EVALUATION OF THE RELIABILITY AND EFFECTIVENESS OF AN ANIMAL DETECTION SYSTEM ALONG STATE HWY 3 NEAR FT JONES, CA

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We investigated the reliability and effectiveness of a microwave break-the-beam animal detection system along State Hwy 3 near Ft Jones, northern California, USA. The results indicated that the system was capable of detecting a human and was therefore likely to be able to detect large ungulates such as black-tailed deer. While blind spots were absent some of the beams did show evidence of desensitizing during testing. A comparison of the detection data to video images associated with the system showed that at least 74% of all detections could be considered “correct”. Unidentified triggers occurred mostly in the late afternoon or night when camera range was limited. About 93% of the correct detections related to vehicles turning on and off the highway on side roads. Only about 4% of the correct detections related to black-tailed deer. Drivers reduced vehicle speed by about 5.5% when warning signs were activated (from 56.2 mi/hr (90.4 km/h) to 53.1 mi/hr (85.4 km/h)). Regarding the effectiveness of the system, speed reductions were greatest during the evening and night. There was one deer-vehicle collision recorded in the road section with the system after the system and signs were put into operation. However, it was not possible to conclude whether the animal detection system may have reduced the number of large mammal-vehicle collisions. We recommend improving the reliability of the system, reducing potential downtime, operation, and maintenance costs, improving the warning signs, and to implement an extensive public outreach program.
INTRODUCTION
Animal–vehicle collisions affect human safety, property, and wildlife. In the United States, more than 90% of animal–vehicle collisions involve deer (1), with the total number of deer–vehicle collisions estimated at one to two million per year (2, 3). In the mid-1990s these collisions were estimated to cause 211 human fatalities, 29,000 human injuries, and over $1 billion in associated costs per year (2). These numbers have increased even further over the last decade (1, 3, 4, 5). In most cases, the animals die immediately or shortly after the collision (6). In some cases, it is not just the individual animals that suffer; some species are also affected on the population level and may even be faced with a serious reduction in population survival probability (e.g., 7, 8, 9). In addition, for some species a monetary value (e.g., hunting, recreation) is lost to society once an individual animal dies (4, 10, 11).

Historically, animal–vehicle collisions have been addressed through signs warning drivers of potential animal crossings. In other cases, wildlife warning reflectors, mirrors or wildlife fences have been installed to keep animals away from the road (e.g., 12, 13). However, conventional warning signs appear to have only a limited effect because drivers are likely to habituate to them (14) and wildlife warning mirrors or reflectors may simply not be effective (15, 16). Wildlife fences can keep animals off the road but can also isolate wildlife populations. Therefore fences are often combined with wildlife crossing structures (e.g., 17, 18). Primarily due to their high upfront cost, such crossing structures are limited in number and size.

For this project we investigated a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape: animal detection systems. Animal detection systems detect large animals (e.g., deer, elk, moose, or pronghorn) as they approach the road. When an animal has been detected, signs are activated warning drivers that large animals may be on or near the road at that time. Previous research has shown that, depending on road and weather conditions, the warning signs can cause drivers to reduce their speed (reviews in 19, 20, 21, 22). Warning signs may also result in more alert drivers (23), which can lead to a reduction in stopping distance of 20.7 m (68 ft) at 88 km/h (55 mi/h) (24). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 81-82% (25, 26). Similar results come from Arizona (97%; 21) and Montana (58–67%; 22).

Since the effectiveness of animal detection systems depends on driver response, reliable warning systems are essential. Therefore we investigated system reliability in great detail at a controlled access facility in central Montana and also along a real world highway (Hwy 3), near Ft Jones, in northern California, USA. In addition we investigated system effectiveness in terms of potentially reduced vehicle speed in response to activated warning at a site in northern California.

METHODS
Study Areas and System Tested
Montana Site
The test-bed was located along a former runway at the Lewistown Airport in central Montana, USA. The test-bed location experienced a wide range of climatological conditions, the topography was flat, and the rocky soil did not sustain much vegetation that may have obstructed
the beam. The test-bed consisted of an animal enclosure, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities. The distance covered by the system tested for this project was 91 m (300 ft). The enclosure included shelter, water, and an area alongside the fence that was designated for feeding. Two horses, two llamas, and two sheep roamed inside the enclosure as models for large wild ungulates such as white-tailed deer (Odocoileus virginianus), mule deer (O. hemionus), pronghorn (Antilocapra americana), elk (Cervus canadensis) and moose (Alces alces). Horses are similar in body shape and size to moose, llamas represent deer and elk, and sheep represent small deer.

The system tested for this project was a microwave radio signal break-the-beam system manufactured by ICx Radar Systems (formerly Sensor Technologies and Systems, Inc.). The system was the third generation of this detection technology (RADS III) and was not previously evaluated for its reliability. This system was the exact same detection technology as was installed along Hwy 3 near Ft Jones, CA (next section). The system was installed in Lewistown, MT on 16 December 2009. The center of the beam was set at about 73.7 cm (29 inches) above the ground.

The system transmitted microwave radio signals (around 35.5 GHz). These signals were received by a sensor on the other end, and whenever an animal or object passed between the sensors, the signal was reduced. If certain thresholds were met, the reduction in signal strength resulted in a detection. The detection line was the line between the transmitter and receiver sensors where the break-the-beam systems should detect large animals. The detection line was marked with cones just adjacent to the actual detection line to prevent interference with the microwave radio signal. The cones were visible on the images from the individual cameras.

The six infra-red cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection system. These cameras and a video recording system recorded all animal movements within the enclosure continuously, day and night. The animal detection system saved its individual detection data with a date and time stamp. These data were compared to the images from the infra-red cameras, which also had a date and time stamp, to investigate the reliability of the system.

California Site

The exact same animal detection system that was tested at the Montana site was also installed along Hwy 3 near Ft. Jones, in northern California, USA (Figure 1). In September 2009 the animal detection system was installed along a 1,070 m (0.64 mi) long section between mi marker 36.6 and 37.3 (27). This road section was primarily selected because of its history of collisions with black-tailed deer (Odocoileus hemionus columbianus) (30 reported carcasses in the year prior to system installation over (8.0 km (5 mi) road length) and the interest of California Department of Transportation (CALTRANS) District 2 personnel in reducing these collisions. The average beam length was 297 m (range 240-320 m) (974 ft (range 787-1050 ft)). Beam 3 (Air Force Way) and beam 4 (farm access) shot across access roads. The system was coupled with four dynamic, LED, driver warning signs, two placed in each direction, one near the beginning and one near the middle of the test site. When off, the sign was simply a 36 x 36 inch (98 x 98 cm) black diamond (i.e. no message was displayed). When the system detected animals, the sign illuminated for three minutes, showing a white silhouette of a jumping deer, an amber boarder along the edge of the sign, and two circles on either side of the deer that flashed alternately (Figure 1). Additionally, seven linked Smart Micro Systems (SMS) GmbH 24.125
GHz radars and 6 video cameras were placed along the roadway to measure vehicle speeds through the test site.

![Figure 1. Layout of the animal detection system and photo of one of the warning signs along Hwy 3 north-east of Ft Jones, CA. Letters indicate poles, numbers and red lines indicate beams. Note that the beams do not start at the same location for the two road sides. Beam 3 shoots across an access road, and beam 4 shoots across a farm access point.](image)

**System Reliability**

*Montana Site*

We conducted reliability tests during three ten day test periods:

- December 17, 2009 through December 26, 2009.
- July 30, 2010 through August 8, 2010.

Each test period started and ended at midnight. For each test day (24 hours), we selected three random one-hour-long sections of video for review (stratified random). This resulted in a total of 30 hours during which the reliability of the system was investigated for each test period, and 90 hours for the three test periods combined.

The test periods were analyzed for valid detections, false positives, false negatives, intrusions in the detection area, and downtime. These terms are defined below.

- **Valid detections** – A valid detection was defined as the presence of an animal in or immediately adjacent to the detection line in conjunction with a corresponding detection recorded by the system’s data logger.
- **False positives** – A false positive was defined as when the system reported the presence of an animal, but there was no animal in the detection line or immediately adjacent to it.
Thus, each incident in which the system’s data logger recorded a detection, but there was no animal present in the detection zone of the system, was recorded as a false positive.

- **False negatives** – A false negative was defined as when an animal was present but was not detected by the system.
- **Intrusions in detection area** – An intrusion was defined as the presence of one or multiple animals in the detection zone. An intrusion began when one or more animals entered the detection zone and ended when all animals left the detection zone.
- **Downtime** – Downtime was defined as the time when the system was not working at all or when it was not working according to the expectations of the researchers or the specifications of the vendor.

**California Site**

On 2 and 3 April 2012 a researcher (1.82 m (6 ft) tall, 79 kg (175 lbs.)) attempted to trigger the system at about 66 ft (20 m) intervals by crossing through the beam in the different detection zones. Typically the researcher crossed a beam on one side of the road at walking speed, continued walking across the road, and then crossed the beam on the other side of the road. The crossing of two beams and the road typically took about 15-20 seconds. The researcher then waited at least 3 minutes before crossing through the beams again about 66 ft (20 m) further down the road. The purpose of the three minutes waiting time before triggering a beam again was to avoid potentially desensitizing the beam while the warning signs were still turned on (the warning signs stayed on for three minutes after the last detection). The researcher compared the time and number of times the different beams were crossed to the detection log to investigate the presence of potential blind spots or missed detections (“false negatives”). The detection log contained “records” that reported on the status of the sensors and signs.

In addition, the detection data logged by the animal detection system were compared to the images recorded by the video cameras. The cameras were mainly designed to record driver behavior and the movement of their vehicles. The resolution of the images was too low to be confident in detecting medium or large mammal species at the far end of a detection zone. In addition, the range of the video cameras was limited to about 66 ft (20 m) during the night further restricting the distance covered by the cameras. However, when a car happened to pass by, its headlights illuminated the road and the right-of-way allowing for greater range of the cameras during that brief period. This meant that we were able to identify what triggered the system for a selection of the detections, particularly during the day. Because of the blind spots directly beneath the cameras and the limited range of the cameras the researchers could not be certain that a detection was a false positive or perhaps a correct detection after all. In addition, the researchers were not able to identify potential false negatives as there were no images recorded unless a detection had occurred.

We investigated the detection patterns for a period of 30 days in the fall of 2011. The 30 days were divided into three ten day periods (start and end at midnight):

- 1 September 2011 – 10 September 2011.

**System Effectiveness in Reducing Vehicle Speed**

We investigated the effect of activated warning signs on vehicle speed at the California site (details in 28). Two different and complementary experimental designs were employed using
approximately 10 months of vehicle speed data, beginning August 3, 2011 and ending May 30, 2012. For the first analysis, the “control” consisted of vehicle speeds obtained during the first 2.5 months of the study, when the system was operational, but the dynamic animal warning signs were covered. The “treatment” consisted of vehicle speeds obtained for the subsequent 7.5 months of the study, after the dynamic animal warning signs had been uncovered. In both cases, vehicle speeds were examined only for time periods when the system had been triggered, and presumably there was something present that triggered the system. This first analysis provided for the most direct comparison of vehicle speeds both with and without the warning signs when something (including potentially deer) was presumably present on or alongside the roadway. However, this analysis was susceptible to confounding variables such as potential changes in road conditions, deer behavior or driver behavior, as the control and treatment measurements were sometimes many months apart.

The second analysis only used data from the 7.5 months of the study after the dynamic animal warning signs had been uncovered. The “control” consisted of vehicle speeds several minutes prior to detection events. The “treatment” consisted of vehicle speeds obtained during detection events, while the warning signs were activated and visible to drivers. The second analysis examined the potential confounding effects in the first analysis, such as potential changes in road conditions over time or deer behavior or driver behavior adaptation over time. However, in this analysis, potential differences in vehicle speeds between the control and the treatment may not only have been associated with the activated warning signs, but could have been due to the fact that there was presumably nothing on the roadway for the control measurements, whereas for the treatment, there was presumably something on the roadway. Thus any effects observed for the second analysis could have been due to either the activation of the signs or to drivers reacting to having seen something (including deer) on or alongside the roadway.

For each analysis, we calculated the average vehicle speeds through the test site during the control and treatment events (typically at least three minutes). Individual vehicles (whether traveling solo or in a platoon) were tracked through the entire test site across multiple, integrated radars, and an average speed was calculated for each vehicle. An average vehicle speed was computed during the event. In the second analysis, the length of control and treatment time periods was selected to be similar in duration. Both analyses utilized a generalized linear model with the control or treatment event, and mean vehicle speed as the dependent variable.

RESULTS

System Reliability

Montana Site

There were 476 valid detections in 90 hours that detection data were available for, resulting in an average of 12.65 valid detections per hour (Table 1). There was only 1 false positive, but there were 61 false negatives. The false negatives related to all three species: 27 for sheep, 13 for llamas, and 21 for horses. The number of false negatives when the system was actually operational was much lower: 13 for sheep, 5 for llamas, and 2 for horses (20 in total). There were 111 intrusions in the detection area and 88.48% of all intrusions in the detection area were detected. The signal of the system went down regularly (i.e. passing through beam did not result
in detection), causing the system to generate false negatives. The beam appeared to come back in
operation by itself after varying amounts of time. The total number of hours that the system was
"down" during the 90 test hours was 6 hours and 54 minutes (7.67%).

Table 1: Results of the reliability tests with domesticated horses, llamas and sheep.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours analyzed (N)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>Valid detections (N)</td>
<td>140</td>
<td>193</td>
<td>143</td>
<td>476</td>
</tr>
<tr>
<td>Valid detections/hour (N)</td>
<td>4.67</td>
<td>6.43</td>
<td>4.77</td>
<td>12.65</td>
</tr>
<tr>
<td>False positives (N)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>False positives (%)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>False positives/hour (N)</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>False negatives (N)</td>
<td>4</td>
<td>45</td>
<td>12</td>
<td>61</td>
</tr>
<tr>
<td>False negatives (%)</td>
<td>2.78</td>
<td>18.91</td>
<td>7.74</td>
<td>11.36</td>
</tr>
<tr>
<td>False negatives/hour (N)</td>
<td>0.13</td>
<td>1.50</td>
<td>0.40</td>
<td>0.68</td>
</tr>
<tr>
<td>Intrusions (N)</td>
<td>111</td>
<td>112</td>
<td>85</td>
<td>308</td>
</tr>
<tr>
<td>Intrusions detected (%)</td>
<td>97.22</td>
<td>80.75</td>
<td>92.26</td>
<td>88.48</td>
</tr>
<tr>
<td>Downtime (hours)</td>
<td>2:00</td>
<td>3:27</td>
<td>1:27</td>
<td>6:54</td>
</tr>
<tr>
<td>Downtime (%)</td>
<td>6.67</td>
<td>11.50</td>
<td>4.80</td>
<td>7.67</td>
</tr>
</tbody>
</table>

California Site

The researcher successfully triggered all beams, except beam 5 which was not functional because
a car went off the road and destroyed one of the sensors. For three beams (beams 3, 4 and 6)
evidence existed that passing through the beam did not always result in a detection. Subsequent
retesting at those locations showed that the missed detections were the result of the beam having
become desensitized rather than the presence of blind spots. Note that the first evidence of
desensitizing beam 3 was after eight crossings (at least three minutes apart), including a vehicle
that pulled off the road for a few minutes. Beam 4 and 6 both became desensitized after four
crossings (at least three minutes apart). Beam length does not appear to be a primary factor.

Over the 30 days there were 586 detections (Table 2). We were able to identify what
triggered the system in 74% of all cases. In 21% of the cases the researchers were not able to
identify what may have caused the detection. In a relatively small number of cases (<4%) the
video data were not available for analyses. About 1% of the records (records are lines in the
detection log) appeared to be related to a system error in which all beams reported a break at the
same time. All but six records were associated with the warning lights turning on. Five of these six records related to records classified as “system errors”, and the one remaining record related to a record classified as “trigger not identified”. The vast majority of the correct detections related to vehicles that had left the actual highway (with or without associated humans outside the vehicle) (Table 3). Deer were present in about 4% of the correct detections.

Table 2: Classification of the three minute time periods in which detections occurred.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Count (N)</th>
<th>Count/day (N)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct detection confirmed</td>
<td>435</td>
<td>14.50</td>
<td>74.23</td>
</tr>
<tr>
<td>Trigger not identified</td>
<td>124</td>
<td>4.13</td>
<td>21.16</td>
</tr>
<tr>
<td>No video data available</td>
<td>21</td>
<td>0.70</td>
<td>3.58</td>
</tr>
<tr>
<td>System error</td>
<td>6</td>
<td>0.20</td>
<td>1.02</td>
</tr>
<tr>
<td>Total</td>
<td>586</td>
<td>19.53</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 3: Breakdown of what triggered the system (all classified as “correct detection”).

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Count (N)</th>
<th>Count/day (N)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>404</td>
<td>13.47</td>
<td>92.87</td>
</tr>
<tr>
<td>Deer</td>
<td>19</td>
<td>0.63</td>
<td>4.37</td>
</tr>
<tr>
<td>Human</td>
<td>11</td>
<td>0.37</td>
<td>2.53</td>
</tr>
<tr>
<td>Unidentified animal species</td>
<td>1</td>
<td>0.03</td>
<td>0.23</td>
</tr>
<tr>
<td>Total</td>
<td>435</td>
<td>14.5</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Most of the records that related to vehicles were recorded between 6 am and 9 pm (Figure 2). Most of the records where the trigger could not be identified were recorded at the end of the afternoon and during the night. Deer were identified during the day as well as the night. The vast majority of all records where a vehicle triggered the system related to beam 3 and a much smaller number related to beam 4 (Figure 3).
Figure 2. Number of records for the different detection categories by hour of day.
System Effectiveness in Reducing Vehicle Speed

For the first analysis, mean traffic speed was reduced by 3.1 mi/h (5.0 km/h) from 56.2 mi/h (90.4 km/h) when the warning signs were covered (but the system had logged a detection) to 53.1 mi/h (85.4 km/h) when the warning signs were illuminated (Wald $\chi^2_{1} = 15.9$, p <0 .001).

The speed reduction appeared greatest in the evenings and during the night with the average mean speed reduction increasing to 4.9 mi/h (7.9 km/h). For the second analysis, mean traffic speed was reduced by 5.1 mi/h (8.2 km/h) from 58.3 mi/h (93.8 km/h) just before a detection event when the warning signs were still inactivated to 53.1 mi/h (85.4 km/h) just after a detection when the warning signs were activated (Wald $\chi^2_{1} = 198.6$, p <0 .001). Similar to the first analysis, the mean vehicle speed reduction tended to be greatest during the evenings and nights with the average mean speed reduction increasing to 8.3 mi/h (13.4 km/h). Finally, there was very little variation in speed reduction over time, ranging from 4.5-5.8 mi/h (7.2-9.3 km/h) throughout the 7.5 months after the signs were uncovered.
DISCUSSION

Reliability
Based on reliability tests at the Montana site the number of false positives was relatively low but the number of false negatives was relatively high. The percentage of all intrusions in the detection area that was detected was relatively low (29). Based on the values for the reliability parameters, the system does not meet the recommended minimum norms (91–95% or more of all large animals that approach the road should be detected, 6-10% or less false positives) for the reliability of animal detection systems (29). Specifically, the percentage of false negatives is too high, and the percentage of intrusions detected is too low. However, when the downtime of the system was excluded, the percentage of false negatives dropped to about 4%. This suggests that the system can meet the suggested norms for reliability if the beam remains operational. Thus it is the substantial downtime of the system (7.67%) during the tests that is a major concern.

Reliability tests at the California site showed that the system is capable of detecting a human and therefore is likely to also be able to detect large ungulates such as black-tailed deer. While the system did not have any blind spots, three of the beams did show evidence of desensitizing during testing, even with at least three minutes between consecutive triggers. This means that while the system is likely to detect deer as they approach and leave the road, the system may not be triggered another time if an animal continuously blocks the beam or if multiple animals cross the beam. Since the warning signs are programmed to remain on for three minutes after the last detection the desensitizing of the beams is likely to only affect a relatively small number of the deer crossings. Nonetheless, it is possible that deer are on or near the road without the warning lights being activated. While this can be considered a problem this phenomenon is also possible if the beams would not desensitize at all. For example, if an animal crosses a beam but then stays in the right-of-way (having fully passed the beam) or on the road for more than three minutes, the warning lights would also turn off with a deer still present.

The comparison of the detection data from the animal detection system with the video images from the cameras showed that at least 74% of all detections can be considered “correct”. Because of the limited range of the cameras, especially during the night, it is likely that the percentage of correct detections is substantially higher; most of the triggers that were not identified were in the late afternoon and during the night when not all deer triggers could be identified. There were some system errors but except for one system error they did not result in the activation of the warning signs. About 93% of the correct detections related to vehicles turning on and off Hwy 3. The vast majority of the vehicle detections came from beam 3 that cuts across Air Force Way. A much smaller number of detections came from beam 4 where vehicles turned on and off a farm road. Other vehicle detections related to vehicles parking or turning around in the right-of-way. Only about 4% of the correct detections related to black-tailed deer. However, compared to vehicles the number of deer that triggered the beam is more likely to have been underestimated as deer cannot be identified on night images if they are further away than about 66 ft (20 m) from the cameras.

System Effectiveness
The two vehicle speed analyses both showed that activated warning signs were associated with a reduction in vehicle speed and that vehicle speed reduction was greatest during the evening and
night. This is not only when deer tend to be more active but also when the visibility to drivers is reduced and drivers need more time to respond to deer (or other animals or objects) on the road. We did not find any evidence that driver response to the signs changed over the course of the study. This suggests that the drivers did not habituate to the signs and continued to respond as desired. While we did not have sufficient data to investigate whether the animal detection system and associated warning signs resulted in fewer collisions with large wild mammals, there was only one black-tailed deer carcass reported in the road section with the system after the warning signs were attached. The collision occurred at mi marker 36.64, just inside the road section with the system, but where the system is only present on the north side of the road and not on the south side.

Management Considerations
Blind spots or false negatives: Apart from the car accident that caused beam 5 to be out of commission, the system appeared reliable and did not have any blind spots. The absence of blind spots was not surprising considering the even terrain (i.e. no depressions where the beam would shoot over the head of large mammals).

Desensitizing: If an animal (or a car or human) blocked the beam for more than about 10 seconds some beams became desensitized and no longer reported the beam as being broken. The same situation occurred if the beam was broken multiple times in a short time period. In those cases deer may be present in the right-of-way or on the road without the warning lights being activated. The researchers found evidence of a deer desensitizing a beam once in the 30 days that the data were analyzed for. However, there may have been more instances that were not visible on the video images. While no animal detection system is likely to detect all large animals that approach the road under all conditions, the information described above may be considered when deciding on the type of system, the specific characteristics of the technology, and it may also help the manufacturer with potential further refinements to the system.

False positives: The average number of records per day in the detection log was not very high; about 20. This is important because if the warning signs would be on most of the day it would be too similar to warning signs that are always turned on (without being attached to sensors). Nonetheless, most of these detections do not relate to the target species (black-tailed deer), and one could consider efforts to minimize the number of detections that do not relate to the target species. Most of the detections related to vehicles turning on and off Hwy 3 (especially at Air Force Way). To minimize these “unwanted” triggers one may consider installing a detector loop for vehicles that would cancel a detection by the animal detection system. Large animals, including deer, would still trigger the beam if they use the side road as they are not detected by the vehicle detector loop.

We recommend improving the reliability of the system, reducing potential downtime, operation, and maintenance costs, improving the warning signs, and to implement an extensive public outreach program.

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REFERENCES


