

Warning signs as countermeasures to camel–vehicle collisions in Saudi Arabia

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Abstract

The camel–vehicle collision (CVC) problem has been increasing in Saudi Arabia and countermeasures are urgently needed to alleviate the heavy losses from such accidents. A research project was funded by the Saudi Arabian government to investigate the problem and to develop techniques to deal with it. Among the different techniques investigated were camel-crossing warning signs. In this study, seven camel-crossing warning signs were tested to determine if they would reduce the number of CVCs on rural roads. The measure of effectiveness utilized was the mean speed reduction of motorists passing such signs. In this paper, the experiments of warning sign testing are detailed, and the evaluation of the signs, based on the results of the testing experiments, is presented. Although most of the signs brought about significant reductions in mean speed, indicating statistical effectiveness, the speed reductions were not relatively large; they ranged from around 3 to about 7 km/h. Furthermore, statistical analysis was used to rank the signs according to their effectiveness. A triangular warning sign with a black camel silhouette and diamond reflective material (220 cm × 220 cm × 220 cm) is recommended in this study. This sign is similar to the standard warning sign used in Saudi Arabia except that it is twice the standard size and uses diamond reflective material.

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1. Background

More than half a million camels graze freely in Saudi Arabia. In their search for scarce food, camels travel long distances and cross a number of rural highways. This results in the occurrence of the camel–vehicle collision (CVC) problem. Summaries of traffic accident data show that more than 600 CVCs occur each year. Due to the large size of camels and the high speed of vehicles travelling on rural highways, CVC is usually severe. The fatality rate of a CVC is 0.25 fatalities per accident; about six times that of all types of traffic accidents in the country; the corresponding CVC injury rate is four times as much (Al-Amr et al., 1998).

Available information indicates that camels are by far the most frequently involved animals in animal–vehicle collisions; almost 97% of all reported animal–vehicle crashes were camel related (i.e. CVC). More than 90% of these accidents occur at dark, between dusk and dawn (Al-Amr et al., 1998). CVC result in substantial economic costs due to human injuries and/or fatalities, damage to vehicles involved, and loss of valuable wildlife. More data on such accidents,

such as location, characteristics and extent, are not readily available in Saudi Arabia; such data are not routinely collected.

In Saudi Arabia, the most commonly used traffic engineering approach to countering the CVC problem has been installing a camel-crossing warning sign at potential camel-crossings, to alert drivers to unexpected entries of camels into the roadway. Within the Ministry of Communications (MOC), the agency responsible for building and maintaining rural roads, there is no formal procedure for the placement of camel-crossing warning signs. The length of the camel-crossing might be relatively restricted or the crossing activity might occur at random over a substantial distance. Unlike the almost fixed migration routes of other wildlife, camel movement in the desert is dynamic, changing spatially with rain distribution. Therefore, although it is difficult to identify a certain highway section at which camels always cross, potentially affected sections can be identified.

Because of the high severity and frequency of the CVC problem in Saudi Arabia, King Abdulaziz City of Sciences and Technology (KACST) funded a 3-year research project to study the problem and find methods to remedy it. The research project had two main objectives (Al-Amr et al., 1998):

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- to review techniques used internationally to reduce animal–vehicle collisions, and
- to evaluate the effectiveness of some of these techniques as possible countermeasures for the CVC problem in Saudi Arabia.

Although, this research project evaluated several means of dealing with the CVC problem. The focus of this paper is on only one of these countermeasures: camel-crossing warning signs.

The primary purpose of this paper is to evaluate the effectiveness of warning signs as a means of influencing drivers to reduce their speed in camel-crossing zones, especially those drivers traveling at speeds much higher than the posted speed limit. Next section presents a general overview of related literature. Details of the experiments of warning signs testing are described in [Section 3](#), while its results are presented in [Section 4](#). The paper is concluded, in [Section 5](#), with discussion and conclusions.

2. Literature review

The subject of animal–vehicle accidents is not new, and substantial research has been carried out to reduce such road accidents. Past research has shown wide experience among countries in dealing with the problem, but neither unique solutions nor consistent results have been found. Although some remedies were found to be effective in some areas, they were not effective at other sites. In addition, some of these techniques were implemented on different types of animals, for example, deer, panthers, and moose. There were two goals for the review of past research in this project: to learn about others' experience in dealing with this type of accident and to survey all countermeasures used to mitigate this problem, and identify which of these could be evaluated in this study.

Probably the most comprehensive studies of deer–vehicle collisions were those by two of the Scandinavian countries, namely Finland (e.g. [Lehmitimaki, 1984](#)) and Sweden (e.g. [Almkvist et al., 1978](#); [Aberg, 1981](#); [Bjornstig et al., 1985](#)). In the summary report of a 7-year comprehensive study of “deer and traffic”, [Lehmitimaki \(1984\)](#) suggested that there are a number of potential countermeasures to control deer–vehicle collisions. He classified these measures into five major classes:

1. Changing driver behavior through following ways:
 - (a) Educating drivers on how deer behave upon detecting an approaching vehicle.
 - (b) Warning them using deer-crossing warning signs.
 - (c) Educating them on the negative impacts and consequences of overspeeding and other unfavorable driving habits (e.g. fatigue).
 - (d) Informing them on the consequences of deer–vehicle collisions. However, he concluded that the effectiveness of this measure is very limited.

2. Changing the driver environment through following ways:

- (a) Providing better visibility conditions for the driver, by removing obstacles limiting driver's sight distance, such as trees and roadside vegetation, and by lighting dangerous roadway sections. He stated that it is not possible to recommend lighting all roadways that have deer crossing activity, which is practically impossible.

- (b) Reducing the frequency of hazardous conditions, which is affected by the intensity of vehicular traffic volume on rural highways and deer crossing frequency. He suggested that it is not possible to issue laws aimed at reducing the intensity of traffic volumes on rural highways, which are vital to the community, only due to deer–vehicle collisions. Instead, he recommends encouraging deer hunting and increasing the number of wolves to ensure keeping the number of deer at its normal, thus reducing its crossings of rural highways.

3. Changing animal behavior:

There is no simple way to make the animal behave more safely, but with normal evolution and growth it might be probable that animals will learn how to cope with vehicular traffic. However, this might take centuries, thus this measure is not considered as a remedy to the current deer–vehicle collision problem.

4. Changing the animal environment:

This might be accomplished by keeping the animals away from the highways through using countermeasures such as roadway iron fencing and “optical fencing” (e.g. animal mirrors and reflectors). While the iron fences were found effective, the optical ones were not.

5. Reducing deer–vehicle collisions severity:

Following kinetic energy law, the severity of the collision decreases with decreasing speed and mass of the collided object. Furthermore, slow speeds have positive effect on the driver's visibility abilities, since he would have more time to scan the roadway for entering animals. [Lehmitimaki](#) recommends that if the driver have to maneuver to avoid a collision with a moose on the roadway, it would be preferable that the driver targets the softer back part of the moose. Furthermore, if it were not possible to avoid hitting the animal it would be better to hit the carcass of the moose than colliding with a fixed object on the roadside or an opposing vehicle.

From the review of literature on animal–vehicle accidents worldwide, the study team was able to classify the techniques used in past research into two main categories. These two classes are the countermeasures intended for drivers and those directed at animals. The goal of the first category is to alert the driver and warn him to reduce his speed. The second category is intended to frighten the animals and keep them off the roadway.

2.1. Driver-directed countermeasures

The measures directed at drivers found in the literature include.

2.1.1. Warning signs

Dillon (1993) stated that, in Ontario, Canada, deer- and moose-crossing warning signs are usually installed at locations known for heavy deer and moose crossing of highways, thus presenting a threat to passing-by vehicular traffic. The criteria used is to place a deer warning sign at locations experiencing at least one deer–moose accident per 8 km of roadway length annually, or at locations less than 1.5 km of length that have at least four deer–moose accidents per year.

The Ontario Ministry of Transportation erected animal warning signs of double the standard size (i.e. 1.2 m × 1.2 m), but it was not known if increasing the sign size reduced the number of animal collisions (Dillon, 1993). Another type of moose warning signs was tested in Canada. Unlike the traditional sign, the new sign had a moose silhouette in white, while its eyes are in shining yellow. It was believed that the moose would look to drivers like a real animal and alert the driver to be more cautious. As a result, it is reported that the number of moose–vehicle collisions was reduced by 50% (Mclain, 1990).

Another “advanced” type of warning signs was tested. It consisted of the standard shape of the warning sign (diamond shape), but the deer silhouette was replaced by four arched deer silhouettes representing a deer in four movement stages, where each one is lighted sequentially by neon lighting. When tested, it was found that driver speeds were initially slightly reduced, but after the drivers got used to it, it lost its effect in reducing their speeds (Pojar et al., 1975).

Mansfield and Miller (1975) concluded that standard size (75 cm × 75 cm) diamond shape warning signs with deer silhouette reduced the number of animal collisions in 11 of the 19 study areas included in their study in California. Another study in Colorado tested two lighted warning signs with deer crossing silhouette. The results concluded that lighting the sign was not effective; the number of accidents were almost the same whether the sign lighting was turned on or off (Reed, 1981).

2.1.2. Driver education

After conducting four experiments on driver behavior in Sweden, Aberg (1980) stated that the studies has shown that drivers will still collide with the elk in spite of their long driving experience, and their good knowledge about the elk and its danger on traffic. He concluded that driver education, information and training would slightly improve driver behavior regarding deer dangers.

2.1.3. Roadway lighting

Reed (1981) studied the effect of roadway lighting on the number of deer–vehicle collisions in a 1.1 km long highway in Colorado. Roadway lighting was alternately turned on

and off every week for about 2 years. By comparing the driver response when the lighting was on and when it was turned off, he concluded that lighting has no effect on driver speed.

2.2. Animal-directed countermeasures

The measures directed at animals found in the literature include.

2.2.1. Animal crossing overpasses/underpasses

Ford (1980) stated that wide, open deer crossing structures are very effective in providing deer the opportunity to cross under the highway safely. In 4 years of monitoring, there was no evidence that any deer were turned back by the crossings or chose to migrate around the deer-proof fence.

Evink (1990) monitored panther movements and behavior on I-75 across SR-84 in south Florida by radio tracking. Radio-collared panthers crossed the alignment, providing information on locations of crossings and habitat type being used. This information was used to develop 23 wildlife crossings, which are 30 m long and 2 m high, and the extension of 13 existing bridges to provide 12 m of land along the drainage canals under the bridges. Although the crossings and fencing are not completely finished, panthers and other animals are already using these structures.

Fusari (1982) attempted to observe the habits of desert tortoises to determine their acceptance of culverts as a means of crossing under highways. The study reported that a portion of the tortoise population would accept culverts for such crossings when they are directed toward the culverts by drift fences. There also appears to be a learning period in which a tortoise that has been confronted with a fence-culvert system several times soon moves directly to a culvert rather than moving along the drift fence. The study recommended more research to evaluate the results under actual highway conditions.

2.2.2. Roadside vegetation clearing

Lehmtimaki (1984) stated that roadside vegetation clearing would result in a safer deer and moose behavior. He mentioned that Swedish studies indicate that the cost of clearing 20 m from each of the roadway sides would be equivalent to the cost of erecting an iron grid fence, however the effectiveness of vegetation clearing was not assessed in the Swedish studies. Furthermore, vegetation clearing and improving sight distance would loose some of its benefits at night, since the sight distance is limited to that of the vehicle's headlights.

2.2.3. Roadway iron fencing

Ward (1982) indicated that a 2 m high big-game fence is effective in reducing vehicle accidents involving deer. A 12.5 km section of the right-of-way fence was replaced with a big-game fence 2 m high in October 1978 to force the deer

to use three machinery and four box-type underpasses in the area. During four migration periods immediately following installation of the fence, more than 4000 deer used these underpasses. About 70% of the deer used the machinery underpasses to move to their winter range; the rest used the box-type concrete underpasses. During the spring migrations, more than 90% of the deer used the two machinery underpasses at the east, or higher, end of the migration area. Ward reported several difficulties associated with the fencing: (a) selection of the proper area for the fence, (b) inadequacy of deer guards on ramps of an interchange, and (c) the need for continuous monitoring for holes in the fence.

2.2.4. Optical “fencing”

This includes using animal mirrors (e.g. Van De Ree), red reflectors (e.g. Swareflex), and white reflectors (e.g. Bosch), to keep animals off the roadway.

Zacks (1985, 1986) evaluated the effectiveness of Swareflex warning reflectors. When illuminated by the headlights of a passing vehicle, these red reflectors are said to frighten deer from the highway. Although the manufacturer claims that they are effective because deer are innately afraid of red, Zaks’s study found no evidence to support that claim. That is, the barrier of reflectors had no observable effect on the behavior of deer.

Shafer and Penland (1984) tested the effectiveness of Swareflex warning reflectors in reducing deer–vehicle collision rates on a rural road in eastern Washington State, where high mortality rates of white-tailed deer had previously been recorded. Reflectors were placed in four test sections and alternately covered and uncovered at regular intervals during the late fall to early spring from 1981 to 1984. In this study the difference in deer–vehicle collision rates between the covered and uncovered periods was significant, indicating that the reflectors were effective on this highway during this time period.

Armstrong (1992) examined the effectiveness of Swareflex reflectors using an experimental design very similar to that used in the study conducted by Shafer and Penland (1984), but in Ontario. The results of the chi-square analysis showed that the difference between the number of deer–vehicle accidents that occurred when the reflectors were covered (i.e. inoperative) and when they were operative was not statistically significant.

Stanley and Sharon (1993) tested the Swareflex wildlife warning reflectors on an 8 km section of a rural road in California, to determine if it would reduce the number of mule deer killed on the highway. After three seasons, it was determined that there was no statistical difference between the means of deer killed when the reflectors were operating and those when they were not operating. The authors discuss studies on reflectors that have shown a reduction in deer killed, whereas other research has concluded that there is no difference with or without reflectors. They add that test results vary irrespective of the type of reflector used. This

finding may indicate that the issue is not whether the reflectors work in all cases but whether they work in one situation and not in another. The recommendation from Stanley and Sharon is that future research investigate the conditions that contribute to the success or failure of reflectors in lowering highway-related deer kills.

Gilbert (1982) reported no evidence to support the claim that deer mirrors were effective. In his study, deer mirrors were placed in 12 random 0.8 km test sections along a 23.8 km of I-95 in Maine.

2.2.5. Ultrasound whistles

IIHS (1993) states that there is no published scientific research that supports the claim that whistles prevents deer from approach passing by vehicles or that it reduces the dangers of animal vehicle collisions. In support of this claim, a study in Georgia concluded, based on hundreds of observations of vehicles equipped with ultrasound whistles, that deer did not respond the whistles’ presence. Furthermore, the Ohio Highway Patrol tested Hobi and Sav-a-Life whistles on its patrol vehicles for 31 months, and concluded that they were not effective, since the number of animal collisions did not decrease (Baker, 1988). The same conclusion was reached by other studies (Farm, 1993).

2.2.6. Animal frightening models

To determine whether rear-view silhouette models of deer with raised tails would be effective in keeping deer off planted Interstate highway rights-of-way, Graves and Bellis (1978) tested such models in four experiments along Interstate 80 in Pennsylvania. Results revealed that the models were ineffective in deterring deer from gaining access to the right-of-way.

2.2.7. Deterrent chemicals

The National Swedish Road Administration (NSRA) performed a series of experiments to test the effect of Wolfin, a synthetic wolf urine, as a deterrent of moose and deer away from highways. After 3 years of testing the NSRA concluded that it was not effective (Peterson, 1995). Another chemical deterrent is called Dutazun, which is an organic material tested in Germany and Austria and claimed to be effective (Hagopur, 1995).

Finally, Hughes et al. (1996) studies the trends over time, severity, crash circumstances, and crash rates for animal–vehicle crashes in some states in the United States. The results of their analysis indicate that the animal–vehicle crash problem increased steadily between 1985 and 1991, both in numbers and as a percentage of overall accidents. They concluded that no single countermeasure would be able to address the animal–vehicle crash problem. A combination of roadway-, vehicle-, and driver-based countermeasures should be developed, tested, and used. Among their recommendations was the review of policies for installing deer warning signs to limit their use to locations

with significant deer crash problems or areas with high deer activity.

From this review, one can reach the following conclusions regarding animal–vehicle collision prevention:

- Several prevention techniques have been attempted elsewhere.
- Techniques are designed either to deal with drivers or to deal with animals.
- There is no solid agreement on one countermeasure—results can sometimes be inconsistent even for the same technique.
- Some of the techniques appear simple, but others appear complex.

3. Method

As seen from the literature review, two major classes of techniques for reducing accidents between motor vehicles and animals have been evaluated in several studies. Instead of warning drivers of the potential presence of the animal, as promoted by the first class of countermeasures, the other class of techniques attempts to control the movement of the animal itself by, for example, the use of roadway fences and reflectors (optical fencing). In this paper, warning drivers through the use of signs is discussed. Different sign configurations were compared to define the most effective configuration. Because of the poor accident and exposure data collection by local police, a major problem in this developing country (Al-Ghamdi, 1998), the measure of effectiveness used in evaluating warning signs was speed. Comparison analysis was the core for examining a sign's effectiveness.

3.1. Configurations of warning signs

The principal objective of the experiments was to assess the effectiveness of various types of warning signs. The seven warning sign modules examined in this study are described briefly below:

- Module I: The standard module, an upward pointing, equilateral triangle (110 cm × 110 cm × 110 cm) having a red border and a white interior and black shadow for the camel inside the border band (i.e. the silhouette of a camel in black).
- Module II: Similar to Module I but with diamond reflective material.
- Module III: Twice the size of the standard Module I.
- Module IV: Twice the size of Module II (with diamond reflective material).
- Module V: Square sign 300 cm × 300 cm with a black background and a yellow silhouette of a camel with diamond reflective material. The sign also contains a verbal warning message (i.e. camel-crossing) with an advisory speed of 70 km/h.

- Module VI: Similar to Module V but half as large (150 cm × 150 cm).
- Module VII: Similar to Module VI but half as large (75 cm × 75 cm).

It should be noted that the first module is the standard one used by the MOC; the others were specifically designed for this study. The different sign configurations were tested under similar conditions to ensure consistency of reported results.

3.2. Study sites and data collection

The intention had been to find test sections with significant CVC problem. However, because the accident data lacked location information, the experiments had to be sited wherever high camel activity was expected. Fifteen test sections were selected from rural highways throughout the country. Since the measure of effectiveness was vehicle speed, the experiment sites were screened according to certain criteria such that the prevailing conditions would have no impact on speed except that of the experiment tool itself. That is, the test site had to be level, far from weaving maneuvers due to exit/entrance ramps, no activities in surrounding land, have a pavement surface in good condition with no maintenance activity in progress, and free of any speed-zone control signs. The experiments were conducted during the night and in fair weather. To control for the effects of external factors not accounted for by the study, the experiments were performed at sites where geometric conditions and posted speed limits were similar. From volume counts (MOC, 1999), the traffic volumes in these sites are light (less than 500 vph). It was risky in these remote rural sites to stop drivers during nighttime to get their data. The signs are located along routine travel routes. Thus, the drivers are long distance drivers but not daily commuters.

Because accident data with full identification of location were not available, the study team faced the problem of determining a surrogate measure of accident rate, to be used as the measure of effectiveness. As stated earlier, it was decided to use vehicle speed as that variable. Simply put, the idea was to measure the effect of the proposed tool on driver behavior in terms of speed. It was expected that when the driver approaches a camel-crossing warning sign, he would slow down for some distance before resuming his original speed. Numetric[®] NC-90 instruments (detectors) were used in observing speed data; other relevant data collected were vehicle counts and classifications.

Seven speed detectors were placed along the 2000 m-long (2 km) experiment section (i.e. three upstream of the sign, one at the sign, and three downstream of the sign) at predetermined intervals as shown in Fig. 1. Detector 1 was placed 1000 m (1 km) ahead of the sign to measure the speed while, it was assumed, the driver was not under the impact of the sign.

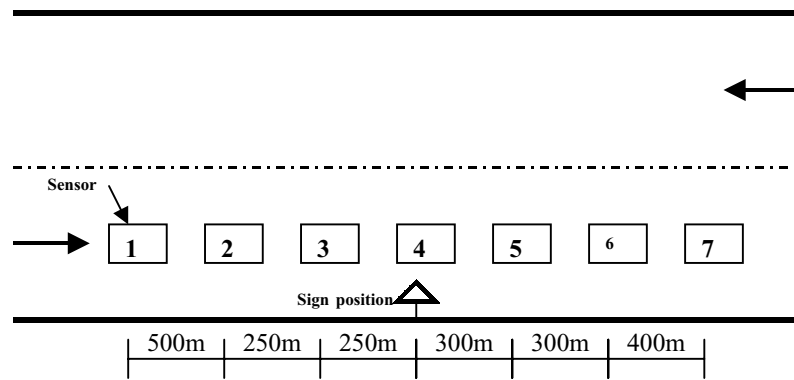


Fig. 1. Typical layout of seven NC-90 detectors and warning sign.

3.3. Sample size requirements

The minimum number of speed observations for each section was computed using a statistical sample estimation procedure (Benjamin and Cornell, 1970). The procedure computes a minimum speed sample observation on the basis of a desired level of confidence (e.g. 95%) and an acceptable level of error (e.g. $e = \pm 2$ km/h for the maximum possible error). Before the experimental work started, a pilot study was conducted to estimate the speed variance needed in calculating the minimum number of required speed observations (minimum sample size) and to learn about the fieldwork and difficulties that might arise. The minimum sample size was found using the following formula (Montgomery and Runger, 1994):

$$n = \frac{\sigma^2 Z_{\alpha/2}^2}{e^2}$$

where σ is standard deviation (from the pilot study, 25.2 km/h), $Z_{\alpha/2}$ the standard normal value at $\alpha/2$ level of significance, α level of significance (5%), and e is the acceptable error (± 2 km/h).

Using that formula, the minimum sample size of speed observations was $n = 200$. The minimum number of observed speeds for any of the study sites was at least two times the minimum sample requirement.

3.4. Comparison analyses

To ascertain whether a particular sign configuration, or module, was superior to others in lessening motorists' speed, two types of comparisons were conducted. First, the differences among mean speeds were statistically measured. Second, the homogeneity of speed variance for the study sites was tested. Deciding which module was superior was based on comparison of the amount of reduction in the mean speed.

3.4.1. Comparison of mean speeds

Before-and-after analysis was used to measure the effectiveness of the sign. Pairwise comparisons were conducted.

The goal was to detect the differences between sites in terms of the mean speed. The hypothesis statements for the pairwise comparisons are as follows:

$$H_0 : \mu_i = \mu_j, \quad H_a : \mu_i \neq \mu_j$$

where u_i and u_j are the mean speed before and after the sign, respectively. The z -statistical test was used to test the pairwise comparisons (Montgomery and Runger, 1994).

3.4.2. Equality of speed variance (homogeneity)

Many research studies show that higher speed variance is usually associated with higher accident rates. Cerelli (1981) pointed out that there is a significant statistical relationship between speed variance and accident rate, and concluded that the accident rate increases as the speed of the vehicle deviates from the average speed of the traffic. Solomon (1964) reported that accident involvement rates were highest for vehicles at very low speeds, lowest at average speeds, and greater at very high speeds. Garber and Gadiraju (1992) 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 the current study accident data to investigate the association between speed variance and accident rates were, unfortunately, not available. Therefore, the homogeneity of speed variance before and after the sign was tested, in addition to the analysis of speed variance.

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

$$H_0 : \sigma_i^2 = \sigma_j^2$$

$$H_a : \text{above hypothesis not true for at least one } \sigma_i^2$$

where σ_i^2 and σ_j^2 are the speed variances before and after the sign, respectively.

A widely used procedure is Bartlett's test (Montgomery, 1984). The procedure involves computing a statistic whose sampling distribution is closely approximated by the chi-square distribution with $a - 1$ degrees of freedom when the a

random samples are from independent normal populations. The test statistic is:

$$\chi_0^2 = 2.3026 \frac{q}{c}$$

where

$$q = (N - a) \log_{10} S_p^2 - \sum_{i=1}^a (n_i - 1) \log_{10} S_i^2$$

$$c = 1 + \frac{1}{3(a - 1)} \left(\sum_{i=1}^a (n_i - 1)^{-1} - (N - a)^{-1} \right)$$

$$S_p^2 = \frac{\sum_{i=1}^{a-1} (n_i - 1) S_i^2}{N - a}$$

and S_i^2 is the sample variance of the i th population.

The quantity q is large when the sample variances S_i^2 differ greatly and is equal to zero when all S_i^2 are equal. Therefore, H_0 should be rejected on values of χ_0^2 that are too large; that is, H_0 is rejected only when

$$\chi_0^2 > \chi_{\alpha, a-1}^2$$

where $\chi_{\alpha, a-1}^2$ is the upper α percentage point of the chi-square distribution with $a - 1$ degrees of freedom.

3.5. Speed trends

It is reasonable to assume that the magnitude of motorists' reactions to signs varies according to how fast they generally drive (i.e. their mean free speed). The best available estimate of motorists' mean free speed was the speed recorded as they entered the instrumented area, that is the entry speed.

It is expected that the driver enters the test section with his normal speed, but when he approaches the experiment device and recognizes it, he starts to slow down. Accordingly, the vehicle speed is gradually reduced until it reaches

its minimum at some point, when it starts increasing gradually until it returns to normal speed. Fig. 2 illustrates such a trend. It must be said that this influence is hypothetical until the statistical test is examined. In other words, the assumption was that motorists behaved differently before they saw the sign and after seeing it. Speed can be staged throughout the experiment area as explained below.

3.5.1. Entry speed

The first detector in the experiment area was 1000 m ahead of the sign (detector 1 in Fig. 1). The motorist located at that position is assumed unable to see the sign (i.e. he is not under the impact of the sign). Thus, the observed speed at this first detector should be his normal speed.

3.5.2. Initial speed change

Soon after the vehicle enters the experiment area, the module warning sign becomes visible (although not legible). The first variable that reflects any possible reaction to the sign treatment is the initial speed change, measured over the first 500 m of the instrumented area ahead of the sign. In other words, speed reduction should be observed at detectors 2 or 3, or both, located 500 and 250 m ahead of the sign, respectively (Fig. 1). Measuring the speed at these points illustrates any speed change due to the motorist's reaction to reading the sign. Measurement of these speed changes also allows for a general overview of when speed changes occur on the approach to the sign.

3.5.3. Speed change at sign

Another speed change is measured at the sign itself. It was assumed that the speed in the vicinity of the sign attains its minimum value if the motorist responds to the message of the sign. Detector 4 measures this speed.

3.5.4. Exit speed

The last observation made was the motorist's speed at the end of the instrumented area (at the exit, i.e. at detector

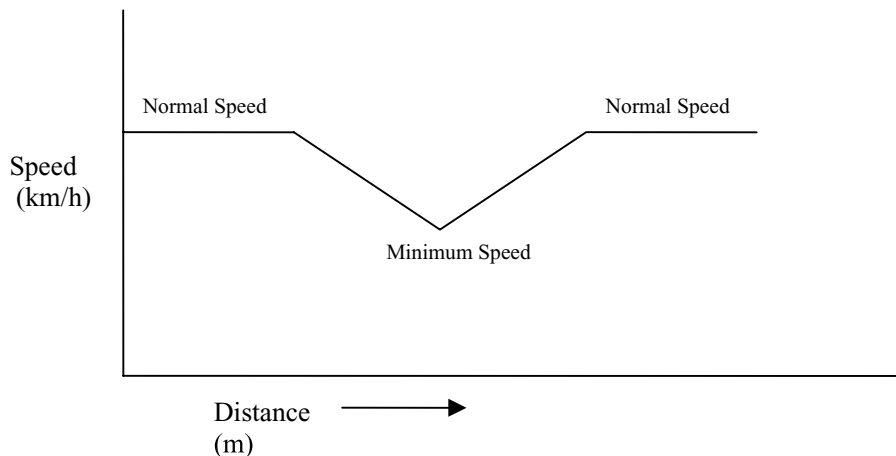


Fig. 2. Hypothetical trend of speed along instrumented section.

7). Comparison of this speed with the speed at the sign (at detector 4) provided an indication of how rapidly the motorist resumed his normal speed. Before the exit speed, two additional speed observations were made at points located 300 and 600 m after (downstream) the sign, as illustrated in Fig. 1. These two detection points (detectors 5 and 6) could reveal that the motorist returns to his normal speed before detector 7, which would help in estimating the distance to which the driver is affected by the sign.

4. Results

As discussed earlier, it was presumed in this study that there is a certain speed trend along the instrumented area, as shown in Fig. 2 (the ideal trend under the impact of the sign). This trend, however, was not apparent, as shown by consideration of the speed trends from different sites for different signs (Figs. 3–7). When the sign was not effective, no specific trend could be detected, as depicted in Fig. 3 (Module I). The sign was found effective (Figs. 4–7) when the trend was similar to but not necessarily identical to the ideal trend.

During the experiment some of the detectors were damaged and excluded from the analysis. Since there were seven detectors along the experiment section, this problem did not affect the final results heavily. However, the first detector must work properly since its speed reflects the entry speed,

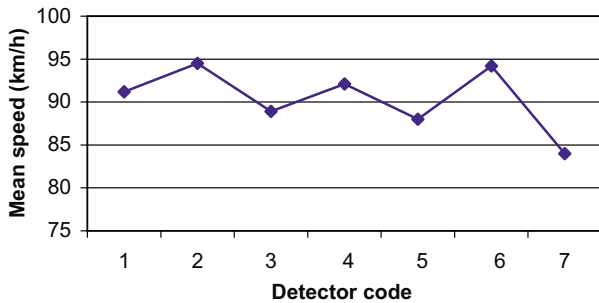


Fig. 3. Standard Module I on Khurais–Riyadh Road (westbound).

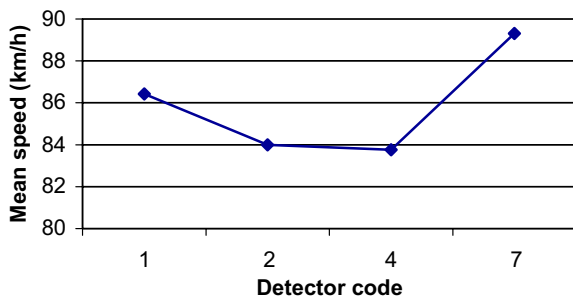


Fig. 4. Module VII, 75 cm × 75 cm, at site on Qassim–Madinah Road (westbound).

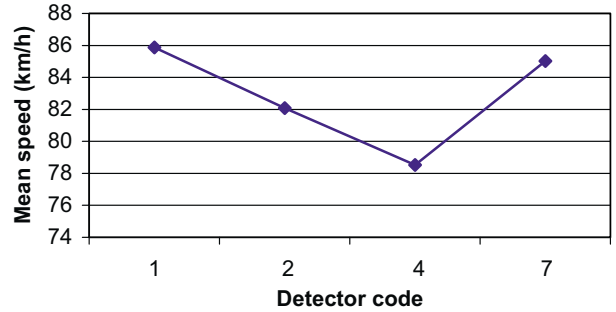


Fig. 5. Module VI, 150 cm × 150 cm, on Qassim–Madinah Road (eastbound).

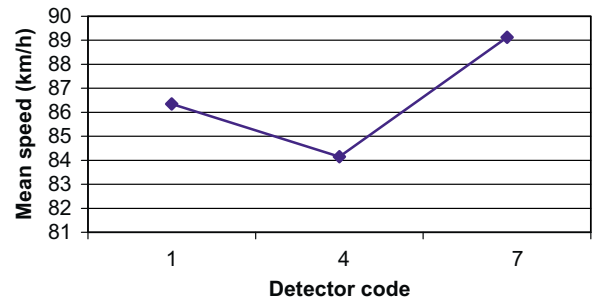


Fig. 6. Module V, 300 cm × 300 cm, on Khurais Road (eastbound).

which is very significant in comparisons with any other speeds within the instrumented area. In other words, if the first detector for any reason had not given proper data, the experiment would have had to be repeated after the problem was fixed. It should be noted that throughout the study no problem was found with the first detector.

Table 1 summarizes results from the data observed at a site on the Qassim–Madinah Road (westbound) with Module VII (75 cm × 75 cm). The speed trend is clearly shown in Fig. 4. Entry speed is high and then decreases; afterward the high speed resumes (exit speed).

The reduction in mean speed for this module is 2.66 km/h, which was found statistically significant at the 5% level. There also exists a reduction in both speed variability (standard deviation is reduced by 3.39) and percentage of drivers

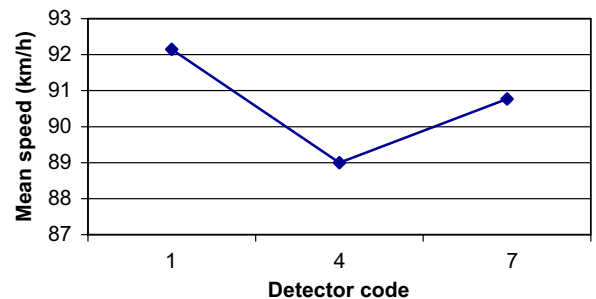


Fig. 7. Double-size diamond on Leeth–Makkah Road.

Table 1
Summary statistics from the site on Qassim–Madinah Road

Detector location		No. of cases	Mean speed (km/h)	S.D. (km/h)	Coefficient of variance	85th-percentile speed (km/h)	% above speed limit
Number	Location						
1	1000 m ahead of sign	807	86.42	21.14	0.24	107	26.5
2	500 m ahead of sign	767	83.99	16.12	0.19	105	22.59
4	At sign	690	83.76	17.75	0.21	104	20.29
7	1000 m after sign	820	89.31	18.62	0.21	109	29.49

Note: Speed limit at this site is 100 km/h.

traveling over the speed limit (reduction 6.21%). This trend was not the case for the standard sign, for which no pattern could be detected; hence it was concluded that the standard sign (Module I) is not effective (Fig. 3).

4.1. Distance of influence

From the analysis of the speed trends for each sign configuration, it was found that the distance of influence for the sign is the middle 1 km of the testing section. That is, the driver goes back to his normal speed after a distance of influence of 1 km, from the point at which he first recognizes the sign in the instrumented section. The impact on the motorist starts within 500 m upstream of the sign and ends within 500 m downstream of the sign. Dart and Hunter (1976) found that the impact of the warning sign starts to diminish 305 m after the sign and is completely gone by 3.2 km.

From Fig. 4, one might say that, on average, motorists are influenced by the sign within the middle 1000 m of the test section but that they forget the message of the sign once they leave this section. That is, the motorists' attention is affected for about 1000 m. This behavior was almost found in those modules found statistically effective in this study (Figs. 5–7). Another interpretation of the 1000 m speed reduction is that the drivers interpret the sign as meaning that the risk of camel collisions is particularly great in this specific area. That is, the drivers may be obeying their understanding of the instruction to exercise care and reduce speed. This result is interesting in that it gives a clear picture of the attitude of motorists toward warning signs. As well, it suggests to the analyst the frequency at which signs should be repeated in the hazardous section. In other words, for a 6 km section, the analyst might suggest that six warning signs be installed at 1000 m intervals.

4.2. Homogeneity of speed variance

It appears from the data in Table 1 that, at the Qassim–Madinah site, all the 85th-percentile speeds are above the speed limit, of 100 km/h. Accordingly, the percentage of drivers overspeeding appears high, but it is lower near the sign (detectors 2 and 4) than at the entry-speed detector (detector 1) and at the exit-speed detector (detector 7). It is also interesting to note that the percentages are almost

equal at detectors 2 and 4 (22.59 and 20.29%, respectively) and at detectors 1 and 7 (26.5 and 29.49%, respectively).

The analysis of variance of speed homogeneity indicates that the variability among speeds at the four detection points for this site is statistically significant. The variability at both entry of the instrumented area (21.14 km/h) and exit from the instrumented area (18.62 km/h) is higher than the variance close to the sign (16.12 and 17.75 km/h). From this result it can be concluded that motorists within the sign area were driving much closer to the mean speed. The same result was found at almost all other testing sites. It is known from other research (e.g. Cerelli, 1981; Garber and Gadiraju, 1992) that higher speed variance is usually associated with higher accident rates. Garber and Gadiraju 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. It should be noted that although the data from the study sites show statistically significant reduction in speed variance within the sign region, the reduction was quantitatively relatively small (from 3 to 6%). Although this reduction appears small, it indicates the sign's influence on motorists.

A summary of the before-and-after (i.e. before the sign and after the sign) results for all modules is given in Table 2. From these data it can be observed that the speed differences were operationally quite small (e.g. the difference between the highest and lowest ranged from 2.2 to 6.51 km/h). In other words, the magnitude of the speed changes seemed generally quite small.

One can argue that these reduced speeds are not enough for safe stopping distance, for example, according to the concept advocated by the American Association of State Highway and Transportation Officials (AASHTO, 1994). Nevertheless, the effectiveness of the sign, even with this small reduction in speed, indicates that the driver responded to the warning message, which in turn means that he became cautious and attentive. It may be surmised that caution and attention would help the driver to avoid hitting a camel on the road, at least by maneuvering. In summary, even though the speed reduction appears small, it could be enough to put the driver on the alert to avoid a collision with a camel. In similar studies elsewhere, small speed reductions were found associated with warning signs (e.g. Kallberg, 1993; Marrony and Dawar, 1987; Dart and Hunter, 1976).

Table 2
Summary results on all modules of warning signs

Module	Site	Amount of reduction			
		Mean speed (km/h)	S.D. (km/h)	85th-percentile speed (km/h)	Above speed limit (%)
I	Khurais–Riyadh	–	–	–	–
II	Khamaseen–Tathleeth	–	–	–	–
III	Qassim Road	2.82 ^a	–	1	3.81
III	Rafha Road	3.1 ^a	0.93	1	7.01
III	Leeth Road	3.47 ^a	–	9.8	9
IV	Qassim Road	3.16 ^a	–	1	0.62
IV	Rafha Road	0.8 ^b	–	–	1.61
IV	Leeth Road	3.15 ^a	–	4	6
V	Qassim Road	5.41 ^a	–	4	5.61
V	Rafha Road	5.55 ^a	–	1	17.2
V	Khurais Road	2.2 ^a	0.15	3	3.3
VI	Qassim Road	6.51 ^a	–	6	4.27
VI	Qassim Road	3.51 ^a	–	2	2.26
VII	Qassim Road	2.66 ^a	5.02	3	3.91
VII	Rafha Road	1.93 ^a	0.37	2.5	6.6
VII	Leeth Road	4.55 ^a	–	8	8

(–) No reduction.

^a Statistically significant at 5% level.

^b Statistically not significant at 5% level.

4.3. Ranking of signs

Modules I and II were excluded from this ranking because the reduction in mean speed associated with them was not statistically significant. An important result from this study was that the standard warning sign is not effective.

As to whether there is conclusive evidence that one sign is superior to another, the answer is apparent from the results in Table 2. According to the amount of average speed reductions, in Column 3, one can rank the modules in this study as follows:

- Module VI,
- Module V,
- Module VII,
- Module III, and
- Module IV.

To compare the amount of speed reduction statistically (e.g. Δ_i and Δ_j for modules i and j), a test statistic is needed. The hypothesis can be stated as

$$H_0 : \Delta_i = \Delta_j$$

$$H_a : \Delta_i \neq \Delta_j$$

where

$$\Delta_i = x_{ib} - x_{ia}, \quad \Delta_j = x_{jb} - x_{ja}$$

where x_{ib} and x_{ia} are mean speeds before and after sign i , and x_{jb} and x_{ja} are mean speeds before and after sign j . If μ_{Δ} and σ_{Δ}^2 are the mean and the variance, respectively, for the speed reduction ($\Delta_i = N(\mu_{\Delta_i}, \sigma_{\Delta_i}^2)$), then:

$$\mu_{\Delta_i} = \bar{x}_{ib} - \bar{x}_{ia}, \quad \mu_{\Delta_j} = \bar{x}_{jb} - \bar{x}_{ja}$$

$$\sigma_{\Delta_i}^2 = s_{x_{ib}}^2 + s_{x_{ia}}^2, \quad \sigma_{\Delta_j}^2 = s_{x_{jb}}^2 + s_{x_{ja}}^2$$

where S^2 is the sample variance (e.g. $s_{x_{ib}}^2 = s_{x_{ib}}^2/n_{x_{ib}}$).

The difference in speed reduction is:

$$\Delta_D = \Delta_i - \Delta_j$$

which is also normal, with mean and variance as follows:

$$\mu_D = \mu_{\Delta_i} - \mu_{\Delta_j} = \bar{x}_{ib} - \bar{x}_{ia} - \bar{x}_{jb} + \bar{x}_{ja}$$

$$\begin{aligned} \sigma_D^2 &= \sigma_{\Delta_i}^2 - \sigma_{\Delta_j}^2 = s_{x_{ib}}^2 + s_{x_{ia}}^2 + s_{x_{jb}}^2 + s_{x_{ja}}^2 \\ &= \frac{s_{x_{ib}}^2}{n_{x_{ib}}} + \frac{s_{x_{ia}}^2}{n_{x_{ia}}} + \frac{s_{x_{jb}}^2}{n_{x_{jb}}} + \frac{s_{x_{ja}}^2}{n_{x_{ja}}} \end{aligned}$$

Then the z -statistic for Δ_D is

$$\begin{aligned} z &= \frac{\mu_D}{\sqrt{\sigma_D^2}} \\ &= \frac{\bar{x}_{ib} - \bar{x}_{ia} - \bar{x}_{jb} + \bar{x}_{ja}}{\sqrt{(s_{x_{ib}}^2/n_{x_{ib}}) + (s_{x_{ia}}^2/n_{x_{ia}}) + (s_{x_{jb}}^2/n_{x_{jb}}) + (s_{x_{ja}}^2/n_{x_{ja}})}} \end{aligned}$$

At a certain level of significance (e.g. 5%), z can be compared with a corresponding tabulated value (from the normal table) to determine whether to reject the null hypothesis above.

The five modules ranked above can be divided into two groups, namely, the square signs (Modules V–VII) and the triangular signs (Modules III and IV). When the amount of reduction among the square signs was compared statistically, using the foregoing statistic, no significant reduction was found at the 5% level. However, the double-size module

with diamond reflective material (IV) within the triangular group showed a significant reduction when compared with the other module with no diamond reflective material (III). Among the square signs, since all three configurations are effectively the same, Module VII (75 cm × 75 cm) was selected to represent this group because of economical considerations, the smaller the size, the lower the cost of manufacturing and installation.

Accordingly, of both groups and as justly discussed, two modules were competitive, namely, Module IV (the triangle) and Module VII (the square). Statistical testing above showed that the difference between these two modules in terms of the amount of speed reduction was not significant (P -value = 0.1314). Hence, both modules were equally effective, and either one could be selected. Since the double-size triangle (Module IV) looks like the standard sign, except for the size and type of reflective material, it would be preferred to the square sign (Module VII).

5. Discussion and conclusions

Warning signs were tested in this study to measure their effectiveness in reducing the average speed of motorists along road sections that have a high potential for camel–vehicle crashes. Seven sign configurations were tested. The standard warning sign showed no effect at all. Almost all the sign configurations specifically designed for this study were found to be effective, yet variability among them in test results was also found statistically significant. However, of the three square signs (Modules V–VII) and the two triangular signs tested, besides the standard sign, (Modules III and IV), the study found the double-size triangular sign, with diamond reflective material, to be effective. Furthermore, the study recommends its use in sections where there is a need to warn drivers about the potential for camel-crossings.

When there was an overall statistically significant speed reduction due to the installation of warning signs, the reduction was found to be either operationally quite small (in most experiments the difference between the highest and lowest speed in the experimental section ranged from about 3 to about 7 km/h) or inconsistent with the other speed reductions; e.g. within the same configuration, namely square module, larger warning signs did not necessarily result in larger speed reductions compared with small signs.

Regarding speed variability, the results showed a relatively small amount of variability reduction due to the sign presence; however, the proportion of drivers who drive over the speed limit showed a significant reduction with most of the sign configurations.

The study also found that the influence of the warning sign on the driver starts nearly 500 m ahead of the sign and diminishes at 500 m downstream of the sign (i.e. the sign's impact extends over a 1000-m section). This finding helps in deciding how frequently signs are need to be posted in a potential camel-crossing section. Still, the frequency

of signs along a hazardous site should be examined in a future study. Additionally, since it was not investigated in this research project, the trade-offs between the cost of the sign and the effectiveness of the sign should be considered in future research. There is a need of some method of assigning values to the cost of implementation and effectiveness of countermeasure so the best module can be identified.

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References

- AASHTO, 1994. A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington, DC.
- Aberg, L., 1981. The Human Factor in Game-Vehicle Accidents: A Study of Drivers Information Acquisition. Monograph No. 6. Uppsala University, Sweden.
- Al-Amr, S.A., et al., 1998. Studying the Impact of Camels on Traffic Safety. King Abdulaziz City of Sciences and Technology, Research Project No. AT-14-72, Final Report. Riyadh, Saudi Arabia.
- Al-Ghamdi, A.S., 1998. Injury severity and duration of hospital stay for urban road accidents in Riyadh. In: Transportation Research Record 1635. TRB, National Research Council, Washington, DC, pp. 125–132.
- Almkvist, B., et al., 1978. The Animal Accident Project. Situation Report. National Swedish Road Administration, Stockholm.
- Armstrong, J.J., 1992. An Evaluation of the Effectiveness of Swareflex Deer Reflectors. Ontario Ministry of Transportation, March.
- Baker, D., 1988. Deer Warning Device Analysis. Internal Report, Ohio State Highway Patrol.
- Bjornstig, V., et al., 1985. Moose-car collisions: mechanisms and injury preventive strategies. In: Bjornstig, V. (Ed.), Snowmobile, Motorcycle and Moose-Car accidents: Aspects on Injury Control. Umea University Medical Dissertations News Services, No. 157. Umea, Sweden.
- Cerelli, E.C., 1981. Safety Consequences of Raising the National Speed Limit from 55 mph to 60 mph. NHTSA, US Department of Transportation.
- Dart Jr., O.K., Hunter, W.W., 1976. Evaluation of the Halo effect in speed detection and enforcement. In: Transportation Research Record 609. TRB, National Research Council, Washington, DC, pp. 31–33.
- Dillon, M.L., 1993. Literature Review of Wildlife-Vehicle Collisions and Highway 24 Deer-Vehicle Accident Analysis Report. Ontario Ministry of Transportation, Canada.
- Evink, G.L., 1990. Wildlife crossings of Florida I-75. In: Transportation Research Record 1279. TRB, National Research Council, Washington, DC, pp. 54–59.
- Farm, 1993. Farm J. Mid-February, C-4.
- Ford, S.G., 1980. Evaluation of Highway Deer Kill Mitigation on SIE/LAS-395 (1976–1979). Report FHWA/CA/TP-8010. US Department of Transportation.
- Fusari, M., 1982. Feasibility of a Highway Crossing System for Desert Tortoises. Report FHWA/CA/TP-81/1, July, p. 41.
- Garber, N.J., Gadiraju, R., 1992. Impact of differential speed limits on the speed of traffic and rate of accidents. In: Transportation Research Record 1375. TRB, National Research Council, Washington, DC.

- Gilbert, J.R., 1982. Evaluation of Deer Mirrors for Reducing Deer-Vehicle Collisions. US Department of Transportation, Federal Highway Administration, Report FHWA-RD-82-061.
- Graves, H.B., Bellis, E.D., 1978. The Effectiveness of Deer Flagging Models as Deterrents to Deer Entering Highway Rights-of-Way. Final Report. Pennsylvania Department of Transportation.
- Hagopur, 1995. Duftazun Scent Barrier. Product Marketing Information, Hagopur GmbH, Germany.
- Hughes, W.E., Saremi, A.R., Paniati, J.F., 1996. Vehicle-animal crashes: an increasing safety problem. *ITE J.* 66 (8), 24–28.
- IIHS, 1993. Insurance Institute of Highway Safety Status Report, vol. 28 (4), April.
- Kallberg, V., 1993. Speed Can Endanger Your Health. *Nordic Road and Transport Research*, No. 2, pp. 9–12.
- Lehmitimaki, R., 1984. Elk and White-Tail Deer as Traffic Hazard. Reports from Liilennefureva 29L1984. The Central Organization for Traffic Safety, Helsinki, Finland.
- Mansfield, T.M., Miller, B.D., 1975. Highway Deer-Kill District 02 Regional Study. Caltrans Internal Report, 49 pp.
- Marrony, S., Dawar, R., 1987. Alternative to enforcement in modifying the speeding behavior of drivers. In: *Transportation Research Record* 1111. TRB, National Research Council, Washington, DC, pp. 121–126.
- McLain, C., 1990. Signs of Determination: A Former Park Warden Broke the Rules to Save Wildlife. *Nature*, Canada.
- MOC. Traffic Couns. Annual Report. Ministry of Communications, Riyadh, 1999.
- Montgomery, D.C., 1984. *Design and Analysis of Experiments*, second ed. Wiley, New York.
- Montgomery, D.C., Runger, G.C., 1994. *Applied Probability and Statistics for Engineers*. Wiley, New York.
- Peterson, R., 1995. Personal Letter to the Authors on 28/06/1995 from Swedish Police Force, Traffic Police Department.
- Pojar, T.M., et al., 1975. Effectiveness of a lighted, animated deer crossing sign. *J. Wildlife Manage.* 39 (1), 87–91.
- Reed, D.F., 1981. Effectiveness of highway lighting in reducing deer-vehicle accidents. *J. Wildlife Manage.* 45 (3), 721–722.
- Shafer, J.A., Penland, S.T., 1984. Effectiveness of Swareflex reflectors in reducing deer/vehicle accidents. *J. Wildlife Manage.* 49 (3), 774–776.
- Solomon, D., 1964. *Accidents on Main Rural Highways Related to Speed, Driver and Vehicle*. Bureau of Public Roads, Washington, DC.
- Stanley, F.G., Sharon, L., 1993. Reflector Use and the Effect they have on the Number of Mule Deer Killed on California Highways. US Department of Transportation, Federal Highway Administration, Report FHWA/CA/PD-94/01.
- Ward, A.L., 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. In: *Transportation Research Record* 859. TRB, National Research Council, Washington, DC.
- Zacks, J.L., 1985. An Investigation of Swareflex Wildlife Warning Reflectors. US Department of Transportation, Federal Highway Administration, Report No. FHWA-MI-RD-85-04.
- Zacks, J.L., 1986. Do white-tail deer avoid red? An evaluation of the premise underlying the design of Swareflex wildlife reflectors. In: *Transportation Research Record* 1075. TRB, National Research Council, Washington, DC, pp. 35–43.