Predicting and Mitigating Wind-Induced Truck Crashes on I-70 in Kansas

Robert Rescot  
University of Kansas  
1530 West 15th Street, Suite 2160  
Lawrence, KS 66045  
rrescot@ku.edu

Romika Jasrotia  
University of Kansas  
1530 West 15th Street, Suite 2160  
Lawrence, KS 66045  
romikajasrotia@ku.edu

Kelly Hovey  
Kansas Department of Transportation  
700 Southwest Harrison Street  
Topeka, KS 66603  
kellyhov@ksdot.org

Yue Li  
University of Kansas  
1530 West 15th Street, Suite 2160  
Lawrence, KS 66045  
ylkx7@ku.edu

Steven D. Schrock  
University of Kansas  
1530 West 15th Street, Room 2150  
Lawrence, KS 66045  
schrock@ku.edu

ABSTRACT

Dangerous weather conditions are a common contributing factor in truck crashes and one such condition is high wind. It is believed that frequent high-wind episodes cause several truck crashes every year in Kansas. This paper presents a literature review and an analysis of wind-related crashes. The data compiled include truck crashes on I-70 throughout Kansas over a three year period from 2005 to 2007 along with independent weather data. The crash data were obtained for all heavy-vehicle crashes on I-70 that involved strong winds. The data were analyzed to determine the correlations between the vehicle characteristics, crash occurrences, and weather conditions. The goal was to construct a model that can predict the likelihood of such wind induced truck crashes, thus providing a tool for increasing safety to both truck drivers and the traveling public.

Key words: crash—truck—wind
INTRODUCTION

Traffic in the state of Kansas is susceptible to frequent severe wind conditions that contribute to several crashes. A significant portion of these traffic crashes involve freight trucks or high-profile vehicles. Statistics show that in Kansas during the years 2005, 2006, and 2007, there were 1,147, 892 and 1,399 wind-related crashes, respectively (1). These crashes contributed to 28%, 27%, and 37% of the total crashes in Kansas in the three respective years (2) (3) (4). Kansas is served by two major Interstate highways—I-70 and I-35—and multiple connector interstate routes—I-135, I-335, I-435, and I-635—covering over 874 miles (1,407 km) in all. Interstate 70 extends from the western border to the eastern border, covering 424 miles (682 km) and passing through many of the state's principal cities (5). The I-70 corridor carries an average annual daily traffic (AADT) of 7,990 to 20,300; the AADT increases from the western border to Topeka. These daily counts consist of 2,990 and 4,100 heavy commercial vehicles (6). I-35 extends from Kansas City through Wichita into Oklahoma covering 235 miles (5). I-35 south of Kansas City carries 21,400 vehicles daily, of which 4,960 are classified as heavy commercial vehicles, and I-35 East of Emporia carries 13,500 vehicles daily, of which 4,260 are classified as heavy commercial vehicles (6).

The western and central parts of the state are more prone to high winds. On March 23, 2009, the Kansas Highway Patrol reported 13 vehicles blown over from high winds in the central and western part of the state. The same day, one semi rollover in Topeka forced cleanup crews to close part of I-70 (7). The combination of large truck volume and high wind speeds leads to a high probability of crashes. These crashes may cause interstate closures, creating significant delays and economic loss. Safety has to be considered not only by the trucking industry but also by engineers; thus, this research looks at the crash data compiled from the Kansas Department of Transportation (KDOT) to determine correlation between wind speed and truck accidents for I-70. Interstate 70 was selected for this detailed analysis as KDOT is actively engaged in a program to deploy dynamic message signs along I-70 between Topeka and the Colorado border (8). Therefore, at the outset of this project, the research team aimed to create a multivariate model to predict wind induced truck crash rates that could be used in conjunction with the dynamic message signs.
LITERATURE REVIEW

The effect of wind on the stability of high-profile vehicles is an important safety consideration as strong winds may lead to the overturning of trucks.

A study was conducted at the University of New Brunswick to investigate the impact of wind forces on heavy truck stability. The goal of the experiment was to calculate the rollover threshold of a truck driving a loop ramp in New Brunswick under varying wind speeds. During the study period, the wind speeds were not significant enough to allow for the calculation of a rollover threshold; however, they were able to determine that wind does affect the stability of trucks. The recommendation was made to use similar methods in high wind areas to investigate wind forces which induce truck rollovers (9). Another study by the University of Manitoba used computer simulation to determine how combinations of weather conditions affect truck traffic. The angle the trailers moved, or yaw angle, was used to measure instability. The program was set up to simulate life-like wind gusts. The study determined that the maximum wind speed a heavy truck with a 48 ft trailer could safely travel in was between 31 and 43 mph when empty and between 62 and 74 mph when loaded (10).

The University of Wyoming suggests using Intelligent Transportation Systems (ITS) technology to communicate weather advisories directly to travelers. Four different mitigation levels were identified. Level 1 operation uses Road Weather Information System (RWIS) data and Dynamic Message Signs (DMS). Level 2 operation uses the same technology as Level 1, but instead of just imposing advisory warnings, a wind and surface condition threshold would be adopted that would lead to roadway closures. Level 3 requires the same decision tree as Levels 1 and 2, with the addition of selective closures to high-profile vehicles on the basis of wind and surface condition thresholds. Level 4 operations take the Level 3 application an additional step by identifying vehicles for partial closure on the basis of vehicle classification, or height and length characteristics, as well as weight characteristics (11).

The September 2007 American Public Works Association Reporter newsletter discussed a few other ways to efficiently communicate with drivers. The article focused on Dynamic Message Signs (DMS) and AM/FM radio, emphasizing AM/FM radio usage, considering it more advantageous than any other technology and believing that it has the ability to reach the majority of motorists. Also, the motorist has a better chance to receive the entire message as signs are easily missed, but the radio will continue to play. The report mentions other popular technologies that are being considered, such as cell phones, navigations systems, and satellite radio. Global Positioning System (GPS) and Highway Advisory Radio (HAR) look very promising because of their unique system to broadcast messages throughout a large area, such as an extended roadway, or an entire city or county (12).

STATE OF THE PRACTICE

There are several states that are currently taking a proactive approach to reduce wind-induced truck crashes. The states of Nevada, Montana, and California utilize Environmental Sensor Stations (ESS) installed on the highway or freeways to collect and transmit environmental data to a central control computer in the Traffic Operations Center/Traffic Management Center (TMC). The ESS measures wind speed and direction, precipitation type and rate, air temperature and humidity, as well as pavement temperature and condition (i.e., wet, snow or ice). During high-wind conditions, advisory or regulatory messages are displayed on DMS (13). Additionally, the state of Oregon also operates a similar system.

The Nevada Department of Transportation operates a high wind warning system on a seven mile section of US Route 395. An ESS is installed on the highway. During high-wind conditions, advisory or
regulatory messages are displayed on DMS. If the average speeds are 15 to 30 mph or the maximum wind gust is over 20 mph, the computer displays “High-Profile Vehicles ‘NOT ADVISED’” on the DMS and for extreme wind conditions when average wind speeds are greater than 30 mph or wind gusts exceed 40 mph. DMS displays “High-Profile Vehicles ‘PROHIBITED.’” Traffic managers may also broadcast pre-recorded messages via three HAR transmitters in the area (13).

The Montana Department of Transportation also uses a similar system to warn motorists and manage vehicle access. Severe wind tunnel conditions pose a safety risk to high-profile vehicles traveling on a 27-mile section of freeway. Traffic and maintenance managers are alerted by the RWIS when wind speeds in the area exceed 20 mph. A warning message—“CAUTION: WATCH FOR SEVERE CROSSWINDS”—is displayed on DMS when wind speeds are between 20 and 39 mph. When severe crosswinds (i.e., over 39 mph) are detected, a restriction message is posted on DMS to direct specified vehicles to exit the freeway and take an alternate route. A typical restriction message reads “SEVERE CROSSWINDS: HIGH PROFILE UNITS EXIT” (13).

Similarly, the California Department of Transportation collects the data from 36 vehicle detection sites and nine ESS that are deployed along freeways. The DMS displays “HIGH-WIND WARNING” if the wind speeds are greater than 35 mph (13).

Oregon operates two wind advisory systems. One system is for the southwest coast of the state and the other system is for the Yaquina Bay Bridge System. Both systems are triggered by anemometers mounted near the roadway. The thresholds for activation are the same for both systems. The first level activation is made when the average wind speed for any two min interval is in excess of 35 mph, and the second tier of activation is made when the same two minute wind speed average exceeds 80 mph. In the event of tier one activation, a warning is posted to a DMS or flashing beacons are activated (depending on site), the alert is posted to the Internet, and for the Yaquina Bay Bridge System, maintenance crews are notified with faxes to other agencies, along with creating an archived file of the details. When tier two is reached, there is no specific change for the southwest coastal roads; however, for the Yaquina Bay Bridge System, the road is closed (14).

An emerging web publishing platform, Twitter, presents potential for communicating with the public. The service limits each message to 140 characters or less, and thus, each message must be clear and concise, similar to limitations on DMS. The Washington State Department of Transportation sends updates of various traffic alerts and route changes for ferries (15). KDOT has also found Twitter to be a valuable tool. Public affairs managers in the cities of Garden City, Topeka, and Wichita provide “tweets” to followers of traffic situations, construction or maintenance lane closures, and KDOT news. This tool has been used to keep travelers up-to-date on emergency closures and construction progress (16). Some other alert systems such as anemometers, text messaging, and wind socks are also being considered. Anemometers, if maintained and operated properly, can provide precise weather documentation. Text messaging is quicker and can be a vital tool for many truck companies. Wind socks are economical and helpful because they show direction and velocity of the wind (17).

DATA ANALYSIS

The crash data used for the analysis were obtained from KDOT’s Kansas Accident Record System (KARS) (1). This system is a compilation of motor vehicle accident reports, investigation reports for fatalities, and truck and bus supplement reports. Crashes involving large/heavy trucks and strong winds were separated out for the years of 2005, 2006, and 2007. This resulted in 247 crash reports being obtained from the original pool of 3,438. In the reports, a large/heavy truck is defined by vehicle body type and includes single-unit large trucks, truck and trailers, or tractor trailers. To be sure each report met
the criteria, the research team individually reviewed each of the 247 crash reports. As a result of this careful review, a number of crashes were found to not be related to a truck causing a crash due to wind (acting alone or in combination with other weather phenomena). The most frequent example was a car sliding out of control in windy/rainy conditions (possibly hydroplaning) and striking a truck. Another common occurrence was that a pickup truck (such as a Ford F150 or Dodge Ram 3500) was inadvertently coded in the crash report as the wrong type of truck and, thus, was also removed. After the team reviewed all 247 crash reports, 52 crash records were confirmed to be the exclusive result of an interaction between wind and a truck.

The team also obtained supplementary data to augment the crash reports. This data included both truck ADT for the segment where the crash occurred and independent weather data. Truck average daily traffic (ADT) information was extracted from KDOT’s statewide traffic volume map by matching the crash location to the ADT for that same location. Weather data were obtained from the Weather Underground website on a county-by-county basis for each day in the three-year study period. The research team then was able to determine for each crash the wind speed and gust speeds as recorded by the Weather Underground (18).

Figure 2. Location of weather stations in Kansas (18)

Figure 3 shows a distribution of the 52 studied crashes and the associated wind gust speeds. What stands out is that crash frequency seems to peak around 40 mph. The research team then compared Figure 3 to a histogram of all the maximum gust speeds for the entire corridor for the entire three-year period, as shown in Figure 4.
The team also was interested in how the changing truck ADT varied by milepost and this resulted in Figure 5.
Taking a closer look at where along I-70 the crashes studied occurred resulted in Figure 6.

In constructing a statistical model, a response variable is required to be predicted. In this case, the response variable chosen was crash rate. The team noted that of the 52 records in the study, none occurred within the same hour of the same day at the same location. It is also important to note that the weather conditions are not constant with location or date. Therefore, the team used the truck ADT data for each location and converted it into an hourly truck ADT; thus, the hourly crash rate was found by dividing one
by the hourly truck ADT. Finally, a logit transformation of the crash rate was taken to normalize the data. Expanding on Figure 6, the transformed crash rate was plotted against milepost to produce Figure 7.

A multivariate linear regression model was then constructed over multiple iterations. The process began considering over 65 variables, including interaction terms, and then evaluating the p-values for the coefficients. Early in the process, it was noted that values for wind speed, wind gust, and empty (no cargo) had p-values in excess of 0.05 but the team forced their inclusion up until the very end. After repeated iterations, including a stepwise regression, the final model for predicting the truck crash rate was found.

Logit(Hourly_Crash_Rate) = - 4.92 + 0.0443 THUNDERSTORM - 0.000721 Milepost + 0.0641 Concrete - 0.127 Hopper - 0.157 Flatbed

SUMMARY

When one looks at the final form of the regression equation for predicting windblown truck crashes in Kansas on I-70, one important thing stands out—namely that neither wind speed nor wind gust speed was found to be a factor. The factors that were found to be statistically significant were the presence of a thunderstorm, the milepost (the further west, or closer to milepost zero, the more risk), presence of concrete pavement, if the truck is pulling a hopper cargo trailer, and if the truck is pulling a flatbed trailer. This absence is accounted for due to driver behavior changes. For an ideal statistical model, drivers would not alter their behavior due to any adverse weather conditions, and obviously there would be more crashes to study, and thus, a better model that would perhaps be better at isolating specific dangerous wind gust speed thresholds. However, that is simply not the case; drivers do in fact take defensive measures and either alter their driving (increased vigilance, decreased speed, etc.) or get off the road and stop driving until conditions improve.
Looking beyond the probability model, the data do tell an interesting story. Since gust speeds were not a factor in the probability model, it might be expected that mean gust speed for the corridor for the study period could be the same as the mean gust speed associated with the studied crashes. However, over the course of the three-year study period for the entire I-70 corridor that contained the 52 crashes that formed the model, the average maximum gust speed was 28.8 mph, while the mean gust speed for all the crashes in the study was found to be 40.8 mph. A 95% confidence interval for the difference between the means was found to be between 9.6 and 14.5 mph. Subsequently, a null hypothesis that the means are the same can be rejected using a two sample t-test.

The difference in mean gust speeds has several possible implications. First, it is important to recognize what this means. The average gust speed for the entire corridor was found to be 28.8 mph, which means that this is the most probable wind speed and that as the wind speed increases above 28.8 mph, the probability of such an occurrence decreases. However, as the wind speed increases above 28.8 mph, the probability of an associated crash increases, until reaching 40.8 mph. This gap is believed to be analogous to the dilemma zone at a signalized intersection. In other words, this gap possibly represents a range or wind speeds where drivers are not taking proportionally precautionary measures as they are taking when the gust speed is in excess of 40.8 mph; thus, they are facing an increased risk but are unaware of doing so. It is theorized that around a gust speed of 40.8 mph is a threshold where drivers begin changing their behavior as previously discussed.

Looking geographically at the data, another interesting observation can be made. Looking at Figures 5, 6, and 7, one observes that the highest frequencies of the crashes studied occur between mileposts 140 and 220 (Figure 6), which accounts for 21 of the 52 crashes (40%). This location bookends around the city of Hays, Kansas, located between mileposts 157 and 161, and is approximately an inflection point on the plots of truck ADT by milepost (Figure 5) and crash rate by milepost (Figure 7).

**CONCLUSION**

The findings of this research are consistent with the other literature identified. Like the University of New Brunswick study, wind speeds were not found to be a statistically significant part of any model based on available data. The University of Manitoba simulation study, which found that an empty truck could drive safely in winds up to a range between 31 and 48 mph with an empty trailer, intersects around the dilemma zone identified for I-70 in Kansas. This overlap in the studies provides mutual support for the idea that this may be a critical range and that based on the Kansas data, suggests that while I-70 trucks in Kansas may possibly have a larger safety cushion (up to 48 mph instead of 40.8); they are being more conservative and making behavioral changes at a lower threshold.

The current state of the practice in reducing wind-related truck crashes also supports this Kansas data. The practices in Idaho and Nevada to warn trucks when wind speeds are above 20 mph and to altogether restrict truck traffic when winds exceed 39 mph is in congruence with this study. The lower bound of 20 mph may be if anything slightly conservative; however, it is only slightly lower than the mean corridor wind speed for I-70 in Kansas. What is more interesting is that the critical speed for trucks to be restricted from the highway is within a 95% confidence interval for the mean gust speed associated with the Kansas I-70 truck crashes. This provides additional support for the anecdotal notion that in Kansas, drivers are altering their behavior when winds gust above 40 mph. If such cross-country drivers have encountered similar restrictions in these other states, it may have conditioned them to respond in a similar manner when transiting Kansas.

The critical element that underpinned this study is the crash report. It cannot be overstated that this is the weakest link in the puzzle. In sorting through the KARS data, a very large number of reports were found
to not be relevant or had miscoded information. This study only focused on crashes that met very narrow criteria that pared down an initial dataset of 3,438 into 247 (7%), which was then further reduced to just 52 (21% of the 247, 1.5% of the 3,438). At the scene of a crash, the various officers who file the report are first and foremost concerned with the safety of the crash victims and providing for suitable (if any) traffic management and often do not write the report that gets submitted into the KARS system until well after the crash has been cleared. Thus, it is understandable that mistakes may unfortunately creep into the system. However, short of dispatching a dedicated researcher to the scene of every such crash, this is the reality that we have to live with.

The implications of this research are assorted. First and foremost, more data are clearly needed to be able to properly construct a model that hopefully would contain a wind (gust) speed variable. However, it is important to note the context sensitive nature of this data. Weather and wind patterns are based on a wide array of factors, not the least of which is effected by the surrounding geography. While it may be convenient to simply lump crashes together from all geographical locations, it would likely not result in a model that can have any location specific relevance. Secondly, this research suggests that more in-depth study of wind-truck interactions around the 28.8 to 40.8 mph spectrum of wind gusts. To better test a hypothesis that drivers are misjudging risks in this dilemma zone, a driver survey could be conducted in coordination with an interactive driving simulator study.

Turning the lessons learned in this study into “shovel-ready” practice, there are several possibilities. Any solution would have two components: namely the system itself and one or more chosen installation locations. Firstly for the warning system, one option would be to trigger messages on the future ITS system’s DMS to report wind (gust) speeds when they reach a threshold (being careful to not use any language with possible legal liability implications). Another option might be to install windsocks along vulnerable stretches of the highway to provide an instantaneous visual representation for the current wind conditions. In both of these possibilities, drivers would not be mandated to exit the highway, but hopefully would have more available information to make a better decision. Another option would be to follow the model of the several states previously discussed and have a formal warning system, perhaps with a regulatory threshold such that if the wind (gust) speed exceeds a given threshold, truck traffic would be temporarily prohibited. Recognizing that KDOT does not have unlimited resources based solely on the frequencies observed, the greatest potential return on investment would be for the stretch of I-70 that surrounds Hays, Kansas, possibly extending all the way to the western border with Colorado. However, any system utilized and installation locations chosen should be given full engineering and legal scrutiny prior to construction.
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