# Evaluation of fog-detection and advisory-speed system

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## Abstract

Highway safety is a major concern to the public and to transportation professionals, so the number of crashes caused by poor visibility due to fog form an alarming statistic. Drivers respond to poor visibility conditions in different ways: some slow down; others do not. Many drivers simply follow the taillights of the vehicle ahead. Accordingly, hazardous conditions are created in which speeds are both too high for the prevailing conditions and highly variable. Findings are presented from a study of traffic crashes due to fog in the southern region of Saudi Arabia. The primary objective was to assess the effectiveness of a fog detection and warning system on driver behavior regarding speed and headway. This warning system includes visibility sensors that automatically activate a variable message sign that posts an advisory speed when hazardous conditions due to fog occur. The system was installed on a 2-km section of a two-lane, rural highway. A data set of 36,013 observations from both experimental and control sections at two study sites was collected and analyzed. The data included vehicle speed, volume, and classification; time headway, time of day, and visibility distance. Although the warning system was ineffective in reducing speed variability, mean speed throughout the experimental sections was reduced by about 6.5 kph. This reduction indicates that the warning system appeared to have a positive effect on driver behavior in fog even though the observed mean speeds were still higher than the posted advisory speed. From relationships found in the literature between mean driving speed and number of accidents, a speed reduction of only 5 kph would yield a 15% decrease in the number of accidents.

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# 1 Background

This paper describes a funded project for the experimental evaluation of a fog detection warning system installed on two-lane rural roads in the southern provision of Saudi Arabia [1]. The terrain of this region is mountainous and suffers from fog during wintertime. Heavy fog is present for at least 25 days a year. The fog forms during night and dissipated early morning hours. This condition tends to routinely occur primarily between December and February. According to traffic police records, the injury and death rates for fog-related crashes (injuries and deaths per 100 crashes) are 180 and 9, respectively. These rates in normal-weather conditions are 48 injuries and 4 deaths. These simple rates show how severe fog-related crashes are. The majority of fog-related crashes (71.7%) occur mainly during the morning hours.

The main objective of this experimental installation evaluation was to evaluate the performance of a fog detection and warning system and to assess its effectiveness on driving behavior with regard to speed and time headway.

While the use fog-detecting meters have been around for some time and are the basis for sensors that are now widely used in automated weather stations, their tests on roadside highway are still going on. The next is a brief review for relevant literature.

# 2 Overall analysis of crash data

Although, as just mentioned, the traffic police accident reporting does not seem professional and has deficiencies in identifying the accident location, other data including accident time, type, crash type, persons involved and their data, and severity are reported in a proper manner. Hence, such data can be said to be good enough to carry out a descriptive statistical analysis.

For the purpose of this study, a sample of 262 fog-related crashes occurred nationwide over 3-year period was collected and subjected to a descriptive analysis in order to develop cross understanding on the types, times, causes, and locations of these crashes. Data was extracted from police records for the period 1998-2000. Table 1 summarizes some general characteristics of these crashes.

From the data, as expected during fog, rear-end accidents and turn-over accidents account for more than two thirds of accidents (each 37%). This relatively proportions is attributed to the fact that reported by similar studies (e.g., [2],[3]) stating that drivers still drive faster than the safe speed under most fog conditions, i.e., collisions are caused by the failure of the most motorists to adapt their speed adequately to the limited sight distance of the foggy area. The National Highway Traffic Safety Administration (NHTSA) General Estimates System (GES) records report that 27% of rear-end accidents occurred during adverse environmental conditions [4].

Looking at the overall crash severity rates from Table 2, it can be seen that fog-related crashes have remarkably higher injury and fatality rates, i.e., fog-related crashes are over represented in terms of severity. Roughly speaking, the

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risk of being injured or died in a fog-related crash is about 6 times of that in all other crashes at this region.

Table 1: Overall statistics for the study sample of fog-related crashes.

| Category | Frequency | Proportion |
|---|---|---|
| **Crash Type** | | |
| Rear end | 97 | 0.37 |
| Right angle | 70 | 0.27 |
| Fixed object | 18 | 0.07 |
| Turn over | 37 | 0.14 |
| Run off road | 21 | 0.08 |
| Other | 19 | 0.07 |
| | | |
| **Accident Time** | | |
| Morning | 173 | 0.66 |
| Night | 75 | 0.29 |
| Unknown | 14 | 0.05 |
| | 262 | |
| **Location** | | |
| Urban | 79 | 0.3 |
| Rural | 183 | 0.7 |
| Total | 262 | |

Table 2: Severity of fog-related crashes versus all crashes.

| Item | Fatalities per 100 accidents | Injuries per 100 accidents |
|---|---|---|
| All accidents | 1.9 | 15.6 |
| Fog-related accidents | 8 | 101 |

## 3 Experiment sites and data collection

Two sites on highway 246 in Al-Baha Region were selected for experiments. The sites on this two-lane highway are straight sections with no horizontal or vertical alignment. The two sites have been known as fog-prone locations. No external factors can affect the driver selection of speed, such as presence of driveway, construction, or any land use activities.

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Since this project aim was to assess the ability of a fog detection and warning system in terms of driving behavior (i.e., speed and headway), two main components form the system, i.e., the visibility sensor and the variable message sign (VMS). In order to measure traffic data (i.e., speed, headway, vehicle classification, and volume) and time in disaggregated or microscopic ways (vehicle by vehicle), NC-97 [5] devices were used. The VMS was installed at the mid of the experimental section and connected to the fog sensor. When the sensor detects a reduction in visibility (falls to less than 200 m) the message sign is activated and displayed the word ``Fog`` and an advisory speed of 40 kph. Although the message sign is variable, there was only one message used during the project.

Sets of 36,013 observations were collected during the course of this study from both sites (on both experimental and control sites) over 3-day period.

Fog classifications vary in past studies. There exists an international classification of the various categories of visibility [6]. Accordingly, this study adopts the following categories:

| Visibility | Description |
| --- | --- |
| Less than 50 m | Dense or critical fog |
| 50 – 200 m | Light fog |
| Over 200 m | Good visibility |

The speed means at the three levels of visibility on experimental segments where advisory sign was active are shown graphically in Figure 1. It appears from this figure that the speed reduction is more sensible when visibility less than 50 m.

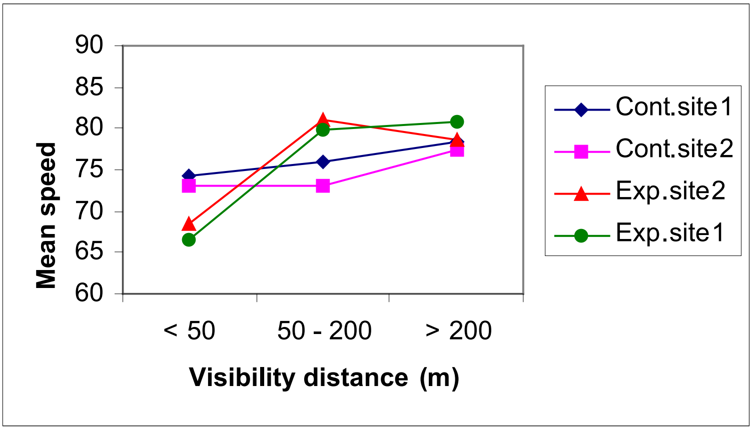


Figure 1. Mean speeds from experimental and control sites.

Figure 1 also presents speed means versus visibility on control segments where no advisory sign was installed. The figure reveals the same trend at control segments as that of experimental segments but with higher mean speed at

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less-than-50m visibility distance. Looking at speeds from both control and experimental segments as presented in Figure 1, one can note that there exists signing effect when visibility is critical (<50 m) but this is not true when visibility >50 m. This indicates that the less-than-50 m visibility is the range where the effects of both visibility and advisory sign appear significantly. Likely, other studies relative to driver behavior under reduced visibility conditions (e.g., [3], [7]) indicate that motorists will not significantly alter their speeds until visibility in fog is below 150 m. The other visibility ranges, i.e., 50-200 m and >200 m, have almost the same effect on speed. In these two ranges of visibility, motorists at both sites drive at almost the same speed as during clear weather regardless of sign presence. These results grasped by eye and cannot be eventual till tested statistically which is presented in the following sections.

## 4 Control versus experimental data

Looking at the speed means from all data sets as presented at Figure 1, one can note that difference appears noticeable at less than 50 m visibility level in experimental sites, but it does not at the other two visibility levels as discussed previously. To verify this eye observation, the following statistical hypothesis was tested:

$H_o : \mu_{el} = \mu_{cl}$

$H_a : \mu_{el} \neq \mu_{cl}$

Where:

$\mu_{el}$ = speed mean at experimental segment for l level of visibility.

$\mu_{cl}$ = speed mean at control segment for l level of visibility.

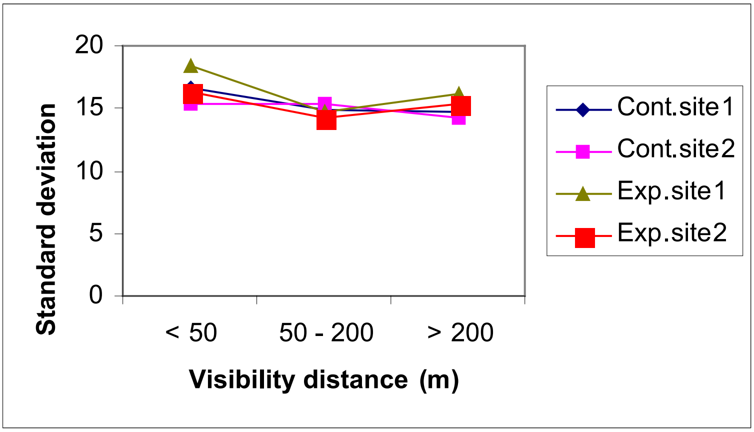


Figure 2: Speed variability on experimental and control sites.

Testing this hypothesis at 5% level of significance showed that there is a significant difference between the means at experimental and control segments at both study sites (*p-value=0.000*) when the visibility is critical (<50 m) but not when it is above 50 m. This result verifies the first eye observation in Figure 1.

For speed variability during critical conditions, as illustrated in Figure 2, the data from the study sites seem pretty much coincide, that is, the presence of the warning sign may have not affect the variation of speeds around the mean. Yet, this cannot be clear-cut result without subjecting it to statistical investigation.

## 5 Statistical tests for equality of variance

Many research studies show that higher speed variance is usually associated with higher accident rates. Cerrelli [8] pointed out that there is a significant statistical relationship between speed variance and accident rate. He concluded that the accident rate increased as the speed of the vehicle deviated from the average speed of the traffic. Solomon reported in 1964 that accident involvement rates were highest for vehicles at very low speeds, lowest at the average speed, and greater at the very high speeds. Garber and Gadiraju [9] developed models to examine the influence of speed variance on accident rates for different categories of highways. Their models indicate clearly that accident rates increase as speed variance increases. In this study, unfortunately, accident data to investigate the association between speed variance and accident rates were not available. Therefore, testing the variance homogeneity between the sites and analyzing speed variances were the concern in the study.

The test of homogeneity may be viewed as formal tests of the hypotheses:

$H_o$ : all $\sigma_i^2 = 0$ (i= 1,2,3,4; two experimental sites and 2 control sites)

$H_a$ : not all

shows that motorists speeds seem not homogenous at 5% level of significance (*p-values=0.001*) indicating that some variability exists but the question should be asked is: who is responsible for such a variability? To answer this question, pairwise comparisons among speed variances from experimental and control sites should be carried out using the following hypothesis:

$H_o : \sigma_{ei}^2 = \sigma_{ci}^2$

$H_a : \sigma_{ei}^2 \neq \sigma_{ci}^2$

where;

$\sigma_{ei}^2$ = variance at experimental segment for study site i (i=1,2).

$\sigma_{ci}^2$ = variance at control segment for study site i (i=1,2).

At both sites the above test was rejected (based on F-test: *p-value=0.027* and *0.045* at site1 and site2, respectively). This result means that the speed variances on experimental and control segments are not homogenous.

When speed variances in experimental segments at both study sites are compared, the following hypothesis was tested:

$H_o : \sigma_{j1}^2 = \sigma_{j2}^2$ (1=site1, 2=site2, j for either experimental or control).

$H_a : \sigma_{j1}^2 \neq \sigma_{j2}^2$

the test shows also that speeds tend to be not homogenous (*p-value=0.025*) in both experimental segments. Yet, on control segments the variances were found statistically insignificant (*p-value=0.054*). Accordingly, it can be stated that

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posting warning sign (on experimental segments) has an impact on the drivers leading to some extend different reaction from their side to the warning sign in the two segments. On the other hand, on control segments, where no warning exists, drivers tend to drive consistently.

## 6 Drivers' compliance with the advisory speed

During fog the advisory speed posted to motorists was 40 kph. To measure drivers` compliance to this advisory speed, the following hypothesis was tested:
$H_o : \mu_e = 40$
$H_a : \mu_e > 40$

Although speeds tend to be reduced on the experimental segments during dense fog due to the presence of warning sign, as previously discussed, the mean speed was higher than the advisory speed, i.e., the above null hypothesis was rejected at 5% level of significance (*p-value=0.000*). This result is also consistent with findings from similar studies and indicates that motorists tend to select a speed which they think reasonable to fog circumstances [7],[10].

## 7 Conclusions

This study attempted to investigate these factors through implementing an automated fog-warning system in two sites. It appears that there could be benefit form advisory speed signs in terms of reducing speeds.

The study found that fog visibility less than 50 m is the range that drivers` behavior in the study sites is affected by. Observed speeds showed significant reductions when visibility distances were below 50 m, while no effect was observed for this system for visibility conditions above 50 m. This finding indicates that motorists in the study sites did not significantly reduce their speeds until visibility in fog is below 50 m. The observed reduction in mean speed due to signing was about 6.5 kph, however, there was no effect found on lowering speed variability within the signing segment. Although the advisory speed motivates motorists to reduce their speeds, the mean speed was still over the advisory speed indicating that drivers` compliance with this posted advisory speed during critical fog does not exist. Drivers may have underestimated their own speed or may have driven faster than they thought the safe speed was for the conditions. Another finding is that the 85$^{th}$ percentile speed is reduced as much as 5 kph, which is encouraging.

Although the fog warning system tested lowered the motorists` mean speed, it showed no effectiveness in reducing the speed variability.

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