 80 through southern Wyoming was selected in September 2015 as one of three projects for the U.S. Department of Transportation’s Connected Vehicle (CV) Pilot Deployment Project. The Wyoming CV Pilot site is an important freight corridor that experiences frequent and severe weather including snow and ice conditions, blowing snow and high winds. Winds over 30 miles per hour are common on the corridor, causing frequent blower crashes, particularly for high profile freight vehicles. As part of the Wyoming CV Pilot, the Pikalert System is being integrated into the Wyoming Department of Transportation’s Traffic Management Center back office systems to improve the quality and timeliness of actionable weather information for travelers on the corridor. Weather alerts include precipitation, pavement condition, visibility and blower hazard information for each one-mile segment of the corridor for current conditions as well as hourly road condition forecasts for one to 72 hours. The focus of this paper is to give an overview of how the Pikalert system is being utilized in the Wyoming CV Pilot and to provide details on the new Blower Risk Algorithm that was developed for the Pilot.

High Wind Guidance and Strategies

Multiple Countries

Disaster and Climate-Resilient Transport Guidance Note, O. Keou et al., The World Bank, 2025. <https://documents1.worldbank.org/curated/en/099032625173042760/pdf/P180423-670950ea-9b3e-4cb2-a416-bf19ee625e3e.pdf>

From the executive summary: This Disaster and Climate-Resilient Transport Guidance Note provides strategic guidance to integrate climate resilience into transport investments, facilitating long-term sustainability and economic growth, supported by case studies and best practices from around the world. Building upon the above life-cycle approach, and based on a gap analysis completed from recent donor-funded transport projects, the note identifies four strategic priorities to enhance resilience in the transport sector:

- System Thinking: Shifting from asset-focused investments to system-wide resilience
- Enhanced Risk Governance & Disaster Financing: Ensuring financial mechanisms support long-term climate adaptation
- Innovative Technologies: Improving infrastructure resilience with new engineering solutions, nature-based solutions, or tools like predictive analytics and smart asset management
- Cross-Sectoral Coordination: Integrating emergency response, meteorological services and transport planning for better disaster preparedness

Scotland

High Wind Strategy and National Wind Management Guidelines, Transport Scotland, 2009. <https://www.transport.gov.scot/media/25393/j10783.pdf>

From the summary that begins on page 18 of the report, page 22 of the PDF:

These guidelines are intended for use by all relevant bodies involved with the Scottish road network. Transport Scotland has prepared these guidelines with the intention that they be used as a best

practice guide for all relevant bodies associated in managing the impact of high wind on the Scottish road network.

The key focus of these guidelines is ten basic steps to high wind management embracing pre-planning, incident management and information dissemination prior to, during and after a wind incident has occurred. The scope, complexity and effort required to manage each task will vary dependent on site specifics and the level of perceived risk and disruption at each location.

The 10 steps “required for successful high wind management”:

- Step 1 – Risk Identification
- Step 2 – Organisational Agreements
- Step 3 – Diversion Route Planning
- Step 4 – Monitoring
- Step 5 – Define High Wind Level Thresholds
- Step 6 – Develop the Levels of Restriction
- Step 7 – Enforcement
- Step 8 – Implementation of Traffic Management
- Step 9 – Information Dissemination
- Step 10 – Relaxation of Restrictions and Information Dissemination

United Kingdom

“How Can the UK Road System Be Adapted to the Impacts Posed by Climate Change? By Creating a Climate Adaptation Framework,” Tianni Wang, Zhuohua Qu, Zaili Yang, Timothy Nichol, Delia Dimitriu, Geoff Clarke and Daniel Bowden, *Transportation Research Part D: Transport and Environment*, Vol. 77, pages 403-424, December 2019.

Note: The publication cited below is the accepted version of this journal article and is made available by the researchers through an open access portal. The published version is available via subscription at <https://doi.org/10.1016/j.trd.2019.02.007>.

<https://researchonline.ljmu.ac.uk/id/eprint/10349/3/How%20can%20the%20UK%20road%20system%20be%20adapted%20to%20the%20impacts%20posed%20by%20climate%20change%20By%20creating%20a%20climate%20adaptation%20framework.pdf>

From the introduction:

This paper aims to analyse the impacts of climate change to the current and predicted future situations of road transportation in the UK and evaluate the corresponding adaptation plans to cope with them. A conceptual framework of long-term adaptation planning for climate change in road systems is proposed to ensure the resilience and sustainability of road transport systems under various climate risks such as flooding and increased temperature.

The excerpt below from Table 3. Survey Results of Risk Reduction and Adaptation Costs, which begins on page 29 of the report, page 30 of the PDF, addresses an “environmental driver due to climate change” — more intense and/or frequent high wind and/or storms.

| Environmental driver due to climate change | Potential climate threat on the road | Adaptation measures | Risk Result without adaptations | Risk result with adaptations | Risk reduction on RR _{mn} | Risk reduction grades {VE, E, A, SE, I} | Cost {VH, H, A, L, VL} |
|--|--|--|---------------------------------|------------------------------|------------------------------------|---|-----------------------------|
| More intense and/or frequent high wind and/or storms | C1. Storm cyclone due to heavy rainfall and high wind can trigger flooding, inundation of embankments, affect road transport and stability of bridge decks | (C1b) Consider revised height standards for highways based on scenario modelling in the area | 0.50 | 0.56 | 0.06 | {0, 0, 1, 0, 0} | {0, 0.18, 0.36, 0.36, 0.09} |
| | C2. Damage to lighting fixtures and supports, traffic boards and information sign | (C2a) Resilience in signs and use of nonphysical means such as telematics in vehicle and sensor technology | 0.51 | 0.48 | 0.03 | {0, 0, 0, 1, 0} | {0, 0.18, 0.27, 0.45, 0.09} |
| | C3. Disrupt traffic safety and emergency evacuation operations, increase traffic accidents | (C3a) Map the highway network and infrastructure asset base | 0.48 | 0.51 | 0.03 | {0, 0, 0, 1, 0} | {0, 0.08, 0.25, 0.50, 0.17} |
| | | (C3b) Identify at risk locations / structures where there are issues as measured under different scenarios | 0.48 | 0.51 | 0.03 | {0, 0, 0, 1, 0} | {0, 0.08, 0.46, 0.31, 0.15} |
| | | (C3c) Provision of timely driver information to 'at risk' routes | 0.48 | 0.50 | 0.02 | {0, 0, 0, 0.6667, 0.3333} | {0, 0.10, 0.30, 0.40, 0.20} |

High Wind Warning Systems

Wyoming

“Reducing Blow Over Crashes,” Vince Garcia, *National Society of Professional Engineers (NSPE) Conference 25 (NSPECon25)*, October 14, 2025.

Provided to Caltrans separately.

This presentation describes Wyoming DOT’s mission in undertaking development of the weight-based wind closure system; provides blow-over statistics and research data; describes the legislation supporting the closure system; and examines the additional work to address high wind blow-over crashes in Wyoming.

Blow Over Hazards: Weight-Based Wind Closures, Advisories and Definitions, Public Affairs Office, Wyoming Department of Transportation, September 2025.

<https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Public%20Affairs/brochures/blow-over%20brochure.pdf>

This two-page illustrated brochure provides definitions, images of the truck types prone — and not prone — to blowing over (see Figure 5), and a description of the weight-based wind closure system.

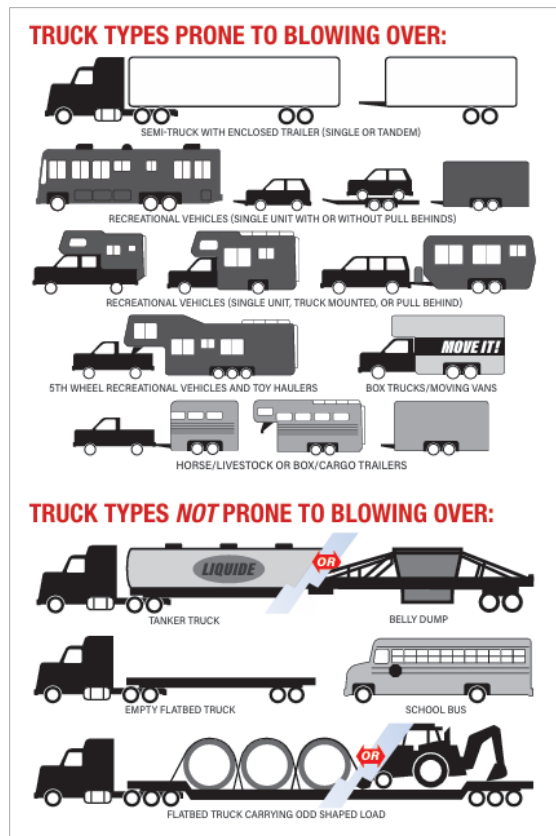


Figure 5. Illustration of Truck Types and Assessment of Propensity for Blow Over
(Source: Blow Over Hazards: Weight-Based Closures, Advisories and Definitions.)

Wyoming Wind: Strong Winds May Prompt Weight-Based Wind Closures, Wyoming Department of Transportation, undated.

<https://dot.state.wy.us/home/travel/wyoming-wind.html>

From the website:

WYDOT has been closing sections of highway to “light, high-profile vehicles” since 2011 due to strong crosswinds and extreme blow over risk.

However, given the large amount of out-of-state commercial vehicle traffic and the hurricane-force winds often seen in Wyoming, WYDOT has received feedback over the years to define light, high-profile vehicles.

Recent research from the University of Wyoming, funded by WYDOT’s Research Advisory Committee, helped the agency more confidently list actual weights with the restrictions. The weight-based wind closure system started in 2023.

This site also provides videos and responses to frequently asked questions about the new system.

Wyoming Report on Traffic Crashes: 2024, Wyoming Department of Transportation, April 2025.

https://dot.state.wy.us/files/live/sites/wydot/files/shared/Highway_Safety/Crash%20Data/Publications/Report%20on%20Traffic%20Crashes/2024%20Report%20on%20Traffic%20Crashes.pdf

See page 76 of the report, page 93 of the PDF, for a discussion of blow-over crashes.

Related Resource:

Wyoming Report on Traffic Crashes: 2023, Wyoming Department of Transportation, April 2024.

https://dot.state.wy.us/files/live/sites/wydot/files/shared/Highway_Safety/Crash%20Data/Publications/Report%20on%20Traffic%20Crashes/2023%20Report%20on%20Traffic%20Crashes.pdf

See page 77 of the report, page 95 of the PDF, for a discussion of blow-over crashes.

WYDOT Reminds Drivers of New Penalties for Weight Based Road Closures, *News Release*, Wyoming Department of Transportation, July 12, 2024.

<https://www.dot.state.wy.us/news/wydot-reminds-drivers-of-new-penalties-for-weight-based-road-closures>

From the news release:

The Wyoming Department of Transportation would like to remind motorists of the new penalties for violating highway closures to light and high profile vehicles that went into effect July 1.

The “Light and high profile vehicle closures bill” (SF0113) passed in the 2024 legislative session. The bill language notes that, “any person who willfully fails to observe any sign, marker, warning, notice or direction” for closures to light, high-profile vehicles is guilty of a misdemeanor, and upon conviction, subject to a fine of \$1,000 and potential imprisonment for not more than 30 days.

If the motorist is convicted of subsequent offenses within three years of the first offense, the violator is subject to a \$2,500 fine. The conviction would be deemed reckless driving under Wyoming Statute 31-5-229, with possible driver licensing action.

Also new with this legislation, the driver of the light and high-profile vehicle at the time of the violation would be liable, upon conviction, for any of the above penalties.

....

As noted in subsection (d), these new fines also apply to “other weight based closures” that aren’t necessarily wind related.

Characterization of Blow Over Risk in the Wyoming Highway System, Noriaki Ohara, Adarsha Neupane, Rhonda Young and Antonio Roman Campos, Wyoming Department of Transportation, November 2021.

https://rosap.ntl.bts.gov/view/dot/61014/dot_61014_DS1.pdf

From the abstract: Blow over crashes caused by severe crosswinds are a common problem on Wyoming highways, as well as roadways elsewhere that are subject to high wind conditions. To characterize blow over-inducing wind gusts, a high-frequency wind monitoring system was installed at a known hazard area along Interstate 25 just north of the Colorado-Wyoming state line. Data collected from this high-frequency system were analyzed along with data from the Wyoming Department of Transportation’s (WYDOT) traditional systems including a Portable Weather Instrument Station (PWIS) and an existing Road Weather Information System (RWIS). Using data collected from these sources and a static vehicle stability model that integrates major influencing factors, the critical vehicle speed for the blow over condition was statistically modeled by distribution fitting. Through this investigation, the exp-gamma distribution was found to be the most appropriate to model the stochastic process of vehicle blow over risk. Applications using historical, statewide RWIS Environmental Sensor Station (ESS) data demonstrated the predictive capability of this developed tool for historical blow over crashes. Furthermore, the sensitivity analysis of this vehicle stability model characterizes the blow over risk of vehicles with various attributes. Finally, blow over hazard maps were produced based on reconstructed historical maximum and mean wind fields using a Weather Research and Forecasting (WRF) model. This dynamic risk-assessing tool, founded in the technology developed herein, will provide significant

additional information to traveler information systems and roadway agencies managing roads with frequent high wind conditions.

Related Resources:

“Blow-Over Risk Evaluation System for High-Profile Light-Weight Vehicles on Wyoming Highways,”

Noriaki Ohara, Adarsha Neupane, Kathy Ahlenius, Rhonda Kae Young and Antonio Roman Campos, *Transportation Research Record 2677*, Issue 12, pages 316-327, January 2023.

Citation at <https://journals.sagepub.com/doi/abs/10.1177/03611981231168118>

From the abstract: Tractor-trailer blow-over crashes caused by strong winds in Wyoming, U.S., can damage roadways, delay goods and threaten the safety of all members of the traveling public. Identifying roadway sections with high blow-over risk is important for taking appropriate and targeted precautions to avoid these serious problems. This study utilizes a vehicle blow-over model compiled from previous research to quantify incident risk on Wyoming roads and test the appropriateness of existing risk assessments. Data about blow-over crashes from 2012 to 2020 were used to calibrate a new statewide model, and this model was leveraged to observe the evolution of blow-over risk during high wind periods from past blow-over crash events. The results from this model show that blow-over crashes occur in specific zones with elevated risk variables. The model was also especially precise at predicting crash locations within 10 km of nearby weather stations. This computationally efficient model can now be used for real time blow-over risk prediction using road weather information system environmental sensor stations throughout Wyoming. This dynamic risk assessing tool, continuously updated online, can help travelers with high-profile light-weight vehicles through existing traveler information systems, and this model also serves as an addition to the typical wind gust data used by decision-makers managing Wyoming roads.

“Blowover Risk Assessment for the Tractor-Trailer Trucks in High Winds Using a Blowover and Statistical Model,” Adarsha Neupane, Noriaki Ohara and Kathy Ahlenius, *Transportation Research Record 2677*, Issue 1, pages 562-576, January 2023.

Citation at <https://journals.sagepub.com/doi/10.1177/03611981221100533>

From the abstract: Tractor-trailer blowover crashes caused by strong winds are a major concern for the safety of their operators and others sharing the road. These crashes also trigger highway closures resulting in considerable economic impact. This study presents a blowover model based on stability forces that integrates the wind field, road geometry and vehicle specifications to provide a critical vehicle speed for blowovers. A high-frequency sonic anemometer was deployed at the study area which witnessed three blowover crashes during the study period. The results showed that the critical vehicle speed from the model dipped below the posted speed limit at the time of blowovers for all three blowover crashes. The risk of a blowover crash was quantified as an exceedance probability of the fitted distribution to the temporal critical vehicle speed variations based on the high-frequency wind data within every 15-min time window. This framework, when applied to a stretch of road, was able to demonstrate the ability to identify the instances and the locations of higher blowover risk using wind measurements from the more prevalent mechanical anemometers.

“High Wind Blow Over Briefing,” Joint Transportation, Highways and Military Affairs Committee, Wyoming State Legislature, August 31, 2023.

<https://wyoleg.gov/InterimCommittee/2023/08-202308317-03WYDOTBlowOverBriefing.pdf>

This presentation that updated Wyoming legislators on the weight-based wind closure system noted that the research informing system development was used “to enhance operational systems that use our current capabilities.” Included are the following topics:

- Why are high wind blow overs increasing?

- Discussion of the recent University of Wyoming research: *Characterization of Blow Over Risk in the Wyoming Highway System*
- Proposed changes to pre-trip, roadside and in-vehicle information systems
- Vehicle-specific review

Proposal: Characterization of Blowover Risk in the Wyoming Highway System, Noriaki Ohara and Rhonda Young, Wyoming Department of Transportation, January 2019.

https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Research/RS06219_Blowover.pdf

This proposal for the research cited above summarizes the issues prompting the research and describes anticipated research activities.

High Wind Warning System for Bordeaux, Wyoming, Rhonda Young, Edward Offei and Quiyue Dai, Wyoming Department of Transportation, July 2010.

<https://rosap.nhtl.bts.gov/view/dot/23965>

From the abstract: The state of Wyoming has frequent severe wind conditions, particularly in the southeast corner of the state along Interstate 80 and Interstate 25. The high winds are problematic in many ways including interfering with the performance of the transportation system, blowing vehicles off the road, or even overturning high profile trucks, which can cause economic losses and safety concerns for road users. The primary objectives of this research involve two parts: First, develop a statistical model that reveals the correlation between likelihood of overturning trucks and the weather conditions. Second, use the result of the statistical model to develop a data driven operation plan for Wyoming Department of Transportation (WYDOT) to use in the winter season at a hazardous high wind corridor to improve truck safety.

“Estimating the Relationship Between Measured Wind Speed and Overturning Truck Crashes Using a Binary Logit Model,” Rhonda Kae Young and Joel Liesman, *Accident Analysis and Prevention*, Vol. 39, Issue 3, pages 574-580, May 2007.

Citation at <https://www.sciencedirect.com/science/article/abs/pii/S0001457506001771>

From the abstract: This paper develops a quantitative model that correlates overturning freight vehicle crash records in Wyoming to measured wind speeds at nearby weather stations. The database consists of 14,700 truck crashes from 1994 to 2003 and wind speed and gust information from 21 weather stations. A binary logit model was estimated from the data to determine if there was significant correlation between weather station wind data and the likelihood that the crash was of the overturning type. While it is reasonably known that local wind speeds at the crash location are critical in predicting overturning truck crash likelihood, it was not known if distant weather station data were an adequate predictor of these crash types. The results from this work indicate that weather station data can be used as a predictor of overturning crashes. This work provides the necessary first step for the development of operational rules for roadway sections that run high risk of overturning truck crashes in high wind conditions.

High Winds and Wildfire

Pacific Northwest

“Charting the Scorched Trails: A Comparative Analysis of Roadway Damage from Historical Megafires to the Unprecedented 2020 Labor Day Wildfires on the USA West Coast,” Kevin Christiansen, Ayat Al Assi, Rubayet Bin Mostafiz and Robert V. Rohli, *Emergency Management Science and Technology*, Vol. 4, 2024.

<https://doi.org/10.48130/emst-0024-0016>

From the abstract:

Roadways in the US states of Washington (WA), Oregon (OR) and California (CA) incurred extraordinary damage during the 2020 Labor Day wildfires. However, the cost and risk of these fires have not been placed in a historical perspective. This study examines the damage to roadways affected by the 2020 Labor Day wildfires in relation to the history of megafires in WA (1902–2023), OR (1845–2023) and CA (1889–2023) using carefully selected data sets gathered from the Washington State Department of Transportation (WSDOT), Oregon Department of Transportation (ODOT) and California Department of Transportation (Caltrans). A method for classifying road damage from the 2020 wildfires is also presented, with classes labeled for traffic control, slope-rock scaling, hazard trees and structures.

From the discussion:

While these large-scale wildfires are associated with dry, easterly winds and concurrent drought, the regionally distinct patterns of wind, fuel, fire size and drought in the 2020 event point to a more complex mechanism than the mere coincidence of wind and drought. A more complex 'recipe' for major westside flames than just wind and drought happening at the same time includes the presence of mountainous areas and valley margins that appear to have affected fire growth and spread. The variation in fire size appears to be partially explained by geographic patterns of wind speed and drought.

“Cascadia Burning: The Historic, But Not Historically Unprecedented, 2020 Wildfires in the Pacific Northwest, USA,” Matthew J. Reilly, Aaron Zuspan, Joshua S. Halofsky, Crystal Raymond, Andy McEvoy, Alex W. Dye, Daniel C. Donato, John B. Kim, Brian E. Potter, Nathan Walker, Raymond J. Davis, Christopher J. Dunn, David M. Bell, Matthew J. Gregory, James D. Johnston, Brian J. Harvey, Jessica E. Halofsky and Becky K. Kerns, *Ecosphere*, Vol. 13, Issue 6, June 2022.

<https://doi.org/10.1002/ecs2.4070>

From the abstract: Wildfires devastated communities in Oregon and Washington in September 2020, burning almost as much forest west of the Cascade Mountain crest (“the westside”) in 2 weeks (~340,000 ha) as in the previous five decades (~406,00 ha). Unlike dry forests of the interior western United States, temperate rain forests of the Pacific Northwest have experienced limited recent fire activity, and debates surrounding what drove the 2020 fires, and management strategies to adapt to similar future events, necessitate a scientific evaluation of the fires. We evaluate five questions regarding the 2020 Labor Day fires: (1) How do the 2020 fires compare with historical fires? (2) How did the roles of weather and antecedent climate differ geographically and from the recent past (1979–2019)? (3) How do fire size and severity compare to other recent fires (1985–2019), and how did forest management and prefire forest structure influence burn severity? (4) What impact will these fires have on westside landscapes? and (5) How can we adapt to similar fires in the future? Although 5 of the 2020 fires were much larger than any others in the recent past and burned ~10 times the area in high-severity patches >10,000 ha, the 2020 fires were remarkably consistent with historical fires. Reports from the

early 1900s, along with paleo- and dendro-ecological records, indicate similar and potentially even larger wildfires over the past millennium, many of which shared similar seasonality (late August/early September), weather conditions and even geographic locations. Consistent with the largest historical fires, strong east winds and anomalously dry conditions drove the rapid spread of high-severity wildfire in 2020. We found minimal difference in burn severity among stand structural types related to previous management in the 2020 fires. Adaptation strategies for similar fires in the future could benefit by focusing on ignition prevention, fire suppression and community preparedness, as opposed to fuel treatments that are unlikely to mitigate fire severity during extreme weather. While scientific uncertainties remain regarding the nature of infrequent, high-severity fires in westside forests, particularly under climate change, adapting to their future occurrence will require different strategies than those in interior, dry forests.

Portugal

“An Integrated Framework for Habitat Restoration in Fire-Prone Areas. Part 2 – Fire Hazard Assessment of the Different Land Management Scenarios,” R. Vaz, P. Maia, J. Keizer, P. Fernandes, S.C. Pereira and D. Carvalho, *International Journal of Wildland Fire*, Vol. 33, Issue 11, November 2024. <https://www.publish.csiro.au/wf/pdf/WF24044>

From the discussion:

Observations of fire spread and intensity

Simulations showed that employing fuel management strategies have reduced fire spread rates in maritime pine forested areas, especially when under a low wind speed regime in Hot/Dry. Fireline intensity patterns in C also show a sharp reduction in managed scenarios S1, S3, S4, when compared to Base and S2. Under a higher wind speed, the reducing effect was less pronounced in Cool/Moist, and was consistent with field observations from prescribed burns for both events (Fernandes *et al.* 2004). Management of the pine forest was the greatest contributor to both fire spread and intensity within the ILMA, effectively reducing fires above the suppression threshold of by up to three times, under very dry fuel conditions in association with low wind speeds.

Results suggest that agricultural/pasture areas could be used as fuel breaks in fires dominated by high winds but moderate humidity levels, and have in fact been used to assist in fire management operations (Ascoli *et al.* 2018; Bertomeu *et al.* 2022). The same authors (Bertomeu *et al.* 2022) have also shown that agricultural areas have proven to produce faster spreading fires due to its low compacted fuel structure, despite producing very lower fire intensities, as is the case in the ILMA.

United Kingdom

“To Cut or Not to Cut: Effect of Vegetation Height and Bulk Density on Wildfire Propagation Under Varied Wind and Slope Conditions,” Mohammad Tavakol Sadrabadi and Mauro Sebastián Innocente, *International Journal of Disaster Risk Reduction*, Vol. 121, April 2025. <https://www.sciencedirect.com/science/article/pii/S2212420925001967>

From the abstract: The frequency, intensity and span of wildfires have surged in the past decades, mainly driven by changes in climatic patterns. Although grasslands cover ≈40% of the Earth’s surface, they account for ≈80% of the burned area. Mowing is a common practice to reduce the Rate of Spread (RoS) and intensity of grassland fires. However, recent studies suggest the RoS may increase instead. This paper combines results from previous experimental studies in Australian grasslands and wheatlands with wildfire propagation simulations under a range of ambient wind speeds, vegetation heights (H_g), and terrain slopes to assess whether grass-cutting is an effective strategy to mitigate fire propagation. Previous investigations of the H_g –RoS correlation led to contradictory conclusions. The main finding here is a statistically significant negative correlation between the vegetation’s bulk density (ρ_b) and the

RoS/u_{10} ratio, where u_{10} is the wind speed 10 m above ground. Seeking a relationship between Hg and RoS , we found positive correlations between Hg and the $RoS/(u_{10}M)$ and $RoS/(u_{10}RH)$ ratios, where M (fuel moisture content) and RH (atmospheric humidity) account for environmental conditions. These correlations seem to hold provided that ρb decreases with increasing Hg and that propagation is plume-driven. For wind-driven propagation, simulations show that decreasing Hg increases RoS/u_{10} for constant M and RH . Further experimental research is needed to confirm this. Thus, grass-cutting is observed to effectively curb fire propagation, although it may be less effective under specific conditions such as high winds, as vegetation characteristics and propagation modes significantly affect fire dynamics.

Wind and Snow Fences

Wyoming

Research in Progress: Evaluation of Blow-Over Risk Reduction by Wind Fences Using Wind Profile Measurements, Wyoming Department of Transportation, anticipated start date: July 2024; expected completion date: June 2027.

Project proposal available at

https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Research/RS02224_Eval_Blowover_Risk_WindFences.pdf

From the study objectives: This study aims to establish the fundamental understanding and technology for wind fence design based on field monitoring and the stochastic blow-over risk model. The objectives of this work are as follows:

- Characterization of mean and gust wind profiles based on field monitoring around an existing snow fence (I-80 MP332, Wyoming).
- Quantification of the local wind momentum loss due to the fence for both mean and gust winds at different downstream distances in response to various wind directions.
- Quantification of the blow-over risk reduction by the fence using the existing UW [University of Wyoming] blow-over risk model (Neupane et al., 2023; Ohara et al., 2023).
- Development of recommendations for potential wind fence installation design and anticipated blow-over risk reduction.

From the project description: The key benefit of this study will be the provision of the information needed to design wind fences for blow-over risk mitigation for high-profile lightweight vehicles under different high wind conditions.

Historical Winter Weather Assessment for Snow Fence Design Using a Numerical Weather Model, Noriaki Ohara, Federal Highway Administration and Wyoming Department of Transportation, February 2017.

<https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Research/RS06215%201703F%20Historical%20Winter%20Weather%20Assessment%20for%20Snow%20Fence%20Design.pdf>

From the abstract: Snow fence is an effective hazard mitigation measure for the low visibility and low friction of the road surface under winter weather condition. Prevailing wind directions and snow precipitation data prepared by Dr. R. Tabler (the Tabler data) that are necessary for snow fence design have not been updated since the 1990s. This project provides new, seamless wind field and snow precipitation data under the adverse winter storm conditions during 1980-2014, using the Weather Research and Forecasting (WRF) model with North American Regional Reanalysis (NARR) data input. The simulated wind fields were successfully validated by using the observed data from airport sites and using

the Tabler data. The WRF simulated precipitation data were assimilated to the observation-based PRISM data in order to obtain the accurate hourly snow precipitation data. Combining all the weather variables, the number of blowing snow events is found to be increasing despite the increasing air temperature because of the sufficiently cold winters of Wyoming. Finally, it was verified that the existing snow fence system is effective under the winter season prevailing wind since the simulation agrees with the Tabler data. However, it was also found that the simulated wind patterns during the blowing snow events can be quite different from the winter season average prevailing wind field. Moreover, the historical wind statistics indicated large deviations in wind direction along I-80.

China

“Numerical Evaluation of the Scale Problem on the Wind Flow of a Windbreak,” Benli Liu, Jianjun Qu, Weimin Zhang, Lihai Tan and Yanhong Gao, *Scientific Reports*, Vol. 4, 2014.

<https://www.nature.com/articles/srep06619>

From the abstract: The airflow field around wind fences with different porosities, which are important in determining the efficiency of fences as a windbreak, is typically studied via scaled wind tunnel experiments and numerical simulations. However, the scale problem in wind tunnels or numerical models is rarely researched. In this study, we perform a numerical comparison between a scaled wind-fence experimental model and an actual-sized fence via computational fluid dynamics simulations. The results show that although the general field pattern can be captured in a reduced-scale wind tunnel or numerical model, several flow characteristics near obstacles are not proportional to the size of the model and thus cannot be extrapolated directly. For example, the small vortex behind a low-porosity fence with a scale of 1:50 is approximately 4 times larger than that behind a full-scale fence.

“3D Numerical Simulation of Wind Flow Behind a New Porous Fence,” Guanghui Chen, Weiwen Wang, Changfeng Sun and Jianlong Li, *Powder Technology*, Vol. 230, pages 118-126, November 2012.

Citation at <https://www.sciencedirect.com/science/article/abs/pii/S0032591012004871>

From the abstract: This paper introduces a new type of wind fence — the deflector-porous fence. The deflectors were bent to a fixed inclination with the fence plate. And they are left attached on the lower edge of the fence holes. Our purpose is to weaken the bleed flow effect on the windward surface of the stockpiles and enhance the shelter efficiency of porous fences. A three-dimensional numerical model was performed to simulate the flow field around a triangular-shaped prism model behind the deflector-porous fence by solving Reynolds-average Navier–Stokes (RANS) equations with standard $k-\epsilon$ turbulence closure model. Data obtained from CFD simulations were then integrated to determine the best structural parameters of the new wind fence. The shelter effect of deflector-porous fence was estimated by comparing with that of the traditional wind fence. The validity of the numerical results has been evaluated by comparing with the wind-tunnel experimental data. As a result, the numerical predictions show good agreement with the wind tunnel results. The simulation results show that the deflector-porous fence with porosity (φ) of 30%, height (H) of 150 mm and the location (G) of 150 mm seems to be most effective in controlling the dust emission. It is suggested that the stockpile behind the deflector-porous fence is much safer than that behind the traditional wind fence (the fence with square or circular holes).

Spain

“Performance Analysis of Wind Fence Models When Used for Truck Protection Under Crosswind Through Numerical Modeling,” A. Alonso-Estébanez, J.J. Del Coz Díaz, F.P. Álvarez Rabanal and P. Pascual-Muñoz, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 168, pages 20-31, September 2017.

Citation at <https://www.sciencedirect.com/science/article/abs/pii/S0167610516303804>

From the abstract: This paper is focused on truck aerodynamic analysis under crosswind conditions by means of numerical modeling. The truck was located on the crest of an embankment during the study. In order to analyze the performance of three wind fence models, the truck's aerodynamic coefficients were obtained and compared in two different situations either with or without the wind fences installed. In addition, the effect of both height and porosity of wind fence models on the aerodynamic coefficients acting on [the] truck with respect to separation distance between the truck and the wind fence, was analyzed. A finite volume (or computational fluid dynamic) code was used to carry out the numerical modeling. The Reynolds-averaged Navier–Stokes (RANS) equations along with the SST turbulence model were used to predict the behavior of turbulent flow. With respect to the results, the influence of the distance on the rollover coefficient is soft for all height values studied except for the lowest value (1 m of fence height), where the maximum value of rollover coefficient was obtained for the truck position closer to the fence. Regarding fence porosity, its effect on rollover coefficient is stronger for truck positions on road closer to the wind fence model.

Contacts

CTC engaged with the individuals below to gather information for this investigation.

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Appendix A: Survey Questions

The online survey represented below was distributed via email to the member list of the AASHTO Committee on Transportation System Security and Resilience and selected California contacts.

Caltrans Survey on Adaptation Strategies to Mitigate the Impacts of High Winds

The California Department of Transportation (Caltrans) is exploring adaptation strategies that combine engineering, ecological and operational solutions to address the impacts of high winds on transportation infrastructure. The lack of integrated wind-resilient features in transportation infrastructure can result in more frequent road closures and detours, increasing overhead and capital costs.

The survey below seeks information about your experience with high wind mitigation strategies that employ structural interventions such as wind fairings or fences, nature-based solutions such as vegetative windbreaks, or other engineering or operational solutions. We estimate the survey will take 20 minutes to complete. We would appreciate receiving your responses by **Friday, December 12**.

If someone else in your agency or company would be more appropriate to address questions related to this issue, please forward this survey to that person.

The final report for this project, which will include a summary of the responses received from all survey participants, will be available on the [Caltrans website](#).

If you have questions about completing the survey, please contact Chris Kline at chris.kline@ctcandassociates.com. If you have questions about Caltrans' interest in this issue, please contact Tori Kanzler at tori.kanzler@dot.ca.gov.

Thank you for your participation.

(Required) Please provide your contact information.

Name:

Title/Division:

Agency/Company:

Email Address:

Phone Number:

Before You Begin

This survey asks about your experience with high wind adaptation or mitigation strategies, which could include:

- Engineering or structural wind-resilient installations.
- Nature-based solutions such as vegetative windbreaks.
- Technology-based strategies that address monitoring and prediction, information dissemination or decision-support.

Note: Responses to the question below determined how respondents are directed through the survey.

(Required) Does your agency/company have experience with implementing a high wind adaptation or mitigation strategy that is intended to protect transportation infrastructure?

- Yes, we have implemented one or more strategies. (Directed the respondent to **Background, Implementing High Wind Adaptation or Mitigation Strategies, Assessment and Wrap-Up.**)
- No, but we're interested in developing these strategies. (Directed the respondent to **Considering the Use of High Wind Adaptation or Mitigation Strategies and Wrap-Up.**)
- No, and we have no plans for or interest in developing these strategies. (Directed the respondent to **Not Considering the Use of High Wind Adaptation or Mitigation Strategies and Wrap-Up.**)

Background

1. Which agency/company assets are most impacted by high winds?
2. What types of wind hazards are most relevant?
3. What operational triggers (formal or informal) are currently used?
4. What impacts have been observed in the past five years?

Implementing High Wind Adaptation or Mitigation Strategies

1. Using the categories below, please list below the **location(s)** for each of the high wind adaptation or mitigation strategies your agency/company has implemented.

Structural (e.g., wind fence, fairing, barrier design)

Vegetative windbreaks

Operational measures (e.g., vehicle restrictions, closures, detour playbooks)

Monitoring/prediction (e.g., sensors, forecasting tools)

Traveler information (e.g., apps, alert systems)

Other strategy (Please describe and provide location(s).)

Before You Continue

Of the strategies listed above, please select **one strategy** and a **single location where the strategy has been implemented** to describe in detail for the following questions.

2. Please describe your agency's/company's high wind adaptation or mitigation strategy by addressing the topic areas below.

Nature of the high wind hazard (e.g., wind speed, season, humidity levels)

Location (consider topography, wind tunnel miles, highways/freeways in the vicinity)

Describe the strategy (consider nature-based and/or structural)

Installation/implementation date

Monitoring practice (if applicable)

Information dissemination (if applicable; consider the use of dynamic message signs, text alerts, reaching out to stakeholders/companies)

Impact on emergency response (consider detours, maintenance costs, response time)

Other details of the strategy

3. Has your agency/company experienced any issues with safety associated with this high wind adaptation or mitigation strategy? Safety issues might include driver behavior/compliance, sight distance/visibility, worker safety during activation/maintenance or vegetation fire risk.
 - No
 - Yes (Please describe the safety concerns.)
4. In addition to the maintenance cost, please describe the short- and long-term maintenance requirements or other considerations for sustaining this high wind adaptation or mitigation strategy. These maintenance requirements might include typical tasks, vegetation care, dust removal or sensor calibration.
5. Has your agency/company conducted a cost–benefit analysis for this high wind adaptation or mitigation strategy? This analysis might consider before/after closures, crash trends, travel time reliability, detour volumes, emergency repair costs avoided or freight delay savings.
 - No
 - Yes (Please describe the analysis and its results.)
6. Has your agency/company developed a protocol or practice for identifying other high wind locations that could benefit from structural/engineering intervention or other strategies?
 - No
 - Yes (Please describe this protocol or practice.)

Assessment

1. What successes has your agency/company observed in connection with the high wind adaptation or mitigation strategy you’ve described?
2. Has your agency/company attempted to measure the success of this strategy? This might be done through tracking the number of road closures, reduced costs or another measure.
 - No
 - Yes (Please describe the measure(s) used and results of the measurement practice.)
3. What challenges has your agency/company experienced when deploying the high wind adaptation or mitigation strategy you’ve described?
4. Please share any best practices or lessons learned your agency/company has identified when implementing high wind adaptation strategies.
5. Please provide links to documents associated with your agency’s/company’s high wind adaptation measures. Send any files not available online to chris.kline@ctcandassociates.com.

Considering the Use of High Wind Adaptation or Mitigation Strategies

1. Which agency/company assets are most impacted by high winds?
2. What types of wind hazards are most relevant?
3. What operational triggers (formal or informal) are currently used?
4. What impacts have been observed in the past five years?
5. Using the categories below, please describe the high wind adaptation or mitigation strategies your agency/company is interested in developing by identifying the **proposed location(s)** and the **issue each location is expected to address**.
 - Structural (e.g., wind fence, fairing, barrier design)
 - Vegetative windbreaks
 - Operational measures (e.g., vehicle restrictions, closures, detour playbooks)
 - Monitoring/prediction (e.g., sensors, forecasting tools)

Traveler information (e.g., apps, alert systems)

Other strategy (Please describe and provide location(s).)

6. What is needed for your agency/company to begin implementing these solutions? Please select all that apply.
- Case studies
 - Design guidance
 - Eligible program pathway
 - Equipment specifications
 - Funding
 - Interagency agreements
 - Measured cost–benefit results
 - Siting guidance
 - Standard details
 - Threshold or operational playbooks
 - Other (Please describe.)
7. What barriers do you see to moving forward with implementing these solutions? Please select all that apply.
- Community or aesthetic concerns
 - Data gaps
 - Funding
 - Interagency alignment
 - IT system deficiencies
 - Maintenance capacity
 - Permitting
 - Procurement constraints
 - Staffing
 - Standards uncertainty
 - Other (Please describe.)
8. When do you anticipate your agency/company will implement these solutions?

Not Considering the Use of High Wind Adaptation or Mitigation Strategies

1. Which agency/company assets are most impacted by high winds?
2. What types of wind hazards are most relevant?
3. What operational triggers (formal or informal) are currently used?
4. What impacts have been observed in the past five years?
5. Why does your agency/company not plan to pursue high wind adaptation/mitigation at this time?
Please select all that apply.
 - Community issues
 - Competing capital priorities
 - Design guidance is unclear or not available
 - Funding constraints
 - Lack of standards
 - Not a priority relative to other hazards
 - Permitting

- Risk is low
- Staffing
- Other (Please describe.)

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses or suggestions.