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# Mitigating Wind Induced Truck Crashes

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# MID-AMERICA TRANSPORTATION CENTER

Report # MATC-KU: 263

Final Report



## Mitigating Wind Induced Truck Crashes

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2010

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## **Mitigating Wind Induced Truck Crashes**

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## Abstract

Dangerous weather and high wind in particular, is a common contributing factor in truck crashes. High wind speeds have been documented as a perennial cause of truck crashes in Kansas and other Great Plains states. The possibility of reducing such crashes, combined with the installation of dynamic message signs along Interstate 70, created an opportunity for further research. To this end, crash data were obtained from the Kansas Department of Transportation's Accident Records System for all heavy vehicle crashes on I-70 that involved strong winds. The data were analyzed to determine the correlations between the vehicle and freight characteristics, crash occurrences and weather conditions. The goal of this analysis was to construct a model that could predict the likelihood of such wind-induced truck crashes. Ideally, this model could furnish officials with a framework for preempting such crashes by imposing highway usage restrictions; thereby increasing safety for both truck drivers and the traveling public. After regressing the data into a model, however, it was found that wind speed was not a statistically significant factor in predicting such crashes. This finding agrees with some of the other literature on the subject and can be attributed to drivers altering their behavior as wind speeds change. From this research, we identified a dilemma zone of wind speeds in which drivers may not be making such a behavioral change. Furthermore, specific corridors in Kansas are identified as potential areas for the implementation of a warning system. It is recommended that Dynamic Message Signs be tied to weather data stations and/or lighted wind socks be installed on selected overpass bridges.

## Executive Summary

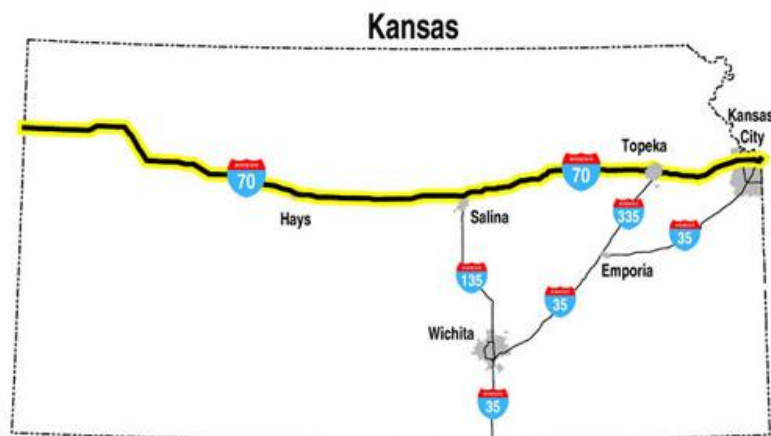
Traffic in the state of Kansas is susceptible to frequent severe wind conditions which contribute to many crashes. A significant portion of these traffic crashes involve freight trucks or high profile vehicles. Statistics show that in Kansas during the study years—between 2003 and 2008—there were 1,739 crashes for which wind was a contributing circumstance. These crashes contributed to 28 percent, 27 percent and 37 percent of the total crashes in Kansas for the years 2005 to 2007 as is show in Table 1.1. These findings are based on information from McCommon et al. (1-5) and the Kansas Department of Transportation, KDOT (6).

**TABLE 1.1** Kansas Statewide Crashes with Wind as a Contributing Circumstance (1-6)

Year	Crashes	% of All Crashes
2003	361	0.39%
2004	240	0.26%
2005	237	0.28%
2006	211	0.27%
2007	317	0.37%
2008	373	0.50%

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, as illustrated in Figure 1.1, extends from the western to the eastern border, covering 424 miles (682 km) and passing through many of the state's principal cities, according to KDOT (7). The I-70 corridor from the Colorado border to Topeka carries an average annual daily traffic

(AADT) of 7,990 to 20,300, with the AADT increasing from the Colorado border to Topeka. This AADT count consists of 2,990 and 4,100 heavy commercial vehicles traveling from the Colorado border to Topeka (see KDOT 8). Covering 235 miles, I-35 extends from Kansas City through Wichita into Oklahoma (refer to KDOT 7). East of Emporia, I-35 carries 21,400 vehicles daily—of which 4,960 are classified as heavy commercial vehicles. I-135 East of Emporia carries 13,500 vehicles daily of which 4,260 are classified as heavy commercial vehicles (KDOT 8).



**Fig. 1.1** I-70 in Kansas (7)

The western and central parts of the state are reported to be 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. On the same day, *Lawrence Journal World* reported that a heavy truck rollover in Topeka forced cleanup crews to close part of I-70 (9). The combination of large truck volume and high wind speeds leads to a higher probability for these types of crashes. These crashes may cause highway closures—creating significant delays and economic

loss. Safety has to be considered not only by the trucking industry, but also by engineers. This research examines crash data compiled from the Kansas Department of Transportation (KDOT) to determine correlation between wind speed and truck crashes for I-70. Interstate 70 was selected for this detailed analysis as KDOT is actively engaged in a program to deploy Dynamic Message Signs (DMS) along I-70 between Topeka and the Colorado border (10).

## Chapter 1 Literature Review

A literature review was conducted to determine the effects of wind on the stability of high profile vehicles. This 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 (11). 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 that similar methods should be used in high wind areas to investigate wind forces which induce truck rollovers (11).

Another study by the University of Manitoba used computer simulation to determine how combinations of weather conditions affect truck traffic (12). The angle the trailers moved, or yaw angle, was used to measure instability. The program was constructed to simulate life-like wind gusts. The study determined that the maximum wind speed a heavy truck with a 48 foot trailer could safely travel in was between 31 and 43 mph when empty and between 62 and 74 mph when loaded (12).

The University of Wyoming suggests using Intelligent Transportation Systems (ITS) technology to communicate weather advisories directly to travelers (13). Four different mitigation levels were identified for notifications. 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 merely imposing advisory warnings, a wind and surface condition threshold is adopted and leads 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 further by identifying vehicles for partial closure on the basis of vehicle classification, as well as height, length, and weight characteristics (13).

The September 2007 American Public Works Association *Reporter* newsletter discussed several ways to communicate efficiently with drivers (14). The article focused on DMS and AM/FM radio, while emphasizing the latter. AM/FM radio was considered more advantageous than any other technology which has the ability to reach the majority of motorists. Accordingly, the motorist has a better chance to receive the entire message since the radio continues to play whereas signs are easily missed. 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, an entire city or county (14). Highway Advisory Radio allows almost every vehicle access to the information being broadcast, since the messages are transmitted on AM waves and can be available 24 hours a day. However, these stations might not receive as much attention as hoped due to the probability of a motorist changing radio stations or because they must seek the information stations themselves.

## Chapter 2 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). According to the FHWA Road Weather Management Program, during high wind conditions, advisory or regulatory messages are displayed on DMS (15).

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 15-30 mph or the maximum wind gust is over 20 mph, the computer displays: “High Profile Vehicles NOT ADVISED” on the DMS. For extreme wind conditions when average wind speeds are greater than 30 mph or wind gusts exceed 40 mph, the DMS display reads: “High Profile Vehicles PROHIBITED.” Traffic managers may also broadcast pre-recorded messages via three HAR transmitters in the area in compliance with FHWA guidelines (15).

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” (15).

Similarly, the California Department of Transportation collects the data from 36 vehicle detection sites and nine ESS, which are deployed along freeways. The DMS display “HIGH WIND WARNING” if the wind speeds are greater than 35 mph (15). Caltrans also built their system with anticipated improvements, such as a HAR system, to supplement visual warning messages as well as the integration of control computers into a single workstation. Another element that Variable Message Signs (VMS) offer is the ability to display graphics. The University of Rhode Island found that motorists react 35% faster on average when a standard industry graphic image is included with text. The symbol or graphic allows the motorist to quickly decipher the message rather than having to read text which could be easily ignored. VMS installations also require precise location placement to maximize viewing angles and efficiency of message distribution. These types of maintenance and installation difficulties are not necessary when working with HAR radio or Twitter, for example.

Nebraska has used Road/Runway Weather Information Systems (RWIS) technology since the 1970’s. They use weather information gathering sites to collect RWIS data, which determine pavement conditions, wind speed and direction through sensors. The Nebraska Department of Roads then uses the data to determine when to dispatch crews during storms (15).

The Maryland State Highway Administration uses RWIS systems to better collect reliable and precise wind speed measurements on bridges. They needed accurate data to coincide with wind restriction policies on bridges to ensure they were meeting the policy conditions, while providing accurate data measurements (15).

Iowa has a project called FORETELL led by Iowa DOT, which creates a self sustaining weather and transportation system. The Iowa DOT has installed RWIS systems in rest areas to capture real time weather information. The goals of the program are to increase passenger safety, collect and provide weather data, and increase efficiency within various maintenance and safety departments of Iowa DOT. The Iowa DOT also conducted a study from 1993 through 2000 to assess the changes of driver behavior as a result of messages on DMS. When DMS displayed messages during winds over 20mph they found that average vehicle speed was reduced by 23% from 54.8mph to 42.3mph (15). Although their data were not specific to trucks, it does show that DMS can have an impact on drivers' actions.

Montana also uses DMS for warnings of bad pavement conditions, which can also play a large factor in how wind affects the trucks and should be considered while implementing a weather data collection system.

The Idaho DOT uses environmental sensor stations to detect pavement conditions as well as wind speed and other weather conditions. They post warnings of bad conditions on four Dynamic Message Signs. The computer is set to respond to preset values and once the weather reaches these limitations, the system alerts traffic managers, who then decide which messages to display on the DMS.

In 2001, Colorado DOT's Safety and Traffic Engineering Branch performed a Safety Assessment Report for a resurfacing project on I-25 and found strong evidence that high winds in the area were directly related to many of the more serious accidents. They determined that many truck overturns resulted from high winds and decided to place high wind warning VMS along a 9-mile strip. The VMS use simple phone lines to communicate to and from an operations

center (15). This seems to be a low technology system, but the report findings on high wind are very useful.

There are many different RWIS system manufacturers and installation setups that can be customized to fit geographical locations, as well as to ensure cooperation with already installed data collection systems and instruments, such as anemometers. Other technologies include wireless wind sensors to collect data and vehicle-mounted wind tracking units, which could be purchased and utilized efficiently by trucking companies.

Oregon operates two wind advisory systems. One system is for the southwest coast of the state and the other is for the Yaquina Bay Bridge System. Both systems are triggered by anemometers mounted near the roadway and have the same thresholds for activation. The first level activation is made when the average wind speed for any two minute interval is in excess of 35 mph (56 km/hr), and the second tier of activation is made when the same two minute wind speed average exceeds 80 mph (128 km/hr). In the event of tier one activation, a warning is posted on a DMS, flashing beacons are activated (depending on site), and the alert is posted to the internet. In addition to these procedures, for the Yaquina Bay Bridge System, maintenance crews are notified along with faxes to other agencies, and an archived file of the details is created. 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 (16).

An emerging web publishing platform, Twitter, presents potential for communicating with the public. The service limits each message to 140 characters or less; thus, each message must be clear and concise, similar to messages on DMS. The Washington State Department of Transportation sends Twitter updates of various traffic alerts and route changes for ferries (17). KDOT has also found Twitter to be a valuable tool. Public affairs managers in Garden City,

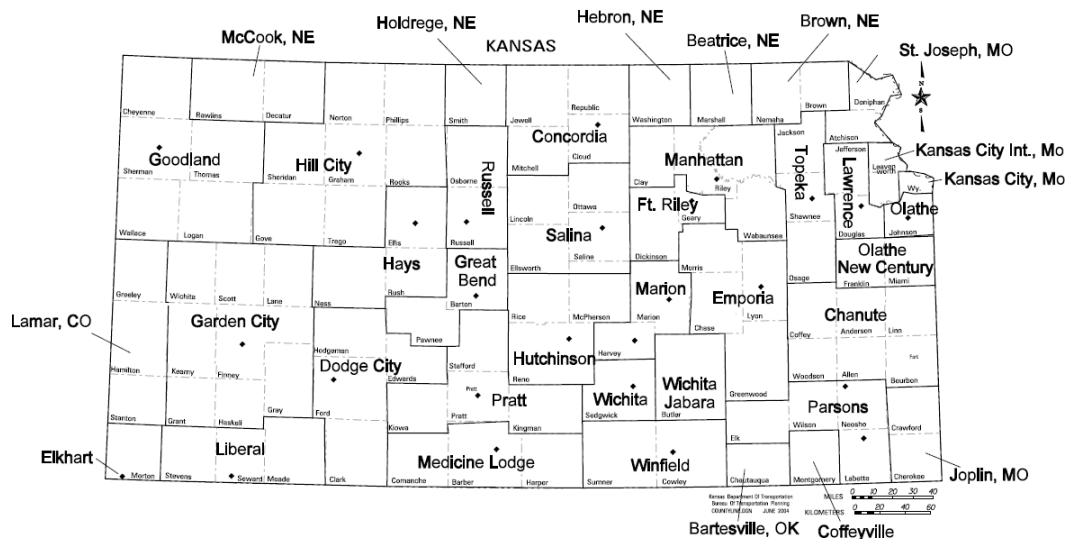
Topeka and Wichita provide “tweets” to followers of traffic situations, which inform the public about construction or maintenance lane closures and KDOT news. This tool has been used to keep travelers up to date on emergency closures and construction progress as shown in research by Whitley and Stich (18). However, as text messaging and other forms of hand-held communication become more prevalent, the utilization of these technologies needs to be compared with their vulnerability to safety. Other alert systems, such as anemometers, text messaging and wind socks are also being considered as forms of communication. 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. The wind socks can also be lit through small and inexpensive solar lighting, if other methods of lighting or electricity are not available. This would allow the wind socks to be seen at night and during other times of low visibility. The installation of wind socks would be a very quick and easy way to improve notification of high wind speeds to drivers at all hours of any day with minimum maintenance and therefore should be looked into further. Wind socks are economical and helpful because they show direction and relative velocity of the wind (19). There are also various vehicle mounted instruments that can be linked into state RWIS networks; a magnetic antenna can be easily mounted to the roof of any vehicle and operates with the power supply from a 12V jack.

### Chapter 3 Case Study: I-70

Crashes on I-70 involving large/heavy trucks and strong winds were separated out for the years of 2003 through 2008. The crash data used for the analysis were obtained from KDOT's Kansas Accident Record System, KARS (20). This system is a compilation of motor vehicle accident reports, investigation reports for fatalities, and truck and bus supplement reports. This resulted in 408 crash reports being analyzed. 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 408 crash reports. As a result of this careful review, a number of crashes were found to be unrelated to wind-induced truck crashes (i.e., 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 from the study. After the team reviewed all 408 crash reports, 114 crash records, or 28 percent were confirmed to be the exclusive result of wind interaction with a heavy truck.

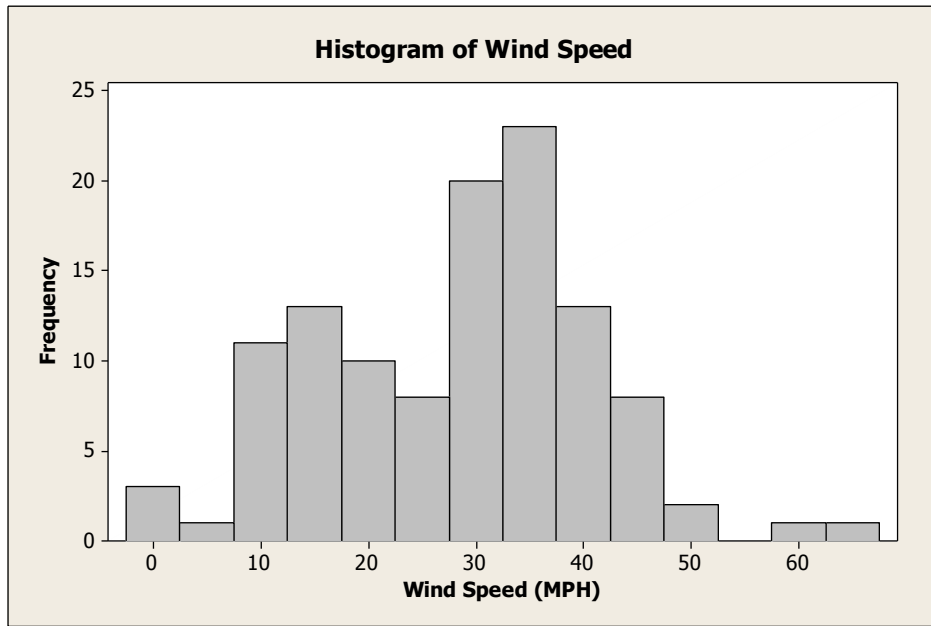
The team also obtained supplementary data to augment the crash reports. These data included both truck ADT for the segment where the crash occurred, hourly truck volume percentages, and independent weather data. Truck ADT information was extracted from KDOT's statewide traffic volume map by matching the crash location to the ADT for that same location (references 8 and 21-25). To factor the truck ADT into an hourly exposure measure of how many other trucks also on the road may have also been exposed to similar conditions, data on hourly truck volumes were collected. In 2008, KDOT conducted a 159 hour classification count near

Solomon, Kansas using standardized Federal Highway Administration bins (21). For this study, bins 4 to 13 were used to find an hourly percentage to factor the truck ADT. 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 this website (27). Figure 3.1 shows the locations of the weather stations in Kansas.

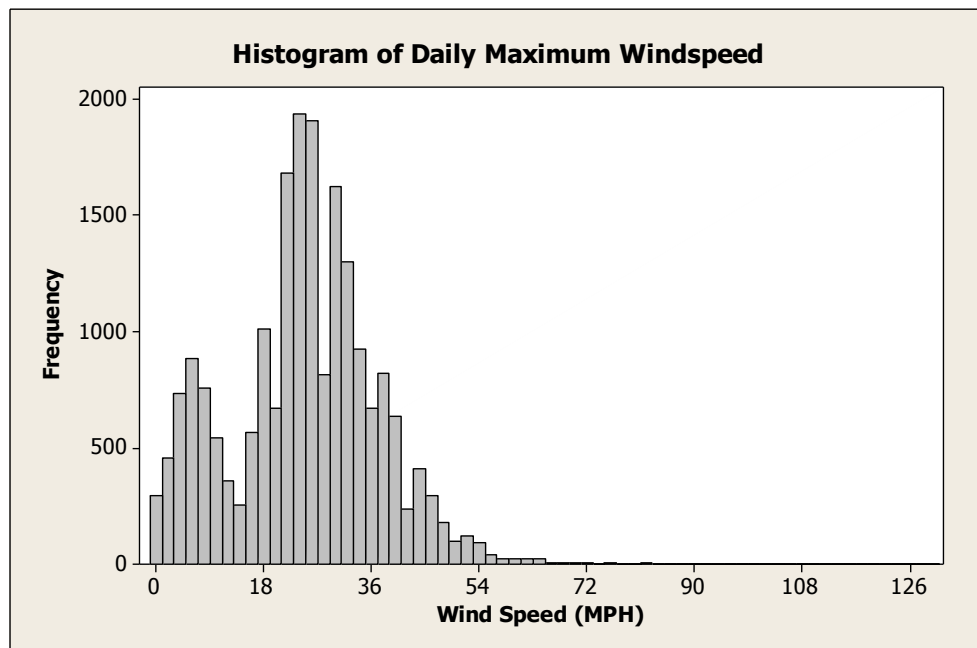


**Fig. 3.1** Location of Weather Stations in Kansas (22)

Figure 3.2 shows a distribution of the 114 studied crashes and the associated wind gust speeds. What is distinct in this model is that crash frequency seems to peak between thirty-two and thirty-seven miles per hour. The research team then compared figure 3.2 to a histogram of all the maximum gust speeds for the entire corridor for the entire six year period, which are displayed in figure 3.3.

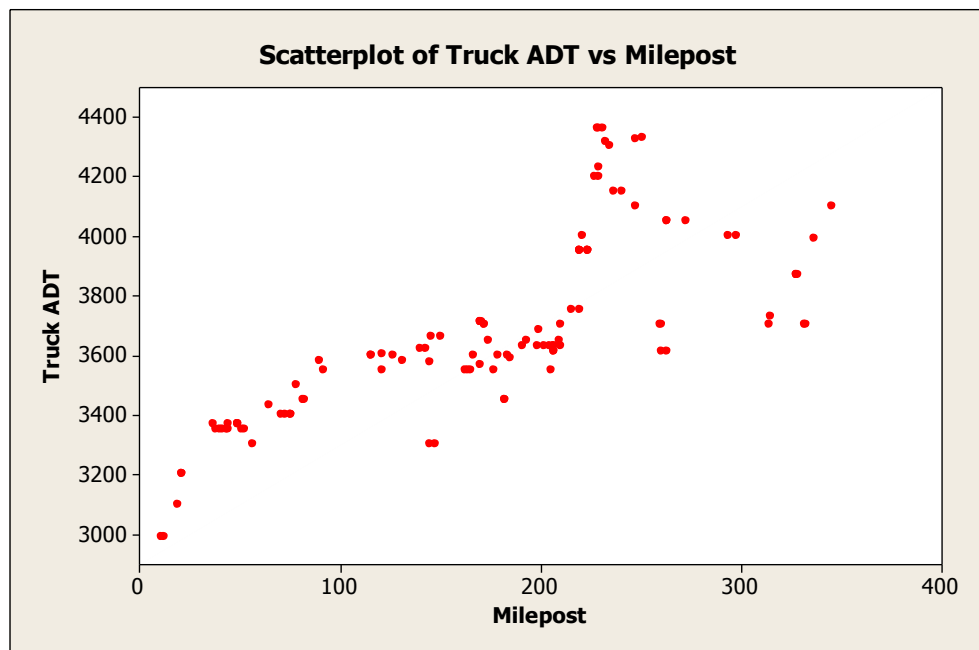


**Fig. 3.2** Histogram of Maximum Gust Speed for Each Crash, N=114



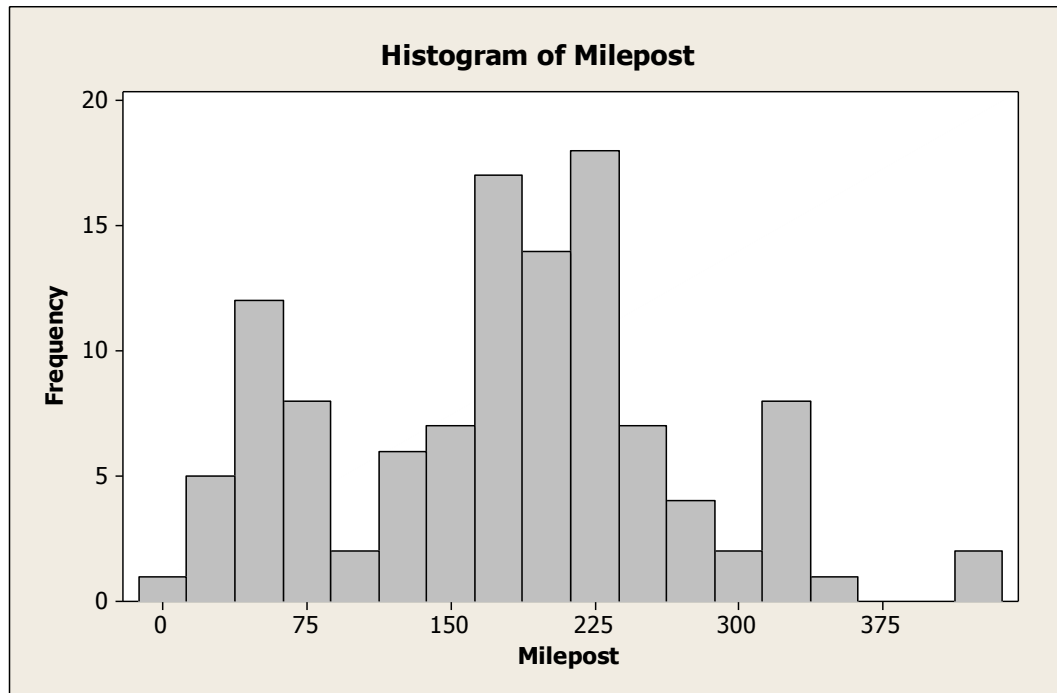
**Fig. 3.3** Histogram of Maximum Gust Speeds for I-70 Corridor, 2003-2008, N=20,456

The team also was interested in how the changing truck ADT varied by milepost and this resulted in figure 3.4. It should be noted that Wyandotte County contains a portion of the Kansas City metropolitan area, mileposts 410 – 422, and has truck ADT values upwards of 7,900.



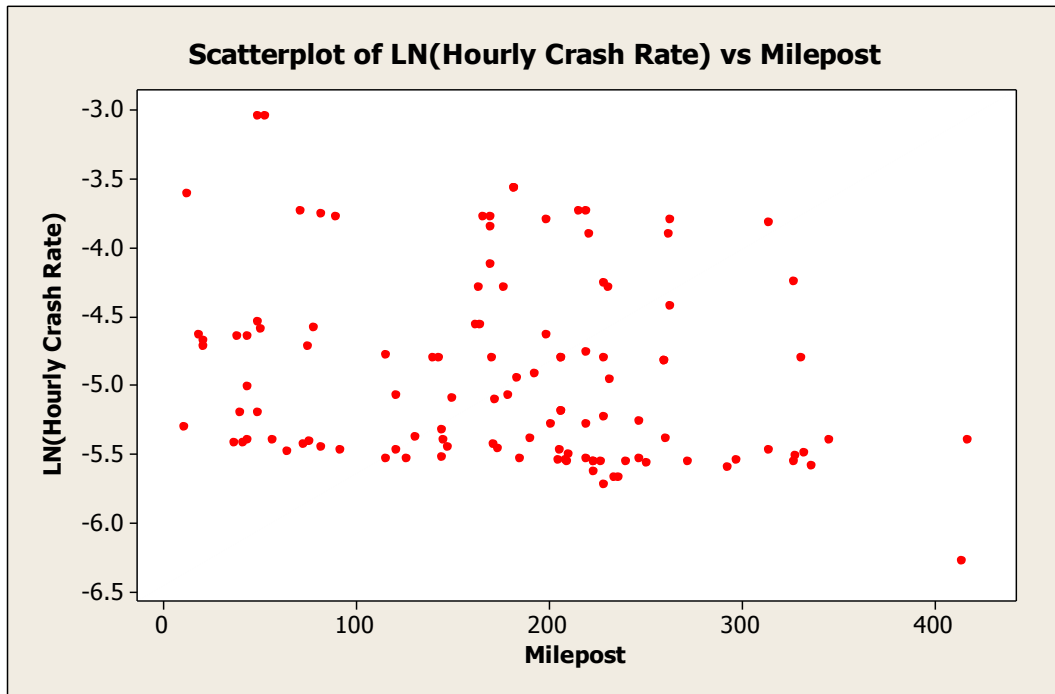
**Fig. 3.4** Scatterplot of Truck ADT vs. Milepost on I-70 in Kansas  
(excluding Wyandotte County)

Taking a closer look at where the crashes studied occurred along I-70 resulted in figure 3.5.



**Fig. 3.5** Histogram of Wind Induced Truck Crashes by Milepost, N=114

In constructing a statistical model, a response variable is required to be predicted. In this case, the response variable chosen was hourly crash rate. It is also important to recognize that the data are both spatially and temporally variant, since the weather conditions are not constant with location or time. Therefore, the team used the truck ADT data for each location and converted it into an hourly truck ADT using an hourly factor. Thus, the hourly crash rate was found by dividing each crash by the hourly truck ADT for that location. Next, the data were scanned for spatially and temporally related crashes. If two or more crashes were within ten miles and one hour of each other, the denominator (hourly truck ADT) of the hourly crash rate for each related crash was divided by the number of related crashes. Finally, a log transformation of the crash rate was taken to normalize the data. Expanding on figure 3.5, the transformed crash rate was plotted against milepost to produce figure 3.6.



**Fig. 3.6** Scatterplot of I-70 Wind Related Truck Crash Rates versus Milepost, N=114

A multivariate linear regression model was then constructed over multiple iterations. The process began by considering over 65 variables, including interaction terms, and then evaluating the p-values for the coefficients. Early in the process, it was noted that the 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.

$$\begin{aligned} \text{LN(Hourly Crash Rate)} = & - 3.56 - 0.0487 \text{ Hour} - 1.58 \text{ Precipitation(in.)} + 0.331 \text{ Rain} \\ & + 0.390 \text{ Thunderstorm} + 0.651 \text{ Scattered Clouds} \\ & - 0.00140 \text{ Milepost} - 0.944 \text{ Daylight} - 0.756 \text{ Dawn} \end{aligned} \quad (1.1)$$

When one looks at the final form of the regression equation for predicting windblown truck crashes in Kansas on I-70, one important conclusion is evident: neither wind speed nor wind gust speed was found to be a factor. The factors that were found to be statistically

significant were the hour of the day (0 to 23), inches of precipitation in the hour, presence of rain, presence of a thunderstorm, presence of scattered clouds, the milepost (the further west, or closer to milepost zero, the more risk), daylight driving conditions and dawn driving conditions. The absence of wind as a factor may be accounted for by driver behavioral changes. In an ideal dataset, to underpin such a statistical model, drivers would not alter their behavior due to any adverse weather conditions. Obviously, this would create more crashes to study and possibly create a significant variable for wind gust speed, and, consequently, a more robust model.

However, under real world conditions, this is simply not possible; drivers do in fact take defensive measures, and either alter their driving (increased vigilance, decreased speed, etc.) or exit the road and stop driving until conditions improve. Although the regression equation did not indicate that wind speed or wind gusts are factors for predicting windblown truck crashes on I-70, it is a fact that high wind speeds affect driving conditions. Many drivers will take precautionary measures once they can feel weather effects as they drive, but wind is hard to constantly calculate and display for motorists, and the researchers feel that any measures taken that can help increase highway truck safety are worth a feasibility study. It is important to recall the Federal Highway Administration's Office of Safety's mission, which is:

to reduce highway fatalities by making our roads safer through a data-driven, systematic approach and addressing all "4Es" of safety: engineering, education, enforcement, and emergency medical services. Increasing awareness of the need for roadway safety infrastructure improvements is very important. We are striving to provide decision-makers important information, tools and resources that will improve the safety performance of roadways. Safety should be considered first, every time and at every

stage of a project. Make safety your first consideration in every investment decision.

(29)

Safety must always be a top concern in highway operations. However, looking beyond the probability model, the data tell an interesting safety story.

Since wind speeds of any kind were not a factor in the probability model, it might be expected that mean gust speed for the corridor for the study period would be the same as the mean gust speed associated with the studied crashes. However, over the course of the six year study period, for the entire I-70 corridor that contained the 114 crashes that formed the model, the mean maximum gust speed was 24.2 mph, while the mean maximum gust speed for all the crashes in the study was found to be 28.2 mph. A 95 percent confidence interval for the difference between the means was found to be between 1.74 and 6.26 mph. Subsequently, a null hypothesis that the means are the same can be rejected using a two sample t-test.

The difference in mean maximum gust speeds has several possible implications. First it is important to recognize what this means. The mean average gust speed for the entire corridor of 24.2 mph means that this is the most probable wind speed, and that, as the wind speed increases above 24.2 mph, the probability of such an occurrence decreases. However, as the wind speed increases above 24.2 mph, the probability of an associated crash increases, until reaching 28.2 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 of wind speeds where drivers are not taking proportionally precautionary measures as they are taking when the gust speed is in excess of 28.2 mph, thus they are facing an increased risk, but are unaware of doing so. It is theorized that a gust speed of 28.2 mph is the threshold where drivers begin changing their behavior, as previously discussed.

## Chapter 4 Conclusions and Recommendations

The findings of this research are consistent with the other literature identified. Like the University of New Brunswick study, wind speeds were also 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 travel safely in winds up to a range between 31 and 48 miles per hour, is slightly higher than 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 based on the Kansas data, suggests that trucks on I-70 in Kansas may possibly have a larger safety cushion—up to 48 mph instead of 28.8 mph. Furthermore, it suggests that, in general, they are being more conservative and making behavioral (driving) changes at a much lower threshold relative to the New Brunswick data. However, although there could be behavioral changes, state highway agency officials should not expect that every individual will have the knowledge or ability to detect unsafe wind conditions. Placing DMS tied to weather data stations and/or installing lighted wind socks on selected overpass bridges would be of great value to drivers that might not otherwise take extra safety precautions based on their own judgment.

The current state of the practice in reducing wind related truck crashes also supports the 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 slightly conservative however it is only slightly lower than the mean corridor average wind gust speed for I-70 in Kansas. Furthermore, if cross country truck drivers have encountered similar warnings or restrictions in these other states; it may have conditioned them to respond in a similar manner when traveling through Kansas.

The recommendations based on this project are:

1. Connect the RWIS stations to the DMS, where possible.
2. Install lighted wind socks on overpasses in areas with high velocity wind potentials.
3. The DMS displays should read: “STRONG WINDS” if wind is between 20-40 mph.
4. The DMS display should read: “WARNING, VERY STRONG WINDS” if the winds exceed 40 mph.
5. Communicate wind velocity information at rest stops and weigh stations along I-70.

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