IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

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**RP 247**

# The Reliability and Effectiveness of a Radar-Based Animal Detection System

By


**Marcel P. Huijser, Ph.D**
Western Transportation Institute - Montana State University (WTI-MSU)

**Elizabeth R. Fairbank, M.Sc**
WTI-MSU

**Fernanda D. Abra, M.Sc**
University of São Paulo, Brazil



Prepared for
Idaho Transportation Department
Research Program, Contracting Services
Division of Engineering Services
http://itd.idaho.gov/alt-programs/?target=research-program

September 2017

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|---|---|---|
| 1. Report No.<br>FHWA-ID-17-247 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>The Reliability and Effectiveness of a Radar-Based Animal Detection System | | 5. Report Date<br>September 2017<br>6. Performing Organization Code |
| 7. Author(s)<br>Marcel P. Huijser, Elizabeth R. Fairbank & Fernanda D. Abra | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>Western Transportation Institute (WTI) - Montana State University<br>PO Box 174250,<br>Bozeman, MT 59717-4250 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>2015-01 |
| 12. Sponsoring Agency Name and Address<br>Idaho Transportation Department<br>Division of Engineering Services, Contracting Services, Research Program<br>PO Box 7129<br>Boise, ID 83707-7129 | | 13. Type of Report and Period Covered<br>Final or Interim Report<br>04/01/2015 - 05/15/2017<br>14. Sponsoring Agency Code<br>RP 247 |
| 15. Supplementary Notes<br>Project performed in cooperation with the Idaho Transportation Department, the Federal Highway Administration, Sloan Security Technologies, and University of São Paulo | | |

16. Abstract

This document contains data on the reliability and effectiveness of an animal detection system along U.S. Hwy 95 near Bonners Ferry, Idaho. The system uses a Doppler radar to detect large mammals (e.g., deer and elk) when they approach the highway. The system met most of the suggested minimum norms for reliability. The total time the warning signs were activated was at most 90 seconds per hour, and likely substantially less. Animal detection systems are designed to detect an approaching animal. After an animal has been detected, warning signs are activated which allow drivers to respond. Results showed that 58.1–67.9% of deer were detected sufficiently early for northbound drivers, and 70.4–85% of deer were detected sufficiently early for southbound drivers. The effect of the activated warning signs on vehicle speed was greatest when road conditions were challenging (e.g., freezing temperatures and snow- and ice-covered road surface) and when visibility was low (night). In summer, there was no measurable benefit of activated warning signs, at least not as far as vehicle speed is concerned. Depending on the conditions in autumn and winter, the activated warning signs resulted in a speed reduction of 0.69 to 4.43 miles per hour. The report includes practical recommendations for operation and maintenance of the system and suggestions for potential future research.

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|---|---|---|---|
| 17. Key Words<br>animals, collisions, corridors, crashes, deer, detection, ecology, effectiveness, elk, highways, hits, hotspots, mammals, mitigation, reliability, safety, signs, speed, systems, ungulates, warning, wildlife, wildlife–vehicle collisions | | 18. Distribution Statement<br>Copies available online at http://itd.idaho.gov/alt-programs/?target=research-program | |
| 19. Security Classification (of this report)<br>Unclassified | 20. Security Classification (of this page)<br>Unclassified | 21. No. of Pages<br>91 | 22. Price<br>None |

**FHWA Form F 1700.7**

# METRIC (SI*) CONVERSION FACTORS

| APPROXIMATE CONVERSIONS TO SI UNITS | | | | | APPROXIMATE CONVERSIONS FROM SI UNITS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Symbol | When You Know | Multiply By | To Find | Symbol | Symbol | When You Know | Multiply By | To Find | Symbol |
| | | LENGTH | | | | | LENGTH | | |
| in | inches | 25.4 | | mm | mm | millimeters | 0.039 | inches | in |
| ft | feet | 0.3048 | | m | m | meters | 3.28 | feet | ft |
| yd | yards | 0.914 | | m | m | meters | 1.09 | yards | yd |
| mi | Miles (statute) | 1.61 | | km | km | kilometers | 0.621 | Miles (statute) | mi |
| | | AREA | | | | | AREA | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $cm^2$ | $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $ft^2$ | square feet | 0.0929 | meters squared | $m^2$ | $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ | $km^2$ | kilometers squared | 0.39 | square miles | $mi^2$ |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ | ha | hectares (10,000 $m^2$) | 2.471 | acres | ac |
| ac | acres | 0.4046 | hectares | ha | | | | | |
| | | MASS (weight) | | | | | MASS (weight) | | |
| oz | Ounces (avdp) | 28.35 | grams | g | g | grams | 0.0353 | Ounces (avdp) | oz |
| lb | Pounds (avdp) | 0.454 | kilograms | kg | kg | kilograms | 2.205 | Pounds (avdp) | lb |
| T | Short tons (2000 lb) | 0.907 | megagrams | mg | mg | megagrams (1000 kg) | 1.103 | short tons | T |
| | | VOLUME | | | | | VOLUME | | |
| fl oz | fluid ounces (US) | 29.57 | milliliters | mL | mL | milliliters | 0.034 | fluid ounces (US) | fl oz |
| gal | Gallons (liq) | 3.785 | liters | liters | liters | liters | 0.264 | Gallons (liq) | gal |
| $ft^3$ | cubic feet | 0.0283 | meters cubed | $m^3$ | $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ | $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| Note: Volumes greater than 1000 L shall be shown in $m^3$ | | | | | | | | | |
| | | TEMPERATURE (exact) | | | | | TEMPERATURE (exact) | | |
| $^oF$ | Fahrenheit temperature | 5/9 ($^oF$-32) | Celsius temperature | $^oC$ | $^oC$ | Celsius temperature | 9/5 $^oC$+32 | Fahrenheit temperature | $^oF$ |
| | | ILLUMINATION | | | | | ILLUMINATION | | |
| fc | Foot-candles | 10.76 | lux | lx | lx | lux | 0.0929 | foot-candles | fc |
| fl | foot-lamberts | 3.426 | candela/$m^2$ | cd/$cm^2$ | cd/$cm^2$ | candela/$m^2$ | 0.2919 | foot-lamberts | fl |
| | | FORCE and PRESSURE or STRESS | | | | | FORCE and PRESSURE or STRESS | | |
| lbf | pound-force | 4.45 | newtons | N | N | newtons | 0.225 | pound-force | lbf |
| psi | pound-force per square inch | 6.89 | kilopascals | kPa | kPa | kilopascals | 0.145 | pound-force per square inch | psi |

# Acknowledgments

The authors of this report would like to thank the Idaho Transportation Department (ITD) and the Center for Environmentally Sustainable Transportation in Cold Climates (CESTiCC) for funding this project. Special thanks are due to Brice Sloan (Sloan Security Technologies, Inc.) for system development, operation, maintenance, and help with the data collection. Many thanks also to Robert Beachler, Kelly Campbell, Don Davis, Michael Hartz, Breanna Logerwell, Rob Nettleton, Ned Parrish and George Shutes (all ITD) and Joseph Alloway, Laura Fay, Jenny Liu (all CESTiCC) for their administrative and technical support. The authors thank to Jeff Gagnon (Arizona Game and Fish Department) and Grace Pedersen for reviewing this manuscript. We would also like to acknowledge the support and interest from Patty Perry of the Kootenay Valley Resource Initiative (KVRI) and Norm Merz (Kootenai Tribe of Idaho).

# Technical Advisory Committee

Each research project is overseen by a technical advisory committee (TAC), which is led by an ITD project sponsor and project manager. The Technical Advisory Committee (TAC) is responsible for monitoring project progress, reviewing deliverables, ensuring that study objective are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

**Project Sponsor –** Damon Allen, P.E.

**Project Manager –** Michael Hartz

**TAC Members**
George Shutes
Tim Cramer

**FHWA-Idaho Advisor –** Brent Inghram

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# List of Acronyms

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BACI | Before-After-Control-Impact |
| CESTiCC | Center for Environmentally Sustainable Transportation in Cold Climates |
| GHz | Gigahertz |
| Hwy | Highway |
| ITD | Idaho Transportation Department |
| LED | Light-Emitting Diode |
| SD | Standard Deviation |
| SE | Standard Error |

# Executive Summary

In late 2013, the Idaho Department of Transportation (ITD) District 1 installed a Doppler radar-based animal detection system along U.S. Hwy 95 in Boundary County, Idaho. The district installed the system with the aim to improve highway safety and identify cost-effective options to reduce wildlife-vehicle collisions. ITD was specifically interested in assessing the performance of the system and determining if it could be a possible alternative to wildlife fences and crossing structures on two-lane rural roads with low traffic volume. The district requested research funding to study the performance of the system and the Western Transportation Institute at Montana State University (WTI-MSU) was selected to study system performance.

The system was originally installed south of Bonners Ferry in December 2013. However, the system was moved to its current location, about 4.1 miles (6.6 km) north of the junction with U.S. Hwy 2 north of Bonners Ferry, Idaho, in April 2014. The system was designed to detect large mammals along a 371 ft (113 m) long road section. When a large mammal was detected, warning signs were activated for both northbound and southbound traffic that was approaching the area with the animal detection system.

This document contains data on the reliability and effectiveness of the animal detection system along U.S. Hwy 95 north of Bonners Ferry, Idaho. The system used a Doppler radar to detect large mammals (e.g., deer and elk) when they approached the highway. The system easily met the minimum norm for false negatives that was suggested as part of another animal detection system project funded by the Federal Highway Administration and the Montana Department of Transportation (2.5 percent vs. the suggested “allowable” maximum of 9 percent false negatives). However, the false positives may have been higher than the suggested reliability norm (24.5 percent possible false positives vs. the suggested “allowable” maximum of 10 percent false positives). On the other hand, some, perhaps many, of the “possible false positives” may have been caused by large mammals in the detection zone that were just out of view of the thermal camera used to evaluate the reliability of the system. The total time the warning signs were activated was at most about 90 seconds per hour (2.5 percent of the time), which suggests that drivers are unlikely to habituate to the warning signs.

The average crossing time for large ungulates (elk or deer) that successfully crossed the highway was about 15 seconds. This is perhaps surprising as people may usually see an animal running away from the highway as their vehicle approaches. However, deer and elk may spend a several minutes on the highway, especially when traffic is absent.

For 75 percent of the deer, the warning signs were “on” the entire time the deer was on the pavement, and for elk, this was 100 percent. For about 90 percent of the deer, the warning signs were “on” for the entire time or for part of the time the deer was on the pavement. However, at a minimum, the warning signs should be on the entire time any large mammal is on the pavement. To accomplish this, the time that the warning signs were activated after the last detection should have been longer. Alternatively, the radar should have detected large mammals earlier, or have had shorter gaps between consecutive detections of animals that approached the highway. Warning signs that stay activated for a longer time after the last detection can be easily accomplished through the software. Detecting large mammals earlier would involve either making the sensor more sensitive (lower thresholds) or widening the detection area or both. However, lowering the thresholds can also lead to a higher number of false positives as smaller animals or objects in the detection zone can more easily trigger the system. Furthermore, widening the detection area may only be possible when the vegetation is short and livestock in the areas adjacent to the right-of-way is absent.

The average time between the system detecting a deer and that deer setting its first hoof on the pavement was about 35 seconds. For elk, this was about 268 seconds. However, the sample size for elk was small, and the elk that were recorded happened to forage and approach the highway slowly. Fifty percent of the time a deer crossed the road, there was a warning time of at least 15.5 seconds. Given the distance between the warning signs and the outer edges of the detection area, the warning time was not sufficient to warn drivers early enough for all deer. Northbound drivers needed between 8.4 and 12.6 seconds warning time before a large animal entered the pavement in the detection area. Given the time between detecting a deer and that deer setting its first hoof on the pavement, between 58.1 and 67.9 percent of the deer were detected sufficiently early to expose northbound drivers to the warning signal. Southbound drivers needed between 3.2 and 7.5 seconds warning time before a large animal entered the pavement in the detection area. Given the time between detecting a deer and that deer setting its first hoof on the pavement, between 70.4 and 85.0 percent of the deer were detected sufficiently early to expose southbound drivers to the warning signal. This suggests that there is a need for multiple warning signs per travel direction. Drivers not only need time (and distance to the detection area) to interpret an activated warning sign and reduce the speed of their vehicle or come to a complete stop. Drivers should also not be able to pass a warning sign without being able to see and interpret the next warning sign, all the way through the far end of the detection zone.

Regardless of whether the warning signs were activated, vehicle speed was substantially lower in winter (44.91 mi/h) than in summer (55.01 mi/h) and autumn (51.92 mi/h). In summer, activated warning signs did not result in lower vehicle speeds. However, in autumn activated warning signs resulted in 0.69 mi/h speed reduction. In winter during the night, vehicle speed was 3.01 mi/h lower with lights on than with lights off, but during the day, vehicle speed was higher with lights on than with lights off. In winter, the effect of treatment (warning signs off vs. warning signs on) on vehicle speed was also significant in interaction with travel direction (northbound vs. southbound) and light conditions (day vs. night). During the night, vehicle speed was lower (1.59 mi/h for northbound traffic, 4.43 mi/h for southbound traffic) with lights on than with lights off. However, during the day, vehicle speed was higher (0.35 mi/h for northbound traffic, 1.80 mi/h for southbound traffic) with lights on than with lights off. The data suggest that the effect of activated warning signs on vehicle speed was greatest when road conditions were challenging (e.g., freezing temperatures and snow- and ice-covered road surface) and when visibility was low (night). In summer, there was no measurable benefit of activated warning signs, at least not as far as vehicle speed was concerned. Depending on the conditions in autumn and winter, the activated warning signs resulted in a speed reduction of 0.69 to 4.43 mi/h.

Assuming a vehicle speed of 60 mi/h (96.5 km/h), the minimum distance between the first activated warning sign and the near end of the detection zone should be 477.5-566.0 ft (145.5-172.5 m). Warning signs that are closer to the detection area do not allow drivers to stop their vehicles sufficiently early. Furthermore, the spacing of the warning signs should be such that drivers should not be able to pass a warning sign without being able to see and interpret the next warning sign until the end of the detection zone. At the time of the study, this was not the case; there was only one warning sign for each travel direction. This means that if a driver has passed a warning sign that was not activated, the driver can no longer be warned for large mammals on or near the highway for a road length of 656 ft (200 m) or 7.5 seconds at 60 mi/h for southbound traffic, or 1,109 (338 m) or 12.6 seconds at 60 mi/h for northbound traffic. The font size of the text and the size of the symbols on the signs determines the distance at which drivers can read and interpret the signs. This distance is equivalent to the interval between the warning signs leading up to the detection zone through the end of the detection zone.

The posted speed limit of 60 mi/h (96.5 km/h) does not allow the driver of a vehicle with low beam head lights with a median detection distance of 246.1 ft (75 m) to stop in time after the driver has observed a large mammal on the road. The researchers suggest experimenting with advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) at a maximum. Note that drivers with poor low beam head lights may still drive too fast to be able to come to a stop before hitting the animal. Drivers of cars with poor low beam head lights may need to reduce their speed to 25-30 mi/h (40-48 km/h) to be able to stop in time.

The researchers recognize that the recommendations for the number and placement of warning signs and the advisory or mandatory speed limit reductions associated with activated warning signs may not be consistent with current policy and practice of transportation agencies. The researchers recognize that more study and evaluation by transportation agencies may be required before the recommendations can be considered or implemented. For example, a series of signs at short intervals can result in sign saturation. Therefore, the researchers suggest not using standard warning signs that are always visible. The researchers suggest using LED signs that do not display any message when there is no detection of large animals. Only when a large animal is detected will the LED signs display the warning message and associated advisory or mandatory speed limit reduction.

The short length of the road section equipped with the animal detection system (0.07 mi) and the short time the system has been fully operational (since 2 October 2015), make it not possible to conclude whether the system has resulted in fewer wildlife-vehicle collisions. However, we can conclude that most of the crashes (74.01 percent) occurred during the night and that only 26 percent occurred during the day. This information is important because it means that most of the collisions occur when visibility is low (night time), when drivers, on average, cannot stop in time after the driver has observed a large mammal on the road. Vehicles with low beam head lights only have a median detection distance of 246.1 ft (75 m) (see Chapter 7).[17]. The finding that most wildlife-vehicle collisions occur in the dark, supports the suggestion for a mandatory speed limit reduction when the warning signs are activated (Chapter 7).

The researchers recommend the following for operation and maintenance:

1. As the system appears to be sufficiently reliable in detecting large mammals, consider keeping the current system in place or moving it to another location with a concentration of large mammal-vehicle collisions. Note that the authors of this report do not recommend a particular system type or manufacturer. Instead, the researchers emphasize the importance of using minimum norms for system reliability and selecting a system that best fits the specific conditions at a site, including environmental conditions. The researchers encourage ITD to keep using the current system as the system appears to be sufficiently reliable in detecting large mammals, and the system is already in ITD's possession.
2. Regardless of the location, if the system is kept in in operation, consider conducting system maintenance.
3. Regardless of the location, consider increasing the time the warning signs are activated after the last detection or change the configuration of the radar so that it detects large mammals earlier, and have shorter gaps between consecutive detections of animals that approach the highway. Note that for other types of systems (e.g. break-the beam systems) animals may be detected closer to the highway resulting in even shorter warning time before the enter the pavement.
4. Regardless of the location, and regardless of the type of animal detection system, the researchers recommend the following for the configuration of the warning signs:
    a. Consider placing the first warning sign at least 477.5-566.0 ft (145.5-172.5 m) before the near end of the detection zone. At the study location, north of Bonners Ferry, during the time of the study, the northern warning sign (for southbound traffic) was too close to the near end of the detection zone.
    b. Consider placing additional warning signs after the first warning sign until the end of the detection zone. The font size of the text and the size of the symbols on the signs determines the distance at which drivers can read and interpret the signs. This distance should be equivalent to the interval between the warning signs leading up to the detection zone through the end of the detection zone. Note that curves may reduce the sight distance for drivers and that curves may thus result in a shorter distance between the warning signs. Currently, drivers cannot be warned after they have passed the first warning sign as there are no additional warning signs.
    c. Consider using LED signs that do not display a message unless a large animal is detected. Only when a large animal is detected should the LED signs display the warning message.
    d. At the study location, north of Bonners Ferry, during the time of the study, the warning signs only result in relatively small reductions in vehicle speed under some circumstances. The absolute vehicle speeds were too high for most drivers to be able to stop in time for a large mammal on the highway. Therefore, consider experimenting with advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) or lower in association with activated warning signs.
    e. Consider installing informational signs at the beginning and end of the detection zone: "START DETECTION ZONE" and "END DETECTION ZONE."
5. The components of animal detection systems (all types) continue to improve (e.g., hardware, software). Therefore, system reliability and the equipment's level of sophistication of this and other

systems will likely become higher in the future. Consider upgrading components when better equipment becomes available.

Regardless of the location, and regardless of the type of animal detections system, the researchers recommend considering the following in association with potential future research activities:

1. When video images are used to investigate the reliability of an animal detection system, ensure that the camera view includes the entire detection zone. At the study location, north of Bonners Ferry, during the time of the study, the thermal camera did not cover the entirety of the detection zone. Should the entire detection zone have been covered by the thermal camera, the “possible false positives” would have been classified as either “false positives” or “correct detections”.
2. Investigate what type of warning sign (e.g., message, symbols) may be most effective in having drivers avoid a collision with large mammals (through either reduced vehicle speed, greater alertness, or a combination of the two). For example “Caution, animal detected”.(13)
3. Investigate the effectiveness of advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) or lower when the warning signs are activated.
4. Continue to document wildlife-vehicle crashes and large mammal carcasses. Many years of data are required for an individual location with an animal detection system to generate sufficient data. This is because the road length covered by an animal detection system is typically very short, e.g., a few hundred yards. In addition, consider installing additional animal detection systems at other locations and use the collision data from multiple locations to conduct meta-analyses. This will allow for a more rapid assessment of the effectiveness of the systems in reducing large mammal-vehicle collisions compared to studying one system only along a relatively short road section. Note that, in this context, there is an advantage to keeping the system at the same location north of Bonners Ferry as there is already a few years of crash and carcass removal data available after the system was installed.
5. Increase the spatial accuracy for crash and carcass data, specifically around the edges of the detection area. It should always be clear whether a collision occurred inside or just outside the road section covered by the animal detection system.

# Chapter 1
# Introduction

## Background

In the United States the total number of deer-vehicle collisions was estimated at between 1 and 2 million per year, and that number is increasing.[1,2] These collisions not only lead to substantial property damage, but also cause human fatalities, human injuries, the death of individual animals and the loss of associated economic values, and detrimental effects on the population level of certain species.[3,4,5] Over 40 different mitigation measures have been implemented or described to reduce animal-vehicle collisions.[2] However, except for wildlife fencing, with or without safe crossing opportunities for wildlife, and animal detection systems, these measures appear to be largely ineffective or only marginally effective in reducing collisions.[6,7,8,9,10,11,12]

Animal detection systems are designed to detect large animals as they approach the road (e.g., deer (*Odocoileus sp.*), elk (*Cervus canadensis*) and/or moose (*Alces alces*)). When an animal is detected, signs are activated that warn drivers of large animals on or near the road (Figure 1). Starting in 1993, animal detection systems have been installed at dozens of locations throughout Europe and North America.[9] Some of these systems have been found to be reliable and/or effective in reducing animal-vehicle collisions, whereas other projects have been abandoned because of technical problems, management problems, or changes to the road or surrounding landscape.[9,12,13]

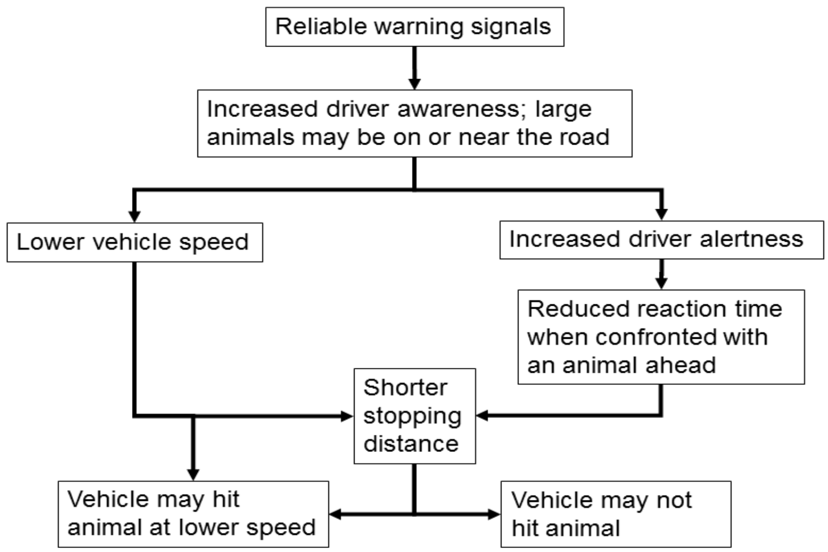



**Figure 1. Warning Signs Must Be Reliable Before They Can Be Effective.**

To reduce the number of animal-vehicle collisions, animal detection systems need to detect animals reliably, and they also need to influence driver behavior so that drivers can avoid a collision. Most animal detection system technologies are vulnerable to “false negatives” and “false positives.” False negatives occur if an animal approaches, but the system fails to detect it. False positives occur if the system reports the presence of an animal, but no animal is present. Keeping false positives and false negatives to a minimum is important as drivers are expected to respond to the warning signals. Once an animal detection system reliably detects the target species and the warning signals and signs are activated, driver response determines how effective the system ultimately is in avoiding or reducing animal-vehicle collisions. Driver response has two components: increased driver alertness and lower vehicle speed. A higher state of alertness of the driver, lower vehicle speed, or a combination of the two can result in reduced risk of a collision with the large animal and less severe collisions. Reduced collision risk and less severe collisions mean fewer human deaths and injuries, and less property damage. In addition, fewer large animals are killed or injured on the road without having been restricted in their movements across the landscape and the road. Furthermore, fewer large dead animals need to be removed, transported, and disposed of by road maintenance crews.

Animal detection systems and wildlife fences combined with wildlife crossing structures can be similarly effective in reducing large mammal-vehicle collisions.(5,12) However, while well designed, constructed and maintained wildlife fences and crossing structures, can reduce collisions with large mammals 80-100%, the range of effectiveness of animal detection systems is much wider (33-97%).(5, 7,12) The initial costs associated with an animal detection system can be lower than that for wildlife fences combined with wildlife underpasses and overpasses.(5) However, since the life span of animal detection systems is projected to be much shorter than the life span of wildlife fences and concrete crossing structures, the long term costs of animal detection systems is higher.(5) An advantage of animal detection systems is that they can be installed relatively quickly while crossing structures typically require major road reconstruction.(12) From an ecological point of view animal detection systems do not reduce the barrier effect of highways, but in contrast to fences in combination with crossing structures, they do not restrict where wildlife can cross a road. (12)

In late 2013, the Idaho Department of Transportation (ITD) District 1 installed a Doppler radar-based animal detection system along U.S. Hwy 95 in Boundary County, Idaho.  The district installed the system with the aim to improve highway safety and identify cost-effective options to reduce wildlife-vehicle collisions. ITD was specifically interested in assessing the performance of the system and determining if it could be a possible alternative to wildlife fences and crossing structures on two-lane rural roads with an annual daily traffic volume of a few thousand vehicles per day.(12) Animal detection systems are considered undesirable for high traffic volume roads (e.g., 10,000-15,000 vehicles per day or higher).(12) The system was originally installed south of Bonners Ferry in December 2013. However, the system was moved to its current location, north of Bonners Ferry, in April 2014. The district requested research funding to study the performance of the system at the location north of Bonners Ferry. The Western Transportation Institute at Montana State University (WTI-MSU) was selected to study system performance.

This manuscript reports on the reliability and effectiveness of this animal detection system at the location north of Bonners Ferry. The reliability of the system was measured through its ability to detect large wild mammals and distinguish these animals from other species, moving vehicles and other situations that might also cause detections. The effectiveness of the system was measured through measuring potential reductions in vehicle speed in response to activated warning signs.

## Goals and Objectives

The goal of the current project was to investigate the reliability and effectiveness of the animal detection system installed along U.S. Hwy 95, north of Bonners Ferry, Boundary County, Idaho. The specific objectives were:

- Verify basic system functioning and research equipment with the Idaho Department of Transportation (ITD)/manufacturer.
- Measure the reliability of the system in detecting large mammals (deer size and larger).
- Measure the effectiveness of the system in reducing vehicle speed.
- Measure the effectiveness of the system in reducing collisions with large wild mammals.
- Discuss the reliability and effectiveness of the system through a comparison with results from similar projects with animal detection systems.
- Analyze driver and large mammal behavior to gain insight into how large mammal-vehicle collisions occur and how they may be reduced.

## Tasks

Tasks for the current project included:

1. Verify basic system functioning and research equipment with ITD/manufacturer through e-mail and telephone communication, and a site visit.
    a. Verify detection area (start and end).
    b. Verify installation date and start (and potential end) date of the animal detection system and the warning signs (i.e., when was the animal detection system with the driver warning signs fully operational).
    c. Verify the duration of the warning signs.
    d. Verify the location, number, and type of the warning signs.
    e. Verify how the detection system works.
    f. Verify how the video system associated with the detection system works.
    g. Verify what data are collected on vehicles by the system.
    h. Obtain potential historical data on vehicle speed in the road section with the animal detection system before the system was installed (may not be available).

2. Measure the reliability of the system in detecting large mammals (deer size and larger).

a. Verify that the system is operational (basic functions at a minimum, see Task 1).
b. Conduct a walk-through test with a human as a model for large wild ungulates (deer size and larger). The researchers will cross the road and detection area at fixed distances (e.g., every 10 or every 25 m). The researchers will record the date and time for each crossing, wait a few minutes for the system to reset (check time with manufacturer), and then cross again 10 or 15 m further down the road. The researchers will then cross reference the field notes on the crossings with the video that should have been recording as the system should have detected people. This allows for the identification of correct detections (i.e., a target species (human) was present and was detected by the system) and potential false negatives (i.e., a target species (human) was present but was not detected by the system).
c. Normally, video images are only available after a detection has occurred. However, the system is capable of recording and storing video images continuously, independent of whether a detection has occurred. The researchers will use the video images to check for correct detections and potential false positives (i.e., no target species present, but the system reported a detection). False negatives (i.e., target species present, but the system did not report a detection) can occur at any time. The researchers will investigate system reliability for 10 consecutive days in each season. The researchers will randomly select 3 hours per day (120 hours in total (3 hours per day, 7 days per season, 4 seasons) and review these selected hours for potential false negatives. The four seasons (spring, summer, autumn, winter) allow for a wide range of environmental conditions that may influence the reliability of the system.

3. Measure the effectiveness of the system in reducing vehicle speed.
   a. ITD will install vehicle speed recording equipment in the road sections before the system, at the system, and after the system for both travel directions. The equipment should be the same at all three locations (e.g., ½ mile north of system, in middle of road section with system, ½ mile south of road section with system). Final locations will be decided after field visit by researcher and ITD personnel. Ideally, the equipment uses a technology that can measure vehicle speed in a wide range of weather and road conditions, including a snow-packed road with snow plows passing by (e.g., pole-mounted radar). The equipment should record the date, time, travel direction, and vehicle speed of all individual vehicles. The speed measurement equipment should be installed for 10 continuous days per season.
   b. The researchers suggest manipulating the signs for 1 hour at a time under different road and weather and visibility conditions, and to "force" obtaining a sufficient sample size from vehicles that were exposed to activated signs under different conditions. By limiting the "warning signs forced on" for 1 hour per 24 hours, the researchers expect to not desensitize the drivers who are exposed to the warning signs. The remaining 23 hours in a day should be largely without detections (i.e., the vehicle speed data relate to "no activated warning signs). The researchers will work with ITD and the system manufacturer to synchronize the date and time of the equipment. Nonetheless, the researchers propose to always have a margin (e.g., at least 5 minutes) around periods with or without detections (a minimum of 1-hour-long bouts for both "with signs continuously activated" and "no detection occurred, thus no sign was activated") to minimize potential noise in the data. The "forced lights on" 1 hour per day

may be on a random schedule which should include a range of visibility conditions (e.g., day vs. night).

c. Vehicle speed data collected by the animal detection system. The researchers assume that vehicle speed data are available for individual vehicles as they travel through the road section with the system. The researchers may use these data to better understand the speed data collected by the ITD equipment. However, the ITD equipment will be the main source of data for speed measurements.

4. Measure the effectiveness of the system in reducing collisions with large wild mammals.
   The researchers will request crash and carcass removal data from ITD for the test (treatment/impact) road section, both before and after system implementation, and in control road sections with no system (Before-After-Control-Impact (BACI) design). Note that the road section equipped with the system is relatively short and the time after installation may also be relatively short (perhaps 1 year). This means that the researchers may not be able to detect a potential decrease in collisions with large mammals. The low absolute numbers and variable numbers of collisions with large mammals limits the power of the analysis to detect a potential reduction should such a reduction indeed be present. The researchers suggest conducting a BACI study with the available crash and carcass data for this project, but also suggest continuing crash and carcass data collection with similar effort for another 3 to 5 years after the current project has ended. After that time, ITD may decide to have the crash and carcass data analyzed again.

5. Discuss the reliability and effectiveness of the system through a comparison with results from similar projects with animal detection systems.
   The researchers will compare the reliability and effectiveness data of the system with that of other systems and suggested norms for reliability.

6. Driver and deer behavior.
   Analyze driver and large mammal behavior to gain insight in how large mammal-vehicle collisions may occur and how they may be reduced. This analysis would be partially descriptive: analyze a great number of events based on video data and speed data (e.g., 100 events (if available)) to investigate what parameters make sense to measure.

# Chapter 2
# Detection System and Research Equipment

## Location of the System and the Detection Area

The animal detection system was located along U.S. Hwy 95 (mile reference post 514.49), about 4.1 mile (6.6 km) north of the junction with U.S. Hwy 2 north of Bonners Ferry, Idaho (Figure 2). The system was installed at this location in April 2014. The system was originally powered through a gas generator. Because of limited operation budget, the generator sometimes ran out of gas, and at other times there was no budget available to purchase gas. The generator needed to be filled with gas about once per month (Pers. Com. Brice Sloan, Sloan Security Technologies). Therefore, the system was intermittently in operation until July 2015, when it was connected to the electric grid. In early September 2015, the radar malfunctioned. A new radar was installed on 2 October 2015, and since then the system has been in continuous operation. Reliability and effectiveness data were only collected after these modifications and improvements. The manufacturer of the system (i.e., Brice Sloan, Sloan Security Technologies) continuously monitored the functionality of the system during the research period.

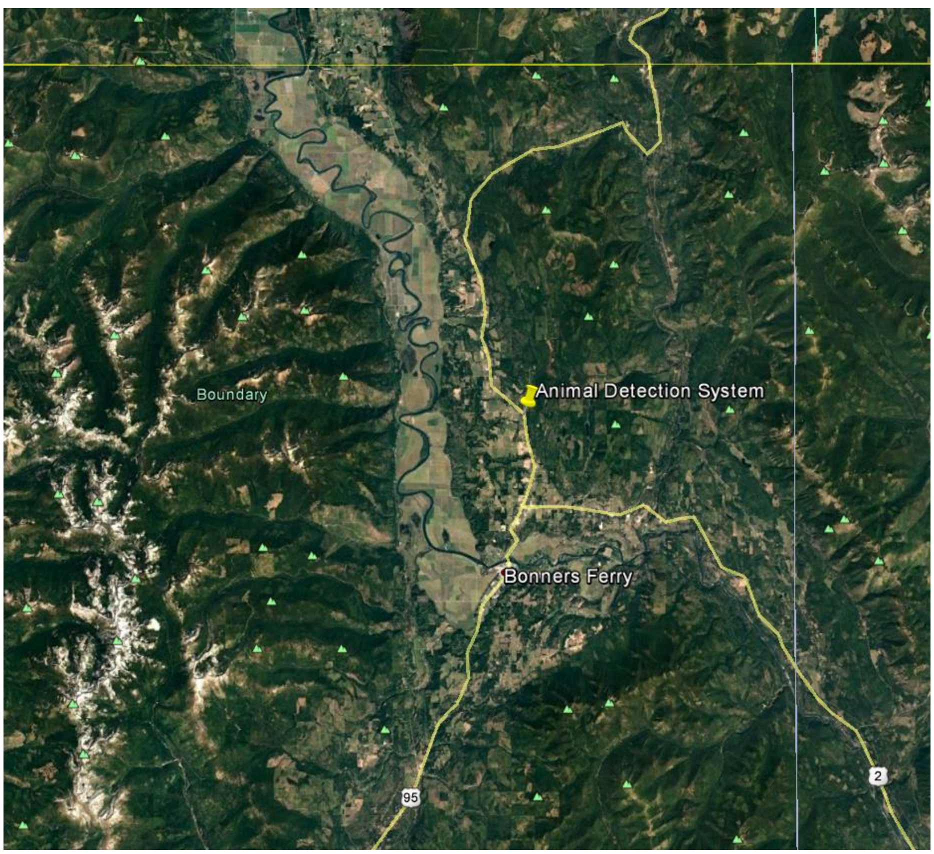



**Figure 2. The Location of the Animal Detection System.**
**Along U.S. Hwy 95, North of Bonners Ferry, Boundary County, Idaho.**

The system used a Doppler radar to detect large mammals along a 371 ft (113 m) long road section (Figure 3). The detection area was between 22 and 37 m wide and included the paved road and a zone adjacent to the paved road. However, the Doppler radar can be programmed to detect large mammals over much longer distances (about 1312 ft (400 m); Pers. Com. Brice Sloan, Sloan Security Technologies).


**Figure 3. The Location of the Doppler Radar System and the Detection Area.**

## Doppler Radar, Thermal Camera, and Detection Data

The sensor that detected large mammals consisted of one Doppler radar mounted on a 24 ft (7.3 m) pole (Pers. Comm. Brice Sloan, Sloan Security Technologies, Inc.) (Figure 4). The height allowed the sensor to "look over" semi-trucks to detect large animals on both sides of the highway and on the road, for several hundreds of meters, even if vehicles were on the road. The high location of the Doppler radar also reduced the risk of theft, vandalism or accidental damage and certain types of false alarms (e.g., caused by spray from snow plows).

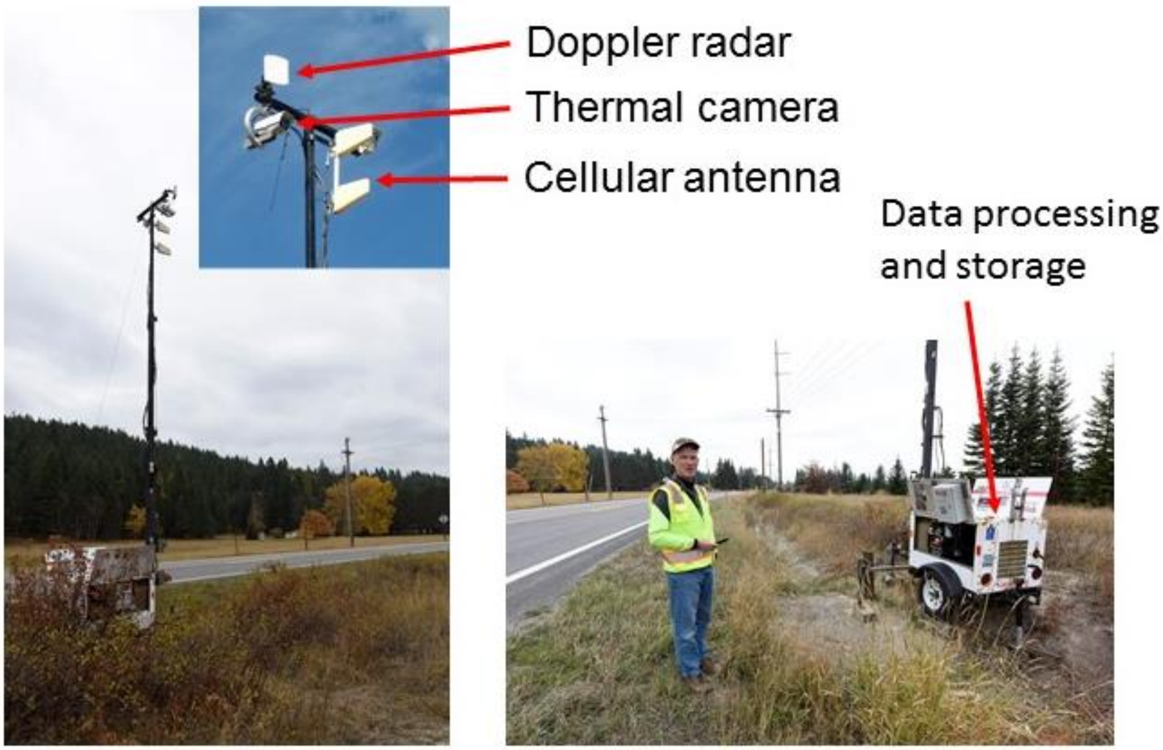
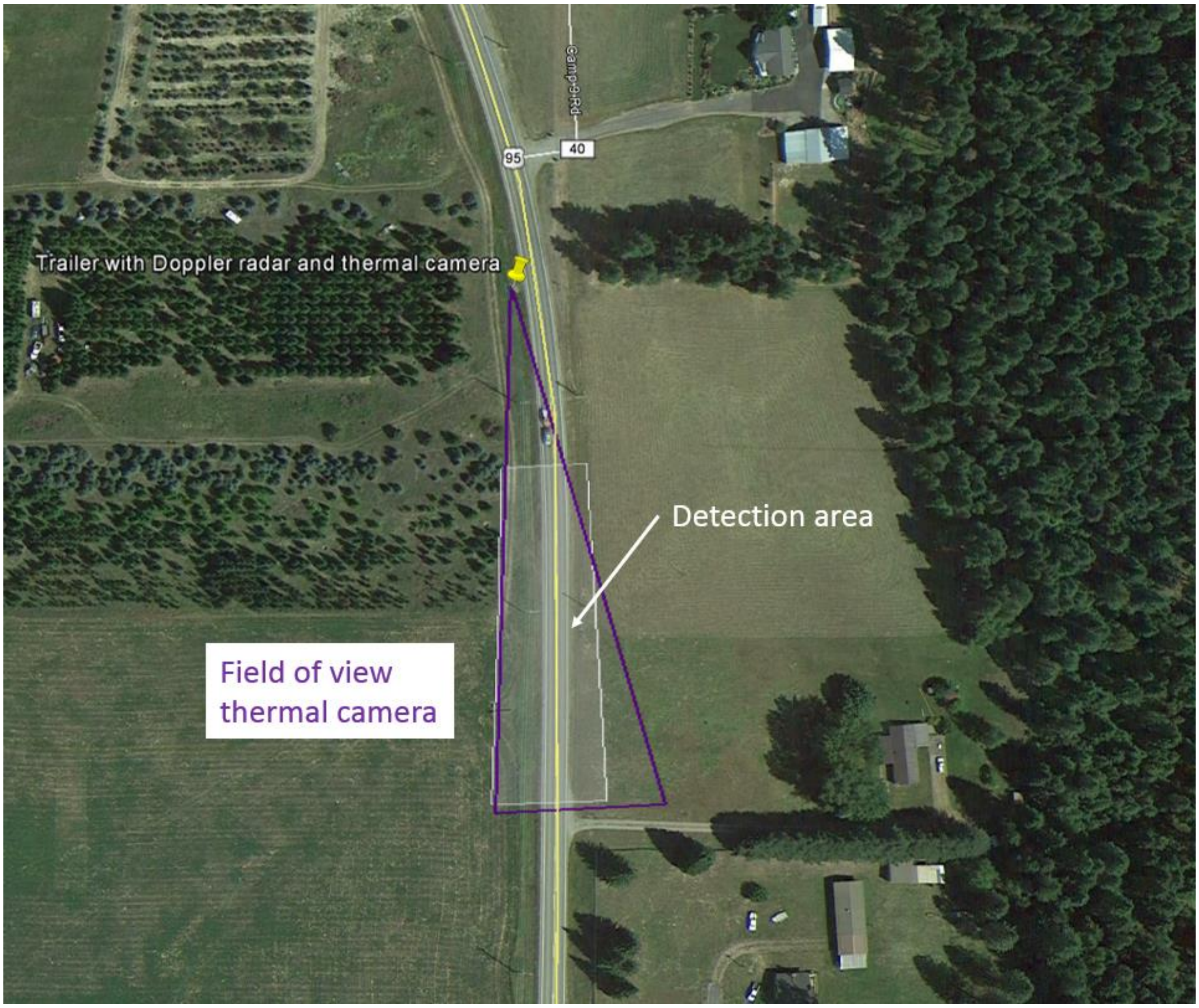



**Figure 4. Detection and Research Equipment.**

The Doppler radar and associated software distinguished between large mammals and other objects (including vehicles) based on several parameters related to the reflecting radar signals and associated thresholds. These parameters included the size of the object, speed, and the direction of the movement (Pers. Comm. Brice Sloan, Sloan Security Technologies, Inc.). Large mammals (e.g., white-tailed deer, mule deer, elk, and moose), pedestrians and bicyclists all fitted the profile for large mammals and should also result in a detection. A vehicle turning around or parking on the roadway (not normal vehicle behavior) may also set off the warning system under some conditions. Vehicles turning off and on the highway at the driveway (southeast of the detection area) were always filtered out during the day.

To evaluate the reliability of the radar in detecting large mammals, a thermal video camera was used to monitor wildlife in and around the detection area (Figure 5). Note the two small areas that were part of the detection area that were not covered by the thermal video camera (a narrow strip west of the highway and a small area in the northwest corner of the detection area (Figure 5). Every detection by the system was associated with a thermal image (1 image every 3 seconds) when the radar was detecting an object that matched the “large mammal” profile (Pers. Comm. Brice Sloan, Sloan Security Technologies, Inc.). The images of the thermal camera were continuously recorded and temporarily saved. When a detection occurred, the images were saved starting 3 seconds before the detection and ending 3 seconds after the detection. The video images had a date and time stamp, and also showed whether the Doppler radar detected an object that was presumably a “large mammal” (Figure 6). This method eliminated potential errors in measuring the reliability of the system because of clock synchronization issues. Note that the thermal camera can also be programmed to record continuously during certain periods and save these recordings independent of whether a detection occurred.




Note: Detection area delineated by the white line, thermal camera view delineated by the purple line.

**Figure 5. The Detection Area of the Doppler Radar and the Thermal Video Camera.**

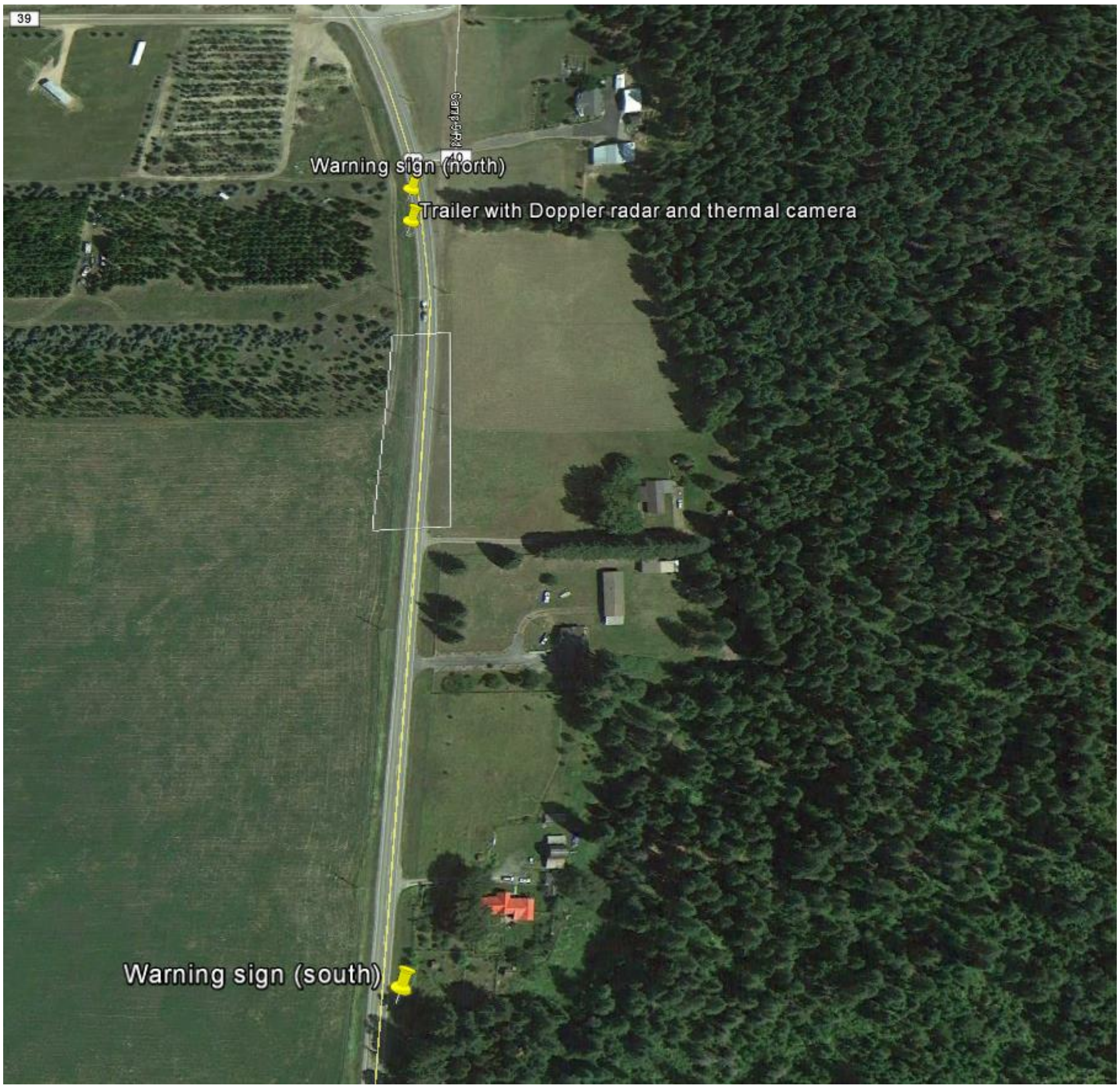

Note: The image shows deer on and near the road. The date, time, and whether the radar is detecting a "large mammal" is imprinted on the video images.

**Figure 6. Screen Shot of Deer from a Video Recorded by the Thermal Camera.**

The system was designed for remote locations. The detection log of the system could be accessed remotely through a cellular network (Figure 4). The system could also receive commands through a cellular network (Figure 4). However, data were also stored in the trailer (Figure 4). Long periods of continuous video of the thermal camera were best downloaded at the trailer, as the files were very large compared with the capacity of the cellular network. The system was designed to be mobile; the equipment was mounted on a trailer. However, the system does need to be calibrated to accommodate the specific conditions of each site. A generator was associated with the trailer, allowing the system to be operational in areas where there is no electric grid. However, at the current location, the system was hooked up to the electric grid. This resulted in more reliable power and reduced operation and maintenance effort (e.g., not having to refuel the generator on a regular basis).

## Warning Signs and Speed Radars

When the system detected a “large animal”, warning signs were activated. There were two warning signs: one was located 285 ft (87 m) north of the detection area (northern edge, mile reference post 514.45) for sound bound traffic, and one was located 735 ft (224 m) south of the detection area (southern edge, mile reference post 514.38) (Figures 7, 8) for north bound traffic.




Note: The detection area covered by the Doppler radar is delineated by the white line.

**Figure 7. The Detection Area and the Location of the Two Warning Signs.**

The warning signs displayed the text “GAME CROSSING” (always visible), and an amber flashing light was present above each warning sign. The amber flashing lights were activated only when detection of a “large mammal” was ongoing, and it remained on for about 40 seconds after the detection stopped. Should another detection occur before the 40 seconds were up, the clock resets and the amber lights remained active until 40 seconds after the last detection. The amber flashing light was “off” when there was no ongoing detection of a “large mammal” or if at least 40 seconds had passed since the last detection. The warning lights were activated through radio signals (2.4 GHz). The northern light was hooked up to the electric grid, but the southern light was powered by a solar panel and a battery.


**Figure 8. The Warning Signs.**

Drivers were informed about the detection zone and associated warning signs through signs stating “WILDLIFE DETECTION TEST AHEAD” (Figures 9 and 10). The southern informational sign (mile reference post 513.62) was located 3,248 ft (990 m) south of the southern warning sign. The northern informational sign (mile reference post 515.22) was located 3,773 ft (1,150 m) north of the northern warning sign.

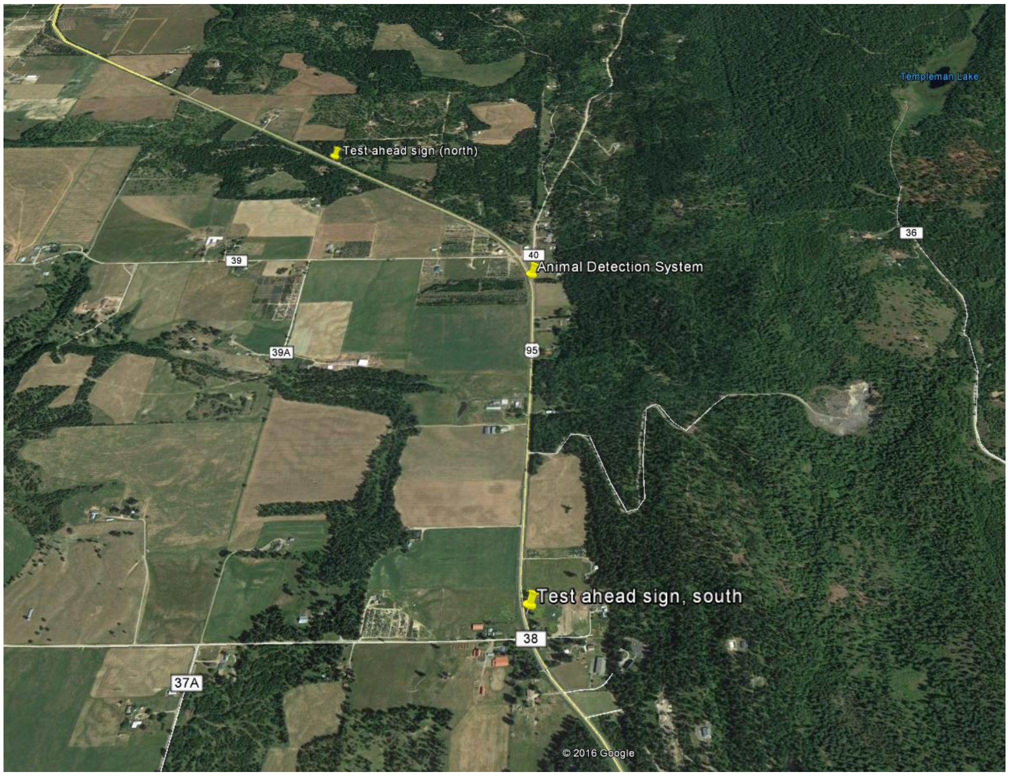
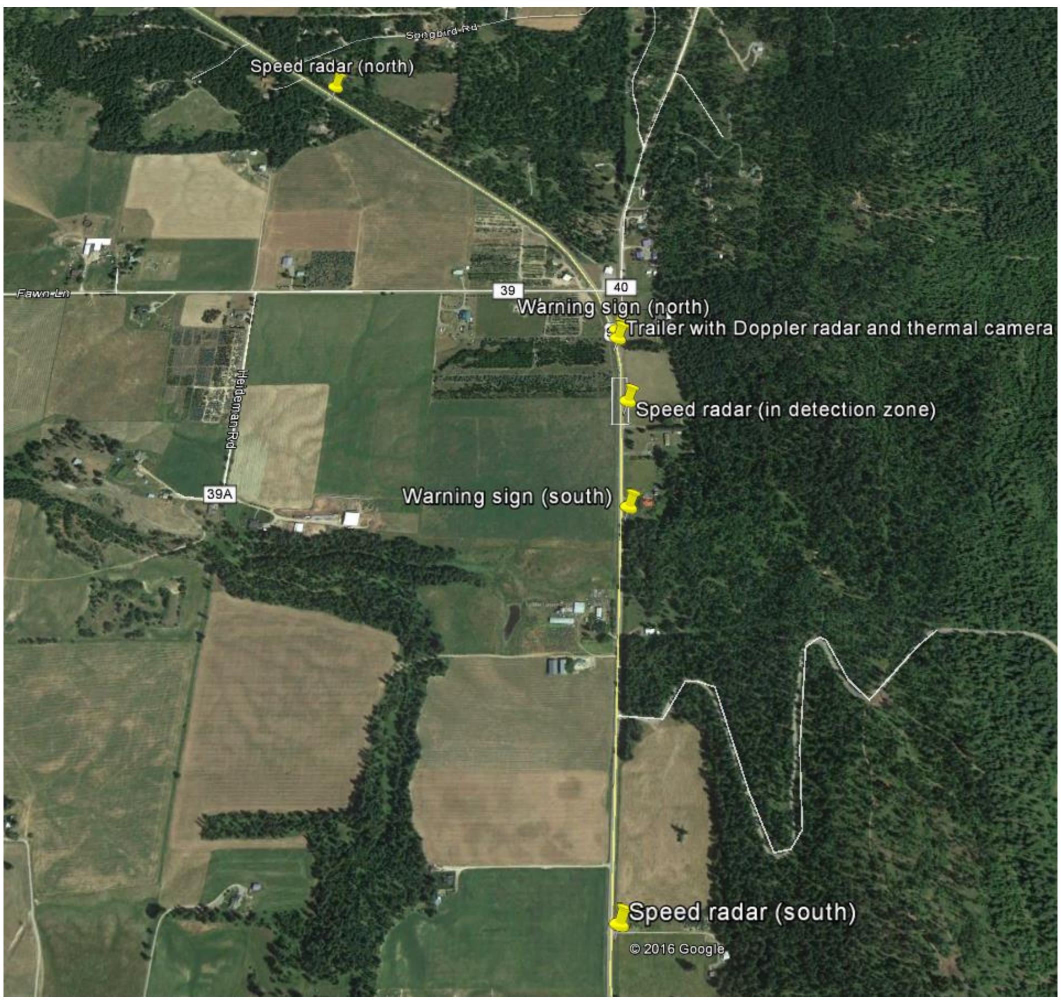



**Figure 9. The Location of the Signs Stating, "WILDLIFE DETECTION TEST AHEAD."**


**Figure 10. The Southern Sign Stating, "WILDLIFE DETECTION TEST AHEAD".**

Three speed radars were installed to record the speed of individual vehicles. The speed radars were installed 0.62 mile (997 m) north of the northern warning sign, inside the detection area, and 0.51 mile (814 m) south of the southern warning sign (Figure 11). The three speed radars recorded the speed of individual vehicles and distinguished between the northbound and southbound lanes. The northern and southern speed radars measured the speed of vehicles before and after the warning signs and detection zone. The distance between these two radars and the warning signs was at least 0.5 mile (800 m). This distance was far enough to assume that the warning signs did not influence the speed of the approaching vehicles at the northern and southern speed radars. It is also likely that vehicles just passing the detection area and associated warning signs would have been able to regain normal operating speed. The distance between the southern warning sign and the central speed radar in the detection zone was 804 ft (245 m). The distance between the northern warning sign and the central speed radar in the detection zone was 590 ft (180 m).




Note: Also shown are the warning signs and the detection zone (delineated by the white line).

**Figure 11. The Location of the Northern, Central, and Southern Radar.**

# Chapter 3
# Reliability

## Introduction

This chapter reports on the reliability of the animal detection system. The reliability of the system relates to the detection of large mammals, especially deer (*Odocoileus* spp.) and elk (*Cervus canadensis*).

## Methods

### Walk-Through Test

On 16 August 2016, a walk-through test was conducted. A person crossed the highway and adjacent right-of-way at 32.8 ft (10 m) intervals through the entire length of the detection area. A second person monitored the system to verify that the Doppler radar detected the person on each pass and that the warning lights were activated when the person was on the paved highway surface.

### Seasonal Reliability Tests

Temperature, precipitation, wind, and other physical parameters can influence the reliability of animal detection systems.[11] Therefore, the researchers conducted reliability tests in four different seasons (Table 1). Each reliability test lasted 10 days. For each test day, the researchers randomly selected three hours and reviewed the images of the thermal cameras. This resulted in the review of 120 hours of video (3 hours per day, 30 hours per season).

**Table 1. The Four Seasons and Associated Dates for the Reliability Tests.**

| Season | Start date | End date | Hours analyzed (n) |
|---|---|---|---:|
| Fall 2015 | 24 Nov 2015 | 3 Dec 2015 | 30 |
| Winter 2016 | 22 Feb 2016 | 2 Mar 2016 | 30 |
| Early summer 2016 a | 1 Jun 2016 | 3 Jun 2016 | 10 |
| Early summer 2016 b | 4 Jul 2016 | 11 Jul 2016 | 20 |
| Summer 2016 | 2 Aug 2016 | 11 Aug 2016 | 30 |

The researchers investigated the reliability of the animal detection system by reviewing 120 hours of continuous video recorded by the thermal camera (see Table 1). This effort allowed the researchers to identify:

1. Correct detections: The radar reported a detection and there was a mammal present. In our case, we classified the detection of any mammal ((i.e., including domestic dog or domestic cat) or person (e.g., walking or cycling) as a correct detection. Note that one animal may be detected multiple times while it is in the detection zone.

2. Possible false positives: The radar reported a detection and there was no (large) animal (i.e., any mammal species) to be seen on the thermal video images. In our case, two parts of the detection area were not covered by the thermal camera (see Figure 5). This means it was possible for an animal to be present in the detection area without being visible on the video images. Therefore, we used the term “possible false positive” rather than “false positive.”

3. False negatives: The radar did not report a detection, but there was a large animal (i.e., deer size or larger) present in the detection area and it had set foot on the paved highway. If an animal was present in the detection area but did not set foot on the paved highway, it could not result in a false negative.

Note that deer (*Odocoileus* spp.) are by far the most frequently reported road-killed species (97 percent) along the highways in the region.[14] Elk (*Cervus canadensis*) and moose (*Alces americanus*) each represent between 1 and 2 percent of all reported road-killed species.[14]

The researchers investigated potential differences in radar detection patterns between “correct detections” and “possible false positives.” The similarity or dissimilarity in the detection patterns may provide insight into the likelihood that “possible false positives” were either “false positives” or “correct detections.”

## Results

### Walk Through Test

The Doppler radar detected a person each time the person crossed the highway at 32.8 ft (10 m) intervals. The warning lights were always on when the person was on the paved surface of the highway. No “blind spots” were present in the detection area.

### Seasonal Reliability Tests

Over the course of 120 hours, there were 201 radar detections (an average of 1.68 detections per hour) (Table 2). At least 75.62 percent of these detections were “correct detections” and 24.38 percent of the detections were classified as "potential false positives (Table 2). The system did not detect two of the 81 large mammals (deer and elk) observed on the paved highway surface (2.47 percent false negatives) (Table 2). Note that not all large mammals that were detected in the detection area ended up on the actual highway. In addition, one animal could be detected multiple times while it was present in the detection area.

**Table 2. The Values for the Reliability Parameters for the Animal Detection System.**

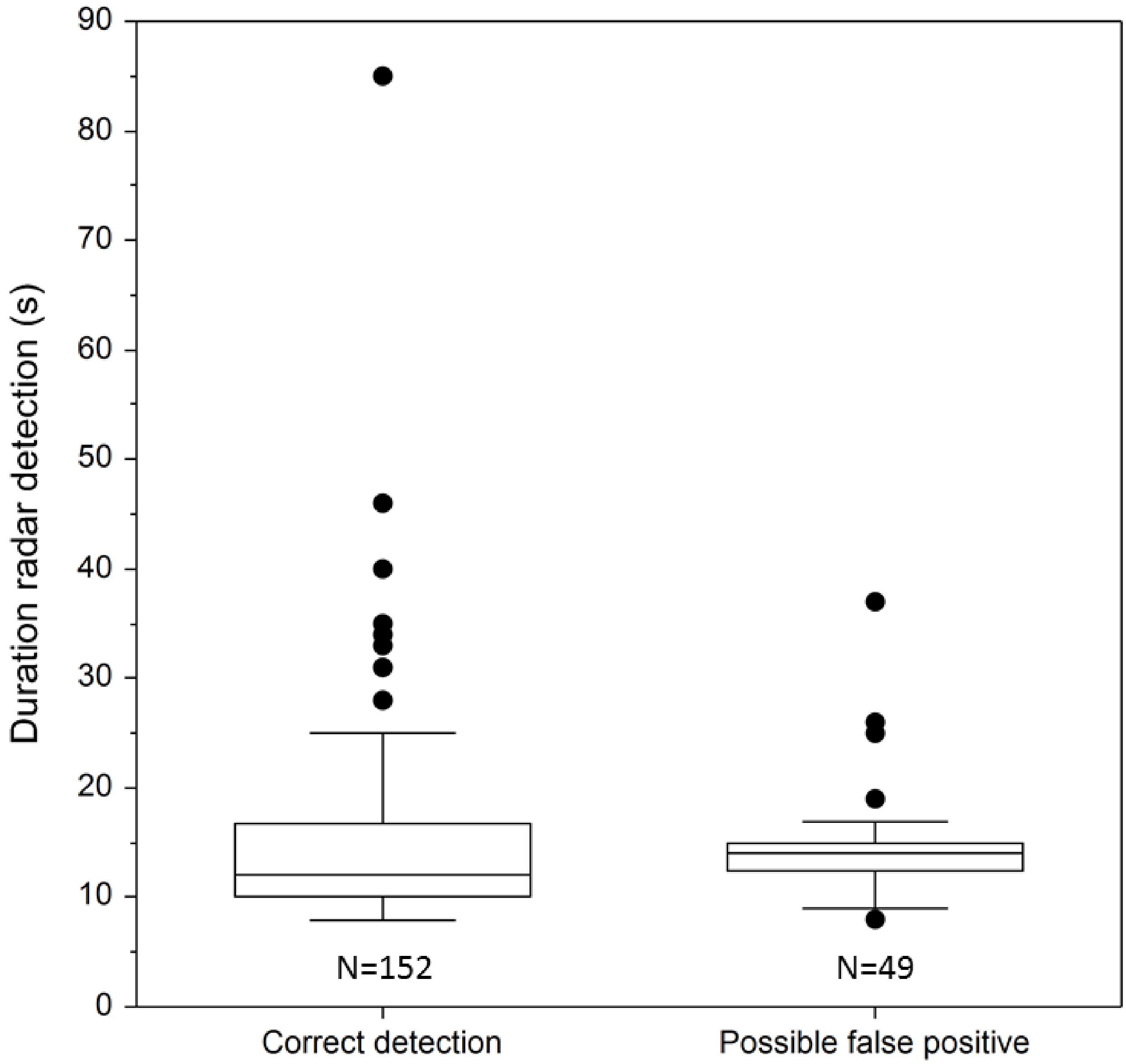
| Session | Total radar detections (n) | Correct detections (n) | Possible false positives (n) | | Large mammals on road (n) | False negatives for large mammals (n) |
|---|---|---|---|---|---|---|
| Fall 2015 | 83 | 63 | 20 | | 24 | 1 |
| Winter 2016 | 34 | 27 | 7 | | 29 | 0 |
| Early summer 2016 | 41 | 29 | 12 | | 11 | 0 |
| Summer 2016 | 43 | 33 | 10 | | 17 | 1 |
| | | | | | | |
| Total (n) | 201 | 152 | 49 | | 81 | 2 |
| Total (%) | 100.00 | 75.62 | 24.38 | | 100.00 | 2.47 |

The "correct detections" related mostly to deer and elk (Table 3). However, humans (on foot, on bicycle) and smaller species (e.g., domestic dogs, domestic cats, wild turkey) were also detected by the system on several occasions (Table 3). Both "false negatives" related to deer (Table 3).

**Table 3. The Species that were Correctly Detected or not Detected by the System.**

| Species | Correct detections (n) | False negatives (n) |
|---|---|---|
| Deer (*Odocoileus* spp.) | 112 | 2 |
| Elk (*Cervus canadensis*) | 23 | |
| Unidentified small species | 7 | 1 |
| Domestic dog | 3 | |
| Possible domestic cat | 2 | |
| Human, on foot | 2 | |
| Human, bicyclist | 1 | |
| Possible coyote (*Canis latrans*) | 1 | |
| Turkey (*Meleagris gallopavo*) | 1 | |
| | | |
| Total | 152 | 3 |

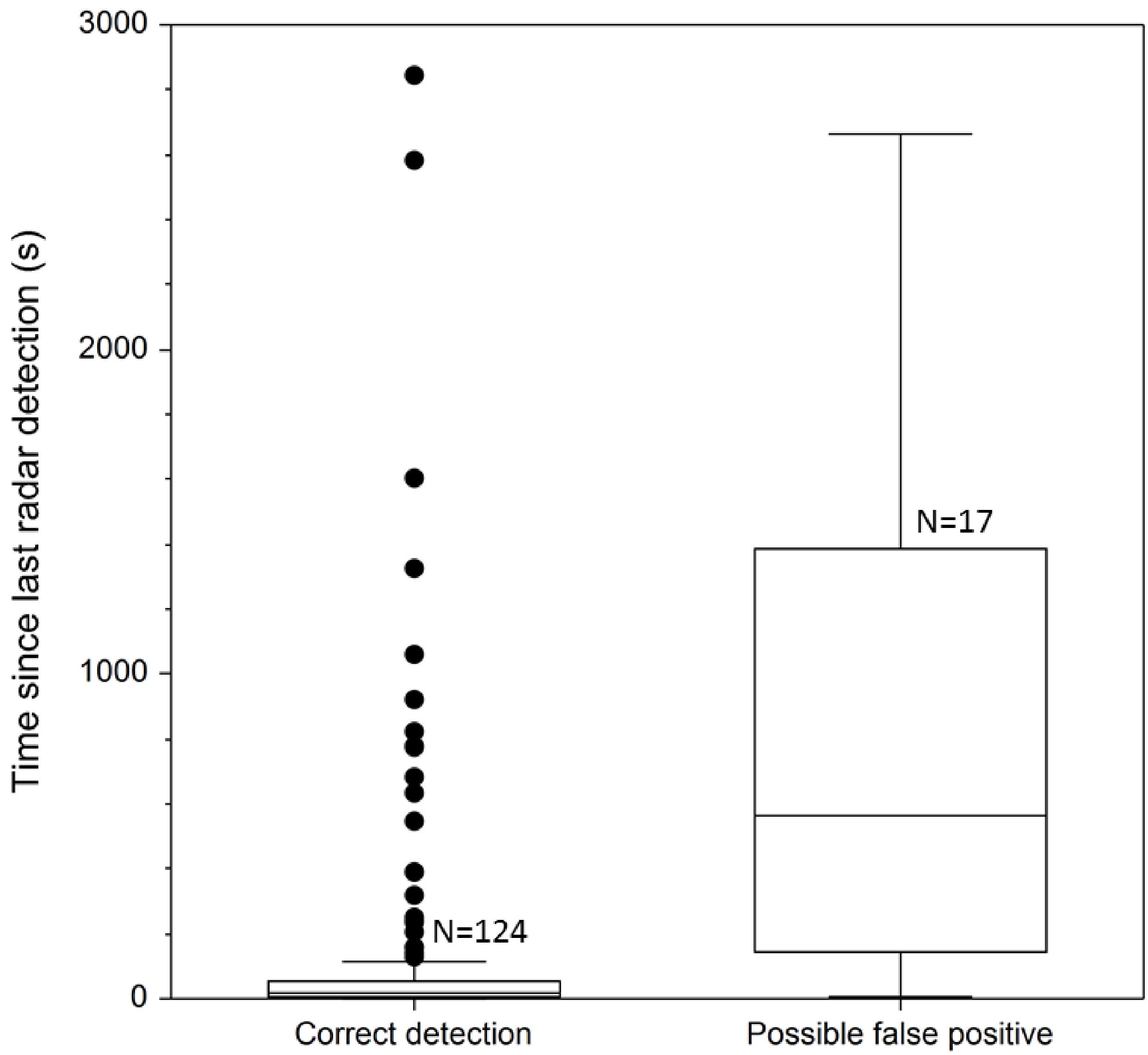
The average radar detection lasted 14.85 seconds (SD = 7.75, N = 201). There was no significant difference between the duration of the radar detections for correct detections and possible false positives (Mann-Whitney U-test, Z-value = 1.270, P = 0.204; Figure 12).




Note: The data relate to correct detections and possible false positives. Box: Middle 50 percent of the data (25–75 quartile); Horizontal line: Median; Whisker boundaries: 1.5 times inter-quartile range; outliers: Over 1.5 times inter-quartile range.

**Figure 12. The Duration of the Radar Detections.**

The researchers investigated potential differences in radar detection patterns between “correct detections” and “possible false positives.” The similarity or dissimilarity in the detection patterns may provide insight into the likelihood that “possible false positives” were either “false positives” or “correct detections.” The average time since the previous radar detection (within the same randomly selected hour) was 236.90 seconds (SD = 535.70, N = 141). There was a significant difference between the time since the previous radar detection for correct detections and possible false positives (Mann-Whitney U-test, Z-value = 4.3171, P < 0.0001; Figure 13). For correct detections, the average time since the last detection was 155.52 seconds (SD = 422.28, N = 124, Median = 16). For potential false positives, the average time since the last detection was 830.47 seconds (SD 845.33, N=17, Median =563).




Note: The data relate to correct detections and possible false positives. Box: Middle 50 percent of the data (25–75 quartile); Horizontal line: Median; Whisker boundaries: 1.5 times inter-quartile range; outliers: Over 1.5 times inter-quartile range.

**Figure 13. The Time Passed Since the Previous Radar Detection.**

With an average of 1.68 radar detections per hour, an average detection duration of 14.85 seconds, and assuming consecutive detections are at least 40 seconds apart and that each detection resulted in the maximum possible time the warning signs could be activated for, the warning signs are activated 1.68*(14.85+40) = 92.15 seconds per hour on average (2.5 percent of the time). However, most radar detections are correct detections that are highly clustered in time (Figure 13). Therefore, the actual time the warning signs are active is likely substantially less than 92.15 seconds per hour.

## Discussion

The walk-through test indicated that the system fully covered the detection zone and that no blind spots were present. The system easily met the minimum norm for false negatives that was suggested as part of another animal detection system project funded by the Federal Highway Administration and the Montana Department of Transportation (2.47 percent vs. the suggested “allowable” maximum of 9 percent false negatives).(11) However, the false positives may be higher than the suggested norm (24.48 percent possible false positives vs. the “allowable” maximum of 10 percent false positives).(11) On the other hand, some, perhaps many, of the “possible false positives” of the system may have been “correct detections.” While “correct detections” were more clustered in time than “possible false positives” this may be an artifact of the location of the two small areas in the detection zone that were not covered by the thermal camera (see Chapter 2); these two areas were on the edge of the detection area which makes it likely that there were no “earlier detections” of the animals concerned. The researchers conclude that the system appears quite reliable in detecting large ungulates, especially considering the small number of false negatives. The total time the warning signs were activated was at the most 92.15 seconds per hour (2.5 percent of the time). Likely, the time was substantially shorter, which suggests that drivers probably will not habituate to the warning signs.

Compared to other systems, the system evaluated for this report had a relatively high percentage of false negatives (Table 4). However, the sample size (2 false negatives) was small, which meant that a difference of just 1 false negative has a substantial impact when calculating the percentage. False positives may or may not have been higher than other systems because the limited view of the thermal camera. Note that most of the other systems were evaluated for their reliability in an enclosure with livestock and that they were not tested along a road with traffic like the system investigated for this report.

**Table 4. Comparison with the Reliability of Selected Other Systems.**

| System | System type | Evaluated along highway? | False negatives (%) | False Positives (%) | Correct Detections | Source |
|---|---|---|---|---|---|---|
| | | | | | | |
| Sloan | Area cover: Doppler Radar | Yes | 2.47 | 0.00-24.48 | 75.62-100.00 | This report |
| | | | | | | |
| Xtralis 7 | Area cover: Passive IR | No | 0.65 | 0.00 | 100.00 | (11) |
| Xtralis 5-6 | Area cover: Passive IR | No | 1.30 | 0.00 | 99.80 | (11) |
| STS I | Break-the-beam: radar | No | 1.61 | 0.00 | 100.00 | (11) |
| STS II | Break-the-beam: radar | No | 0.70 | 0.00 | 100.00 | (11) |
| Calonder Energy I | Break-the-beam: laser | No | 0.02 | 0.60 | 98.91 | (11) |
| Calonder Energy II | Area cover: Passive IR | No | 0.04 | 0.00 | 100.00 | (11) |
| Camrix | Area cover: IR ITS Camera Technology | No | 0.92 | 0.07 | 99.94 | (11) |
| Xtralis 1-2 | Area cover: Passive IR | No | 0.39 | 0.97 | 98.98 | (11) |
| Goodson | Break-the-beam: Active IR | No | 0.00 | 0.82 | 99.22 | (11) |
| ICx Radar Systems | Break-the-beam: radar | No | 0.03 | <0.01 | 99.29 | (19) |
| Electro Braid Fence | Area cover: IR Camera and software | Yes | 1.72 | 4.00 | ? | (13) |
| Senstar Perimitrax® | Buried cable | No | 0.46 | 0.00 | 100.00 | (20) |

Note that it is less acceptable to have false negatives than to have false positives. False negatives result in "no warning, but an animal is on or near the road" which may result in a collision. False positives result in "a warning, but no animal is actually present on or near the road," which may lead to driver habituation, but does not result in a direct and immediate safety threat.

Table 4 distinguishes between area cover, break-the-beam and buried cable systems. Area cover and break-the-beam systems have been used as sensors for animal detection systems since the first animal detection systems were installed in 1993.[9] A buried cable system was first used in in 2000.[9] Area cover systems detect animals within a certain range of a sensor; there is only one sensor at one location required. Break-the-beam systems consist of a transmitter and a receiver. The transmitter transmits a signal that is received by the receiver, and the system is triggered if an object (e.g., an animal) walks through the beam and temporarily blocks the signal for the receiver. Buried cable systems detect large mammals passing over the buried cable through vibrations (geophones) or changes in an electromagnetic field. [6,9] Note that there is no single "best" type of animal detection system. In addition, system reliability can also be influenced by environmental parameters.[11] The authors of this report do not recommend a particular system type or manufacturer. Instead, the researchers emphasize the importance of using minimum norms for system reliability and selecting a system that best fits the specific conditions at a site, including environmental conditions. [11]

# Chapter 4
# Ungulate Behavior

## Introduction

This chapter reports on the behavior of large ungulates on and near the highway section equipped with the animal detection system. The behavior of interest was the time the animals required to cross the highway, and the pace of and potential foraging by the animals as they approached the highway.

## Methods

### Crossing Time

The video images recorded by the thermal camera allowed the researchers to see when the deer and elk were on the paved highway surface. The researchers calculated the time individual animals spent on the paved road surface from the time the first hoof touched the pavement until the last hoof was off the pavement. In addition, the researchers recorded the group size of the animals and the total crossing time for each group. Groups were defined as groups of animals that were detected at least five minutes apart, or groups of animals that had a clearly distinct spatial distribution or direction of travel.

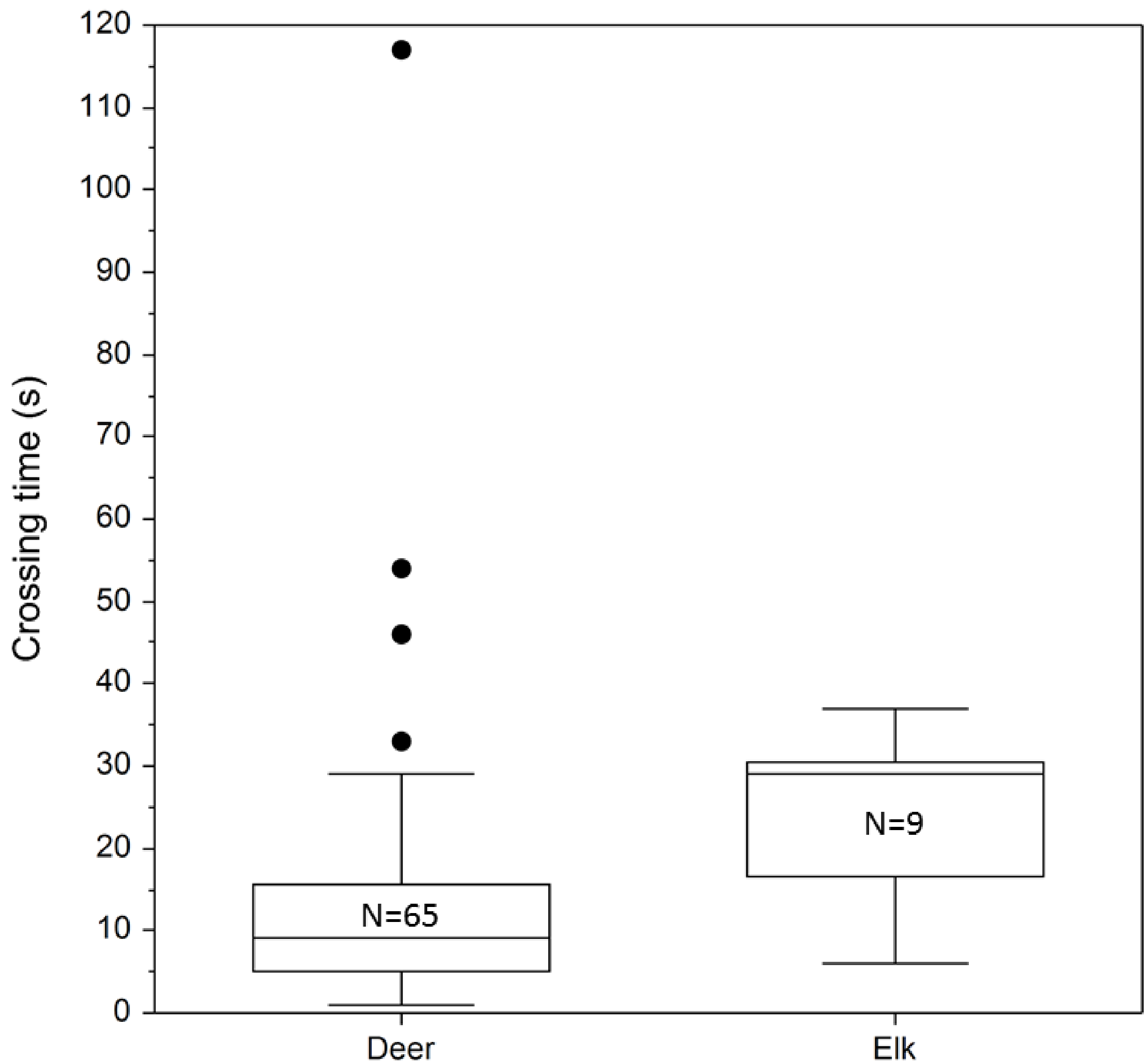
### Pace and Foraging Behavior

The researchers recorded the pace of deer and elk as they approached the highway. Their speed was classified as either “lingering”, “walking”, or “running”. In addition, the researchers recorded whether the deer and elk were foraging or not as they approached the highway.

## Results

### Crossing Time

The average crossing time for large ungulates (elk or deer) that successfully crossed the highway was 14.91 seconds (SD = 16.27, N = 74). There was a significant difference in crossing time for deer and elk (Mann-Whitney U-test, Z-value = 3.1221, P = 0.002; Figure 14). For deer, the average crossing time was 13.60 seconds (SD = 16.62, N = 65, Median = 9). For elk, the average crossing time was 24.33 seconds (SD 9.62, N=9, Median = 29).




Note: The data relate to successful crossings only. Box: Middle 50 percent of the data (25–75 quartile); Horizontal line: Median; Whisker boundaries: 1.5 times inter-quartile range; Outliers: over 1.5 times inter-quartile range.

**Figure 14. The Crossing Time for Deer and Elk.**

The average group size for deer was 2.15 animals (SD = 1.32, N = 27, Median = 2). The average crossing time for a deer group was 50.59 seconds (SD = 129.62, N = 27, Median =16) (Figure 15). No obvious correlation between the size of the deer group and the crossing time for a group was apparent. In two cases, there were extremely long group-crossing times. These long group crossings occurred when traffic was absent. Only two groups of elk were observed, and no group size analysis was conducted.

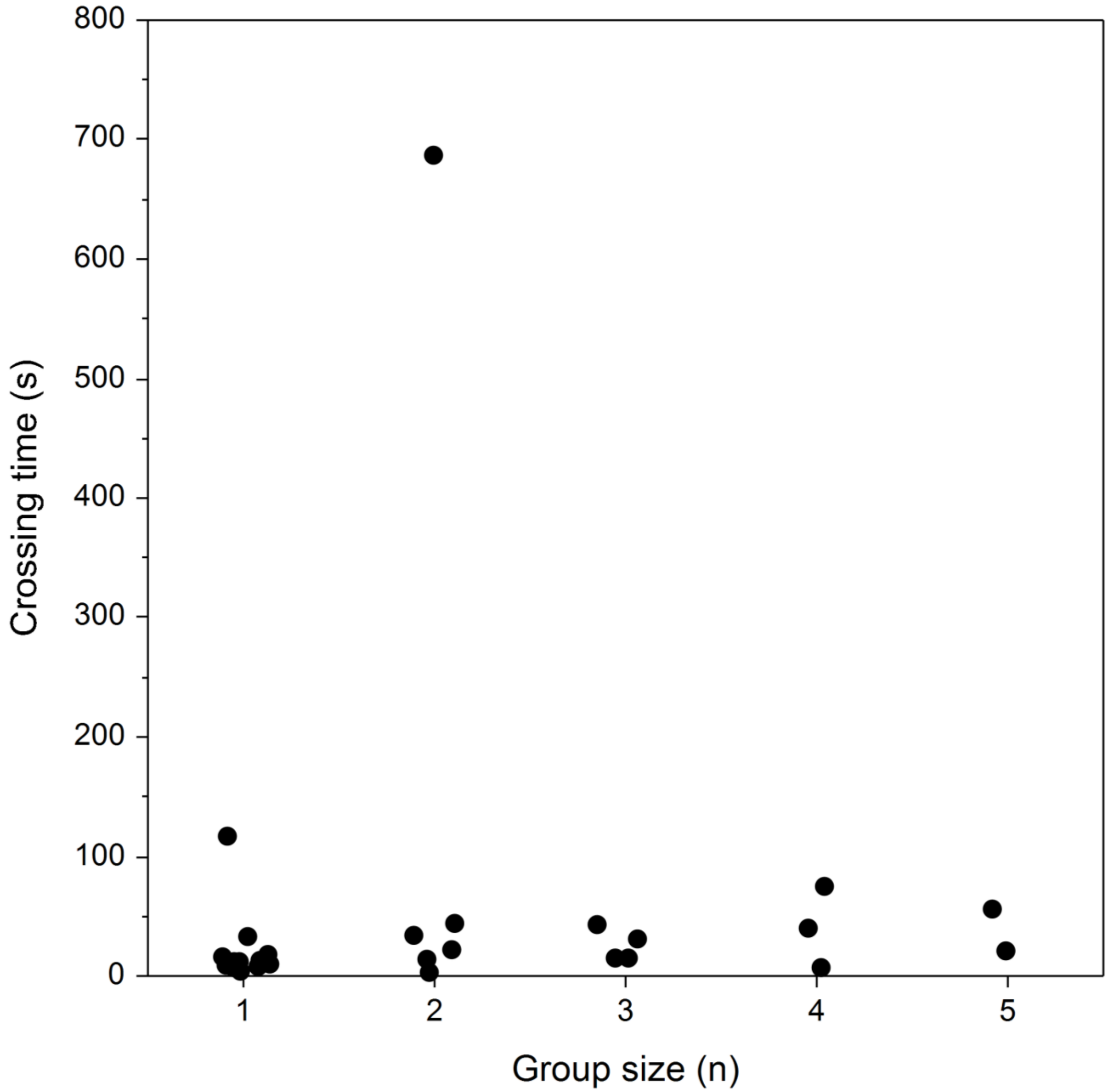



**Figure 15. The Crossing Time for Deer Groups Depending on the Group Size.**

### Pace and Foraging Behavior

Most of the deer that approached the highway walked and were not foraging (79.17 percent) (Tables 5, 6). On the other hand, most of the elk (88.89 percent) lingered as they were foraging (Tables 5, 6).

**Table 5. The Pace of the Deer and Elk as They Moved Towards the Highway.**

| Species | Total | | | Linger | | Walk | | Run | |
|---|---|---|---|---|---|---|---|---|---|
| | N | % | | N | % | N | % | N | % |
| Deer | 72 | 100.00 | | 2 | 2.78 | 57 | 79.17 | 13 | 18.06 |
| Elk | 9 | 100.00 | | 8 | 88.89 | 1 | 11.11 | 0 | 0.00 |

**Table 6. The Foraging Behavior of the Deer and Elk that Approached the Highway.**

| Species | Total | | | Foraging | | Not foraging | |
|---|---|---|---|---|---|---|---|
| | N | % | | N | % | N | % |
| Deer | 72 | 100.00 | | 9 | 12.50 | 63 | 87.50 |
| Elk | 9 | 100.00 | | 9 | 100.00 | 0 | 0.00 |

## Discussion

The average crossing time for large ungulates (elk or deer) that successfully crossed the highway was 14.91 seconds. This time is perhaps surprising, as people usually see animals running away from the highway when they approach in their vehicle. However, especially when traffic is absent, deer and elk may spend a relatively long time on the highway. Note that while elk took longer to cross the highway than deer, this difference may be related to the behavior of the two elk groups rather than a species-specific effect; the elk were lingering and foraging as they approached the highway.

# Chapter 5
# Warning Signs

## Introduction

This chapter summarizes if and how early the warning signs were activated before large ungulates first set a hoof on the pavement. The results have implications for the location and number of warning signs that would be needed to inform drivers sufficiently early.

## Methods

### Activation Warning Signs

The amber flashing lights were activated only when a detection of a "large mammal" was ongoing, and it remained on for about 40 seconds after the detection stopped. Should another detection occur before the 40 seconds were up, the clock resets and the amber lights remained active until 40 seconds after the last detection. This means that it was possible for the warning signs to be "on" without on ongoing detection if the last detection was less than 40 seconds ago. The amber flashing light was "off" when there was no ongoing detection of a "large mammal" or if at least 40 seconds had passed since the last detection.

For the deer and elk on the paved highway surface, the researchers evaluated whether the radar detected the animals at some point when they were on the road surface. In addition, the researchers evaluated whether the warning signs were activated during the entire time the individual animals were on the paved road surface ("entire time"), for part of the time only ("partial"), or "not at all". In some cases, the video images did not show when and where the animals entered or left the pavement ("?"). Note that it was possible for an animal to have been detected by the Doppler radar before it entered the road surface and not while it was on the road surface. This situation could result in "not detected" while on the road surface while the warning signs were still on based on a detection that occurred before the animal entered the road surface (see Chapter 3).

### Warning Time before Ungulates Are on the Pavement

The researchers calculated the time from when deer and elk were first detected to when the animals set their first hoof on the pavement. For deer, the researchers also calculated the percentiles and fitted a Michaelis-Menten function.

### Configuration Warning Signs

The researchers documented the location of the two warning signs (north and south) in relation to the two outer edges of the detection area. The researchers then calculated the travel time between the warning signs and the outer edges of the detection area based on the posted maximum speed limit along the road section with the animal detection system (60 mi/h (96.5 km/h, 26.8 m/s)). Finally, the researchers compared these travel times with the time from when deer and elk were detected to when the animals set their first hoof on the pavement. This comparison showed whether the warning signs were activated sufficiently early for drivers to be able to see and respond to the activated warning signs.

## Results

### Activation Warning Signs

For deer, the radar only detected the animals on the paved highway surface 53 times out of 72 (73.61 percent) (Table 7). For 75.00 percent of the deer, the warning signs were "on" for the entire time the deer was on the pavement (Table 7). For elk, this was 100 percent. For 90.28 percent of the deer, the warning signs were "on" the entire time or for part of the time the deer was on the pavement (Table 7).

**Table 7. The Number of Detected Deer or Elk on the Highway with Activated Warning Signs.**

| Species | Animal at some point detected while on the road surface? | Total | Warning signs "on" while animal was on road surface? | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Entire time | | Partial | | Not at all | | ? | |
| | | N | N | % | N | % | N | % | N | % |
| Deer | Detected | 53 | 41 | 77.36 | 10 | 18.87 | 0 | 0.00 | 2 | 3.77 |
| Elk | Detected | 9 | 9 | 100.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | | | | | | | | | |
| Deer | Not detected | 19 | 13 | 68.42 | 1 | 5.26 | 3 | 15.79 | 2 | 10.53 |
| Elk | Not detected | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | | | | | | | | | |
| Deer | Detected or not detected | 72 | 54 | 75.00 | 11 | 15.28 | 3 | 4.17 | 4 | 5.56 |
| Elk | Detected or not detected | 9 | 9 | 100.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |

### Warning Time before Ungulates Are on the Pavement

The average time between detecting a deer and that deer setting its first hoof on the pavement was 35.35 seconds (Figure 16; Table 8). For elk, the average time was 268.44 seconds (Figure 16; Table 8). For fifty percent of deer crossings, drivers had a warning time of at least 15.5 seconds (Figure 17).

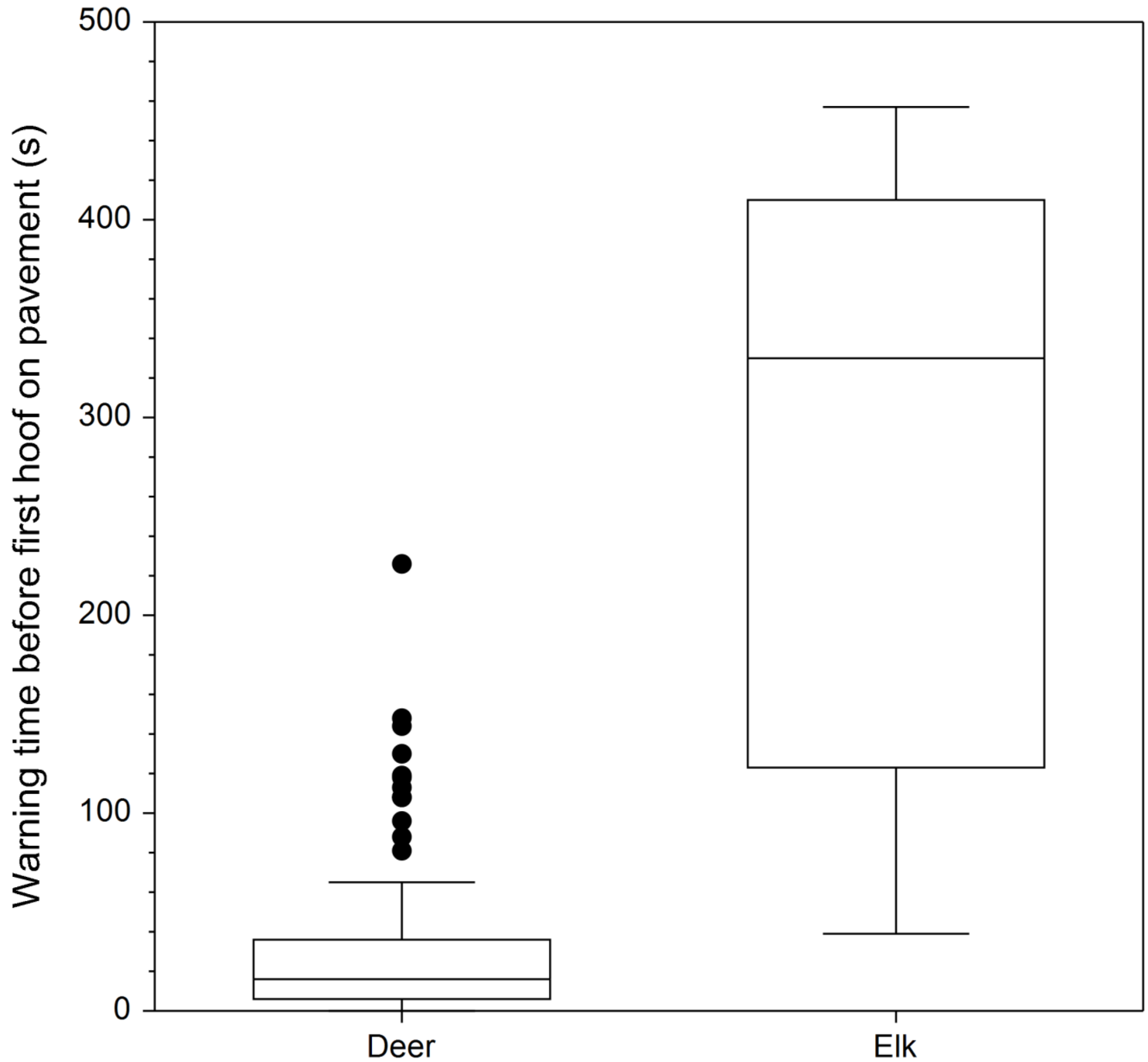
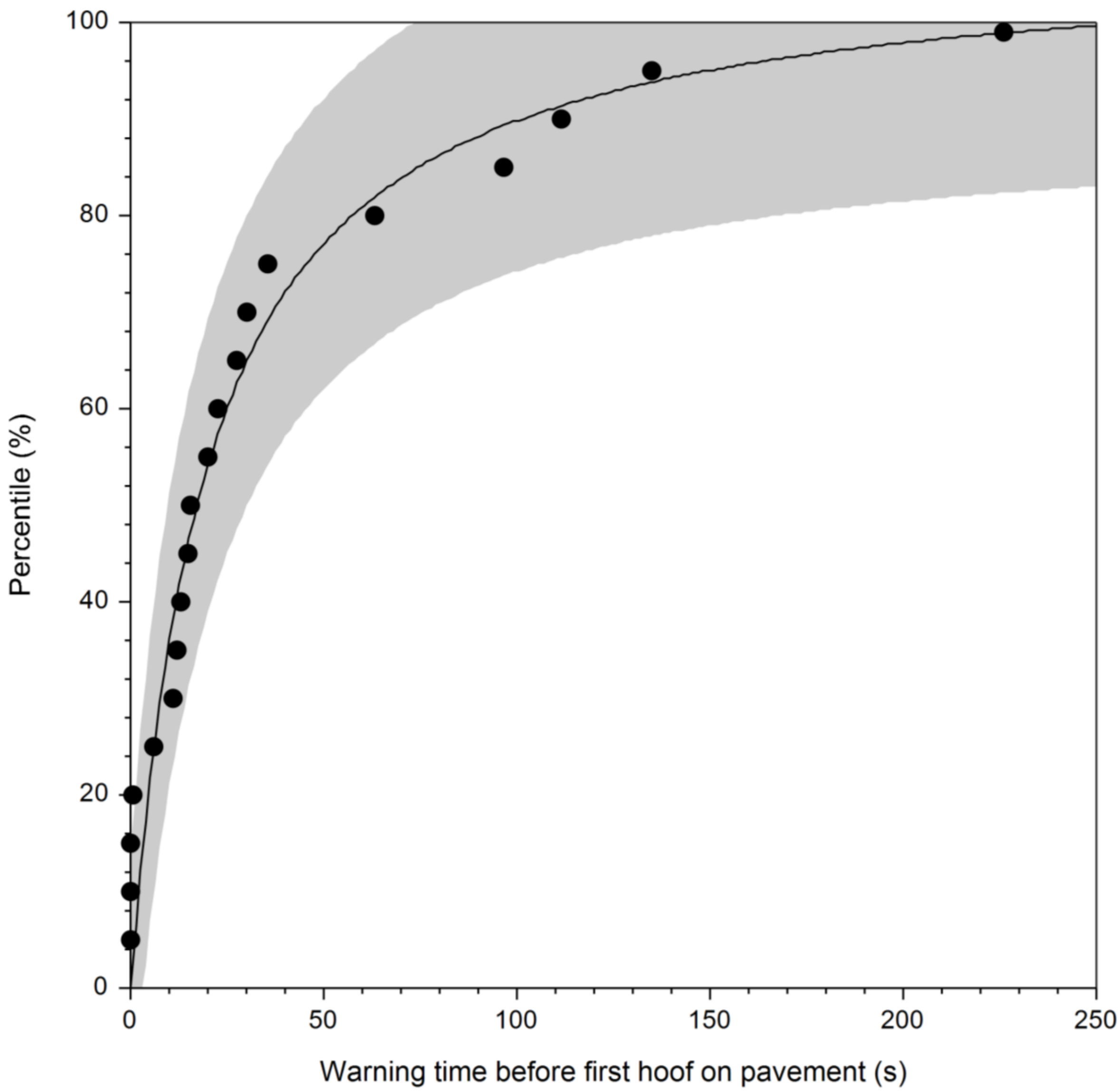



**Figure 16. The Warning Time Before Deer or Elk Set First Hoof on the Pavement.**

**Table 8. The Warning Time Before Deer or Elk Set First Hoof on the Pavement.**

| | Mean | SD | Median | Min. | Max. | N |
|---|---|---|---|---|---|---|
| Deer | 35.35 | 46.05 | 15.5 | 0 | 226 | 72 |
| Elk | 268.44 | 155.13 | 330 | 39 | 457 | 9 |




Note: Percentile = 107.56482*Warning_Time/(19.76350+Warning_Time), R2=0.94844. The shaded area adjacent to the curve represents the 95 percent confidence interval.

**Figure 17. The Percentile of the Warning Time before Deer Set First Hoof on the Pavement.**

**Configuration Warning Signs**

The researchers calculated the travel time between the warning signs and the outer edges of the detection area based on the posted maximum speed limit along the road section with the animal detection system (60 mi/h (96.5 km/h, 26.8 m/s)). The time it took vehicles to travel from either warning sign to the outer edges of the detection area varied between 3.2 and 12.6 seconds (Figure 18). For northbound drivers to receive the warning in time, the warning signs needed to be activated between 8.4 (near edge) and 12.6 seconds (far edge) before a large animal entered the pavement in the detection area. Given the actual time that passed between detecting a deer and that deer setting its first hoof on the pavement (Figure 16), between 58.1 and 67.9 percent of the deer were detected sufficiently early for northbound drivers. For southbound drivers to receive the warning in time, the warning signs needed to be activated between 3.2 (near edge) and 7.5 seconds (far edge) before a large animal entered the pavement in the detection area. Given the actual time that passed between detecting a deer and that deer setting its first hoof on the pavement (Figure 16), between 70.4 and 85.0 percent of the deer were detected sufficiently early for southbound drivers.


Note: Also shown are the detection area covered by the Doppler radar (delineated by the white line) and the location of the two warning signs.

**Figure 18. Distances and Travel Times Between Warning Signs and the Outer Edges Detection Area.**

## Discussion

For 75 percent of the deer, the warning signs were “on” the entire time the deer was on the pavement. For elk this was 100 percent. For 90.28 percent of the deer, the warning signs were “on” for at least part of the time the deer was on the pavement. Ideally, the warning signs should be on the entire time any large mammal is on the pavement. To accomplish this, the time the warning signs are activated after the last detection should be longer, and/or the radar should detect large mammals earlier, or have shorter gaps between consecutive detections of animals that approach the highway. Warning signs that stay activated for a longer time after the last detection can be easily accomplished through the software. Detecting large mammals earlier would involve either making the sensor more sensitive (lower thresholds) or widening the detection area or both. However, lowering the thresholds would likely increase the number of false positives. Furthermore, widening the detection area may only be possible when the vegetation is short and there is no livestock present in the areas adjacent to the right-of-way.

The average time between detecting a deer and that deer setting its first hoof on the pavement was 35.35 seconds. For elk, the average time was 268.44 seconds. However, the sample size for elk was small and the elk that were recorded happened to forage and approach the highway slowly (see Chapter 4). Fifty percent of the deer resulted in a warning time of at least 15.5 seconds. The warning time was not sufficient to warn drivers early enough for all deer. Northbound drivers needed between 8.4 and 12.6 seconds warning time before a large animal entered the pavement in the detection area. Given the time between detecting a deer and that deer setting its first hoof on the pavement, between 58.1 and 67.9 percent of the deer were detected sufficiently early for northbound drivers. Southbound drivers needed between 3.2 and 7.5 seconds warning time before a large animal entered the pavement in the detection area. Given the time between detecting a deer and that deer setting its first hoof on the pavement, between 70.4 and 85.0 percent of the deer were detected sufficiently early for southbound drivers. This suggests that (additional) warning signs should be located closer to the detection area. Depending on the length of the detection area, there may be a need for more than one warning sign per travel direction (See Chapter 7 for specific recommendations).

# Chapter 6
# Vehicle Speed

## Introduction

This chapter reports on the speed of vehicles as they travel through the road section with the animal detection system. The researchers investigated whether drivers reduced the speed of their vehicle in response to activated warning signs.

## Methods

Three speed radars were installed to record the speed of individual vehicles. The speed radars were installed 0.62 mile (997 m) north of the northern warning sign, inside the detection area, and 0.51 mile (814 m) south of the southern warning sign (see Chapter 2 and Figure 11 for the exact locations). The radars recorded vehicle speeds for both travel directions. The northern and southern radars were far enough away from the warning signs for approaching vehicles not to be influenced by the warning signs. Furthermore, drivers leaving the area in between the warning signs had another 0.62 mile (997 m, northern warning sign) or 0.51 mile (814 m, southern warning sign) to resume normal operating speed.

The researchers conducted speed trials in three different seasons. Each speed trial consisted of ten consecutive days (Table 9). For one randomly selected hour each day, the researchers forced both warning signs "on", exposing all drivers to the activated warning signs. The researchers did not include the speed from vehicles that passed during the first and last five minutes of an hour with activated warning signs to make sure that the remaining drivers were all indeed exposed the warning signs. The warning signs resumed "normal operation" immediately after they were turned off again. This meant that the warning signs were off, except when a detection occurred. After each ten-day speed trial, the researchers identified "control" hours just before and just after the hour that the warning signs were forced on. For a control hour to qualify, no detections could have occurred during that hour.

**Table 9. The Dates for the Three Speed Trials.**

| Season | Dates |
|---|---|
| Summer | 5-14 August 2016 |
| Autumn | 9-18 December 2016 |
| Winter | 3-12 February 2017 |

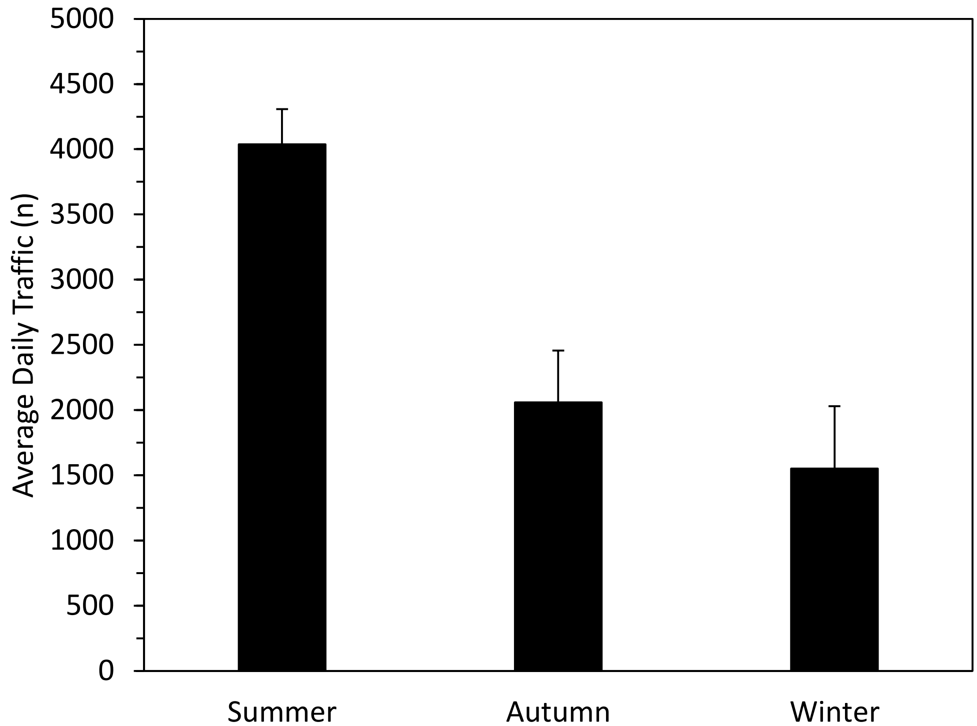
The researchers investigated the effect of the treatment (warning signs off vs. warning signs on) on vehicle speed (ANOVA). However, the researchers also included season (summer, autumn, and winter), light (day vs. night), travel direction (northbound vs. southbound), and location (northern radar, system radar, southern radar) as explanatory variables in the analyses, as the researchers hypothesized that these variables also likely influence vehicle speed. Day was defined as 30 minutes before sunrise until 30 minutes after sunset. Night was defined as 30 minutes after sunset until 30 minutes before sunrise.

The researchers first calculated descriptive statistics on traffic volume and vehicle speed in the three seasons (summer, autumn, and winter). Then the researchers proceeded by investigating the effect of the treatment (warning signs off vs. warning signs on) and other explanatory variables on vehicle speed across all seasons (summer, autumn, and winter). Because of the large number of variables, the researchers only investigated up to two-way interactions between the explanatory variables. Finally, the researchers conducted more detailed analyses for each individual season using a full model with up to three-way interactions between the explanatory variables. For the analyses per individual season, the results were visualized in graphs broken down by day vs. night, and travel direction. Additional analyses were conducted for the speeds observed inside the detection zone (i.e., obtained by the speed radar in the detection zone). With these additional analyses the researchers aimed to investigate the effect of travel direction (northbound vs. southbound), light (day vs. night), and treatment (warning signs off vs. warning signs on) on vehicle speed within a season.

## Results

### Traffic Volume

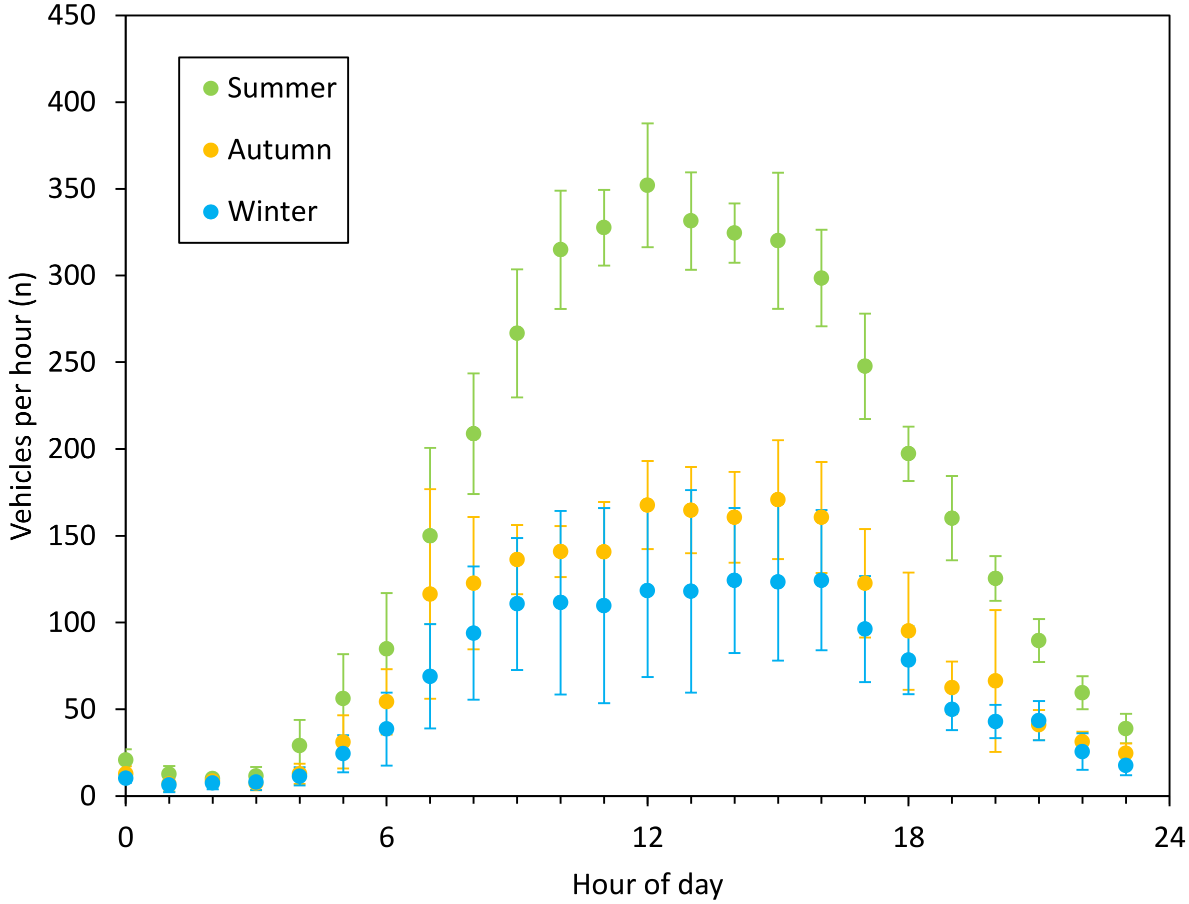
The speed radars also measured traffic volume. Traffic volume was much higher in summer (n=4,039) than in autumn (n=2,059) and winter (n=1,551) (Figure 19).




Note: The data relate to the number of vehicles per day for both travel directions combined (and standard deviation) for the ten consecutive speed trial days in the three seasons at the central radar.

**Figure 19. Average Daily Traffic for the Three Seasons.**

Traffic volume was highest between 9:00 and 17:00 (between 9 a.m. and 5 p.m.), with around 100 to 350 vehicles per hour (Figure 20). Traffic volume was lowest between 1:00 and 4:00 (between 1 a.m. and 4 a.m.) with 6 to 13 vehicles per hour.

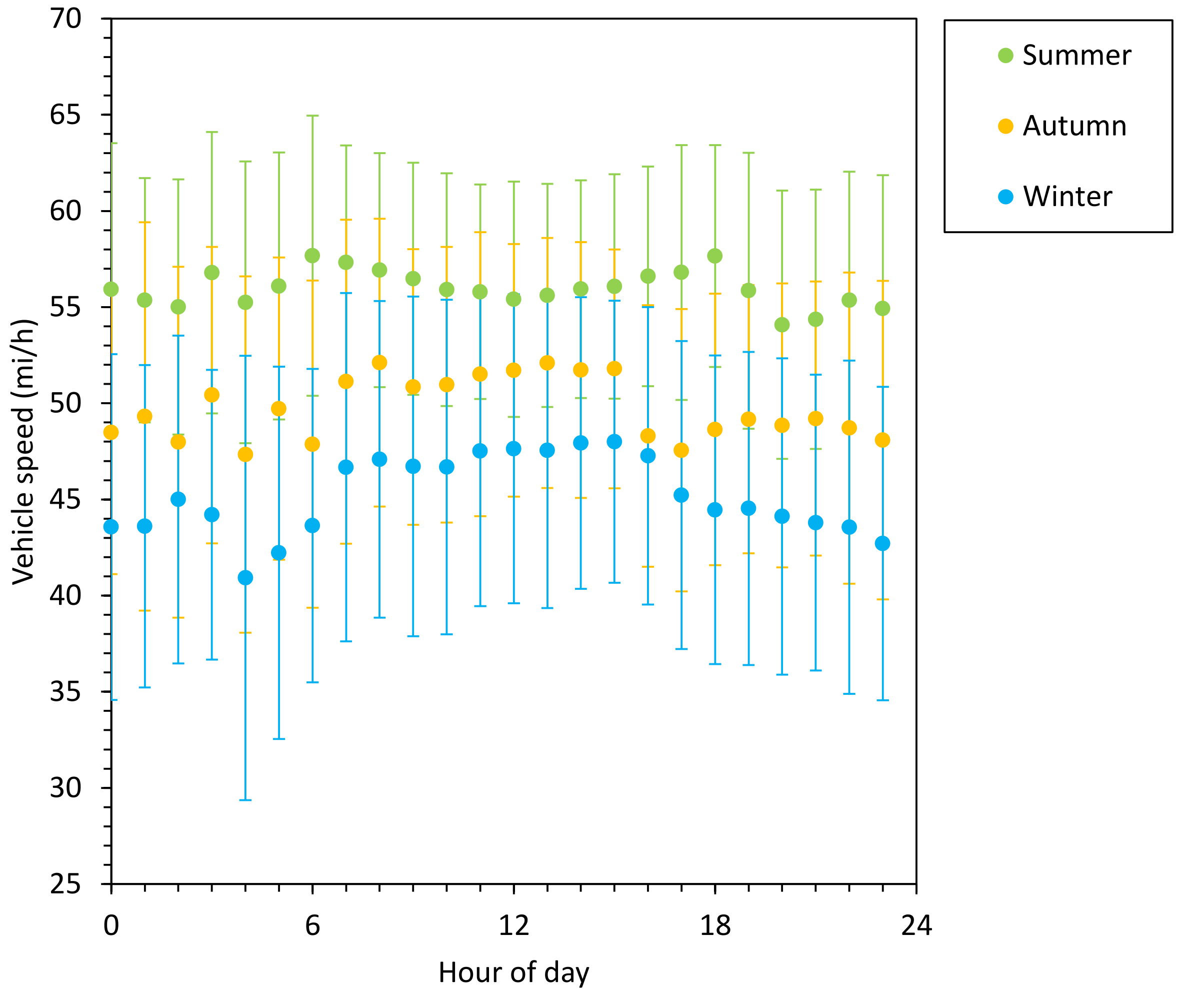



Note: The data relate to ten consecutive speed trial days at the central radar. 6 = Between 6 and 7 A.M., etc.).

**Figure 20. Average Traffic Volume per Hour and Associated Standard Deviation in the Three Seasons.**

**Vehicle Speed per Season and per Hour**

Vehicle speed was highest in summer and lowest in winter (Figure 21). In general, vehicle speed was highest during the day and lowest during the night.




Note: The data relate to the ten consecutive speed trial days in the three seasons. 6 = Between 6 and 7 A.M., etc.).

**Figure 21. Average Vehicle Speed per Hour and Associated Standard Deviation for the Three Seasons.**

**Vehicle Speed with Warning Signs On vs. Off**

***All Seasons***

Treatment (warning signs off vs. warning signs on), season (summer, autumn, and winter), light (day vs. night), travel direction (northbound vs. southbound), and location (northern radar, system radar, southern radar) all had a significant effect on vehicle speed (main effects, Tables 10 and 11). Vehicle speed was lower at the system than at the northern and southern radars, higher during day than during night, lower with warning signs "on" than with warning signs "off", and higher in summer than in autumn and winter (Table 11). Season had the largest effect on vehicle speed (55.01 mi/h in summer vs. 44.91 mi/h in winter). Most of the 2-way interactions between the explanatory variables also had a significant effect on vehicle speed (Table 10).

**Table 10. The Effect of Season, Location, Travel Direction, Light, and Treatment on Vehicle Speed.**

| Explanatory variable | DF | F-Ratio | P | P-level |
|---|---|---|---|---|
| | | | | |
| *Main effects* | | | | |
| A: Season | 2 | 1885.1 | 0.000 | *** |
| B: Location | 2 | 206.29 | 0.000 | *** |
| C: Direction | 1 | 25.74 | 0.000 | *** |
| D: Light | 1 | 31.63 | 0.000 | *** |
| E: Treatment | 1 | 27.01 | 0.000 | *** |
| | | | | |
| *2-way interactions* | | | | |
| AB | 4 | 38.81 | 0.000 | *** |
| AC | 2 | 38.96 | 0.000 | *** |
| AD | 2 | 63.62 | 0.000 | *** |
| AE | 2 | 3.65 | 0.026 | * |
| BC | 2 | 333.37 | 0.000 | *** |
| BD | 2 | 0.52 | 0.592 | ns |
| BE | 2 | 0.12 | 0.886 | ns |
| CD | 1 | 4.02 | 0.045 | * |
| CE | 1 | 2.48 | 0.115 | ns |
| DE | 1 | 1.62 | 0.203 | ns |

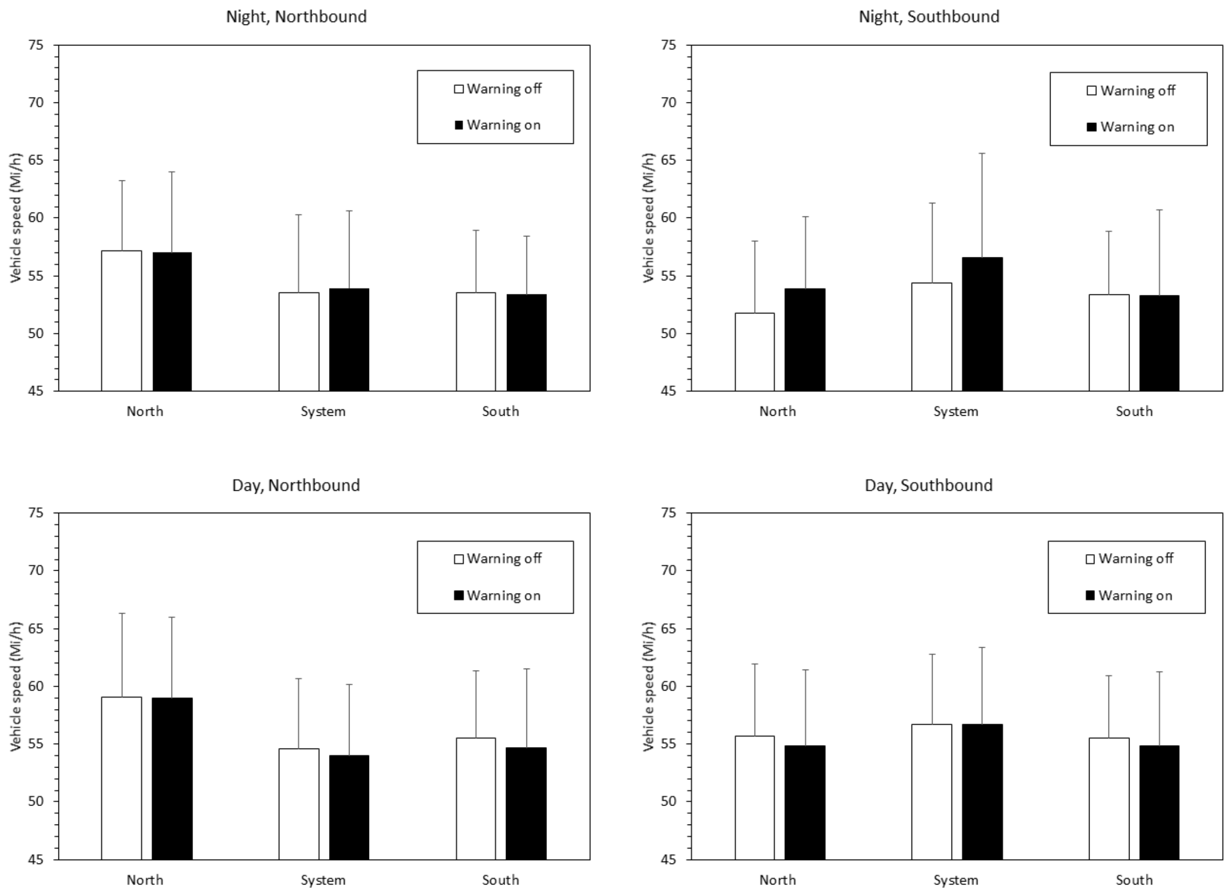
Note: Up to 2-way interactions. *=P≤0.05, **=P≤0.01, ***=≤0.001, ns=not significant.

**Table 11. Vehicle Speed and Standard Error for the Main Effects of the Explanatory Variables.**

| **Explanatory variable** | **Mean** | **SE** | **N** |
|---|---|---|---|
| | | | |
| A: Season | Mean | SE | N |
| Summer | 55.01 | 0.06 | 12033 |
| Autumn | 51.92 | 0.07 | 8486 |
| Winter | 44.91 | 0.12 | 3233 |
| | | | |
| B: Location | | | |
| North | 52.25 | 0.08 | 7025 |
| System | 49.29 | 0.07 | 8275 |
| South | 50.30 | 0.07 | 8452 |
| | | | |
| C: Direction | | | |
| Northbound | 50.31 | 0.06 | 10830 |
| Southbound | 50.91 | 0.06 | 12922 |
| | | | |
| D: Light | | | |
| Day | 50.95 | 0.05 | 17271 |
| Night | 50.28 | 0.08 | 6481 |
| | | | |
| E: Treatment | | | |
| Off | 50.91 | 0.05 | 15585 |
| On | 50.32 | 0.07 | 8167 |

### *Summer*

The average vehicle speed in summer was calculated and broken down by treatment (warning signs off vs. warning signs on), light conditions (day vs. night), and for travel direction (northbound vs. southbound) (Figure 22).




Note: The data relate to vehicle speed with warning signs off and warning signs on, during day and night, and for northbound and southbound traffic.

**Figure 22. Average Vehicle Speed and Associated Standard Deviation) in Summer.**

In summer, travel direction (northbound vs. southbound) and light (day vs. night) had a significant effect on vehicle speed at the location of the system (main effects) (Tables 12, 13). The effect of treatment (warning signs off vs. warning signs on) on vehicle speed was also significant, but the effect depended on the light conditions (day vs. night) (Table 13). At night, vehicle speed was 1.32 mi/h higher with warning signs on than with warning signs off. During the day, vehicle speed was 0.30 mi/h lower with warning signs on than with warning signs off.

**Table 12. Effect of Travel Direction, Light, and Treatment on Vehicle Speed in Summer.**

| Explanatory variable | DF | F-Ratio | P | P-level |
|---|---|---|---|---|
| | | | | |
| *Main effects* | | | | |
| A: Direction | 1 | 43.36 | 0.000 | *** |
| B: Light | 1 | 7.58 | 0.006 | ** |
| C: Treatment | 1 | 2.57 | 0.109 | ns |
| | | | | |
| *2-way interactions* | | | | |
| AB | 1 | 1.09 | 0.296 | ns |
| AC | 1 | 3.35 | 0.067 | ns |
| BC | 1 | 6.54 | 0.011 | * |
| | | | | |
| *3-way interaction* | | | | |
| ABC | 1 | 1.1 | 0.295 | ns |

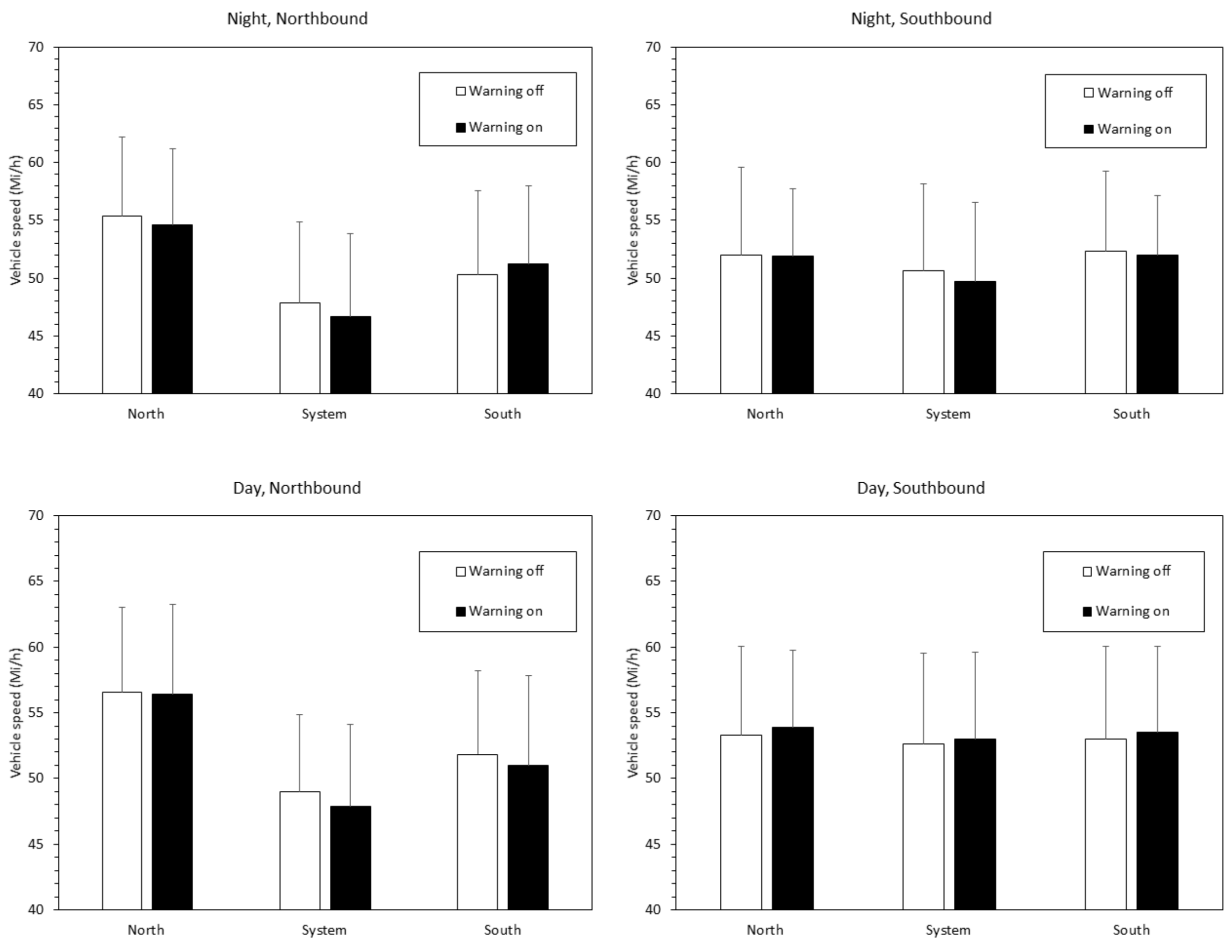
Note: Full model with 3-way interactions. *=P≤0.05, **=P≤0.01, ***=≤0.001, ns=not significant.

**Table 13. Mean Vehicle Speed and Standard Error for the Explanatory Variables in Summer.**

| Explanatory variable | Mean | SE | N |
|---|---|---|---|
| | | | |
| *Main effects* | | | |
| A: Direction | | | |
| Northbound | 54.01 | 0.13 | 2243 |
| Southbound | 56.10 | 0.14 | 2017 |
| B: Light | | | |
| Day | 55.49 | 0.10 | 3691 |
| Night | 54.62 | 0.26 | 569 |
| | | | |
| *2-way interactions* | | | |
| Day, warning signs off | 55.65 | 0.13 | 2383 |
| Day, warning signs on | 55.34 | 0.17 | 1308 |
| Night, warning signs off | 53.95 | 0.31 | 408 |
| Night, warning signs on | 55.28 | 0.50 | 161 |

### *Autumn*

The average vehicle speed in autumn was calculated and broken down by treatment (warning signs off vs. warning signs on), light conditions (day vs. night), and for travel direction (northbound vs. southbound) (Figure 23).




Note: The data relate to vehicle speed with warning signs off and warning signs on, during day and night, and for northbound and southbound Traffic.

**Figure 23. Average Vehicle Speed and Associated Standard Deviation in Autumn.**

In autumn, travel direction (northbound vs. southbound), light (day vs. night), and treatment (warning signs off vs. warning signs on) all had a significant effect on vehicle speed at the location of the system (main effects) (Tables 14, 15). Vehicle speed was 0.69 mi/h lower with warning signs on than with warning signs off (Table 15).

**Table 14. Effect of Travel Direction, Light, and Treatment on Vehicle Speed in Autumn.**

| Explanatory variable | DF | F-Ratio | P | P-level |
|---|---|---|---|---|
| | | | | |
| *Main effects* | | | | |
| A: Direction | 1 | 190.86 | 0.000 | *** |
| B: Light | 1 | 50.44 | 0.000 | *** |
| C: Treatment | 1 | 6.76 | 0.009 | ** |
| | | | | |
| *2-way interactions* | | | | |
| AB | 1 | 7.5 | 0.006 | ** |
| AC | 1 | 2.45 | 0.118 | ns |
| BC | 1 | 1.74 | 0.187 | ns |
| | | | | |
| *3-way interaction* | | | | |
| ABC | 1 | 1.62 | 0.204 | ns |

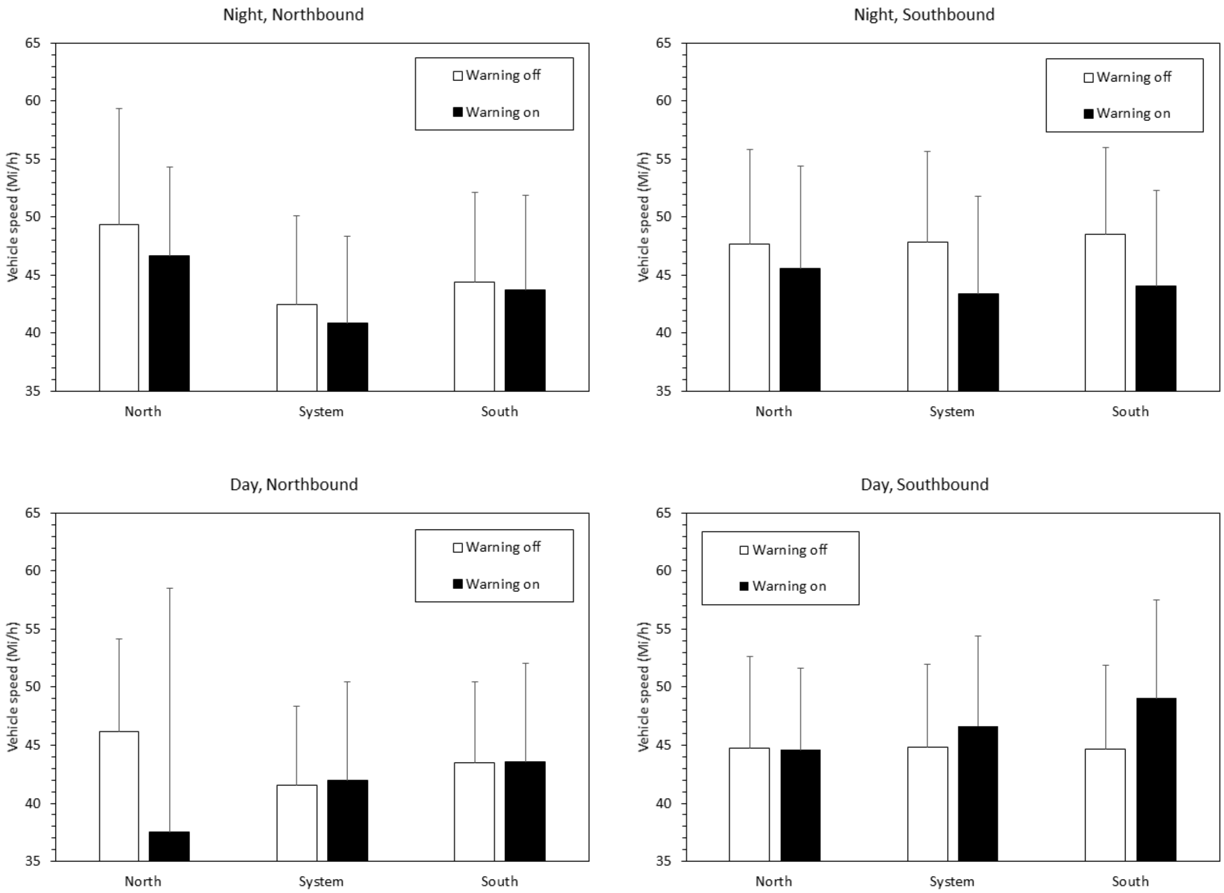
Note: Full model with 3-way interactions. *=P≤0.05, **=P≤0.01, ***=≤0.001, ns=not significant.

**Table 15. Mean Vehicle Speed and Standard Error for the Explanatory Variables in Autumn.**

| Explanatory variable | Mean | SE | N |
|---|---|---|---|
| | | | |
| *Main effects* | | | |
| A: Direction | | | |
| Northbound | 47.85 | 0.18 | 1350 |
| Southbound | 51.51 | 0.17 | 1605 |
| B: Light | | | |
| Day | 50.62 | 0.16 | 1842 |
| Night | 48.74 | 0.20 | 1113 |
| C: treatment | | | |
| Off | 50.03 | 0.16 | 1860 |
| On | 49.34 | 0.20 | 1095 |
| | | | |
| *2-way interaction* | | | |
| Northbound, day | 48.43 | 0.24 | 792 |
| Northbound, night | 47.28 | 0.29 | 558 |
| Southbound, day | 52.82 | 0.21 | 1050 |
| Southbound, night | 50.21 | 0.29 | 555 |

***Winter***

The average vehicle speed in winter was calculated and broken down by treatment (warning signs off vs. warning signs on), light conditions (day vs. night), and for travel direction (northbound vs. southbound) (Figure 24).




Note: The data relate to warning signs off and warning signs on, during day and night, and for northbound and southbound traffic.

**Figure 24. Average Vehicle Speed and Associated Standard Deviation in Winter.**

In winter, travel direction (northbound vs. southbound) had a significant effect on vehicle speed at the location of the system (main effect) (Tables 16, 17). The effect of treatment (warning signs off vs. warning signs on) on vehicle speed was also significant, but the effect depended on the light conditions (day vs. night) (Tables 16, 17). At night, vehicle speed was 3.01 mi/h lower with the warning signs on than with warning signs off. During the day, vehicle speed was 1.08 higher with warning signs on than with warning signs off (Table 17). The effect of treatment (warning signs off vs. warning signs on) on vehicle speed was also significant in interaction with travel direction (northbound vs. southbound) and light conditions (day vs. night) (Table 16). During the night, vehicle speed was lower (1.59 mi/h for northbound traffic, 4.43 mi/h for southbound traffic) with warning signs on than with warning signs off

(Table 17). However, during the day, vehicle speed was higher (0.35 mi/h for northbound traffic, 1.80 mi/h for southbound traffic) with lights on than with lights off.

**Table 16. Effect of Travel Direction, Light, and Treatment on Vehicle Speed in Winter.**

| Explanatory variable | DF | F-Ratio | P | P-level |
|---|---|---|---|---|
| | | | | |
| *Main effects* | | | | |
| A: Direction | 1 | 58.47 | 0.000 | *** |
| B: Light | 1 | 0.06 | 0.800 | ns |
| C: treatment | 1 | 3.46 | 0.063 | ns |
| | | | | |
| *2-way interactions* | | | | |
| AB | 1 | 0 | 0.950 | ns |
| AC | 1 | 0.45 | 0.503 | ns |
| BC | 1 | 15.51 | 0.000 | *** |
| | | | | |
| *3-way interaction* | | | | |
| ABC | 1 | 4.27 | 0.039 | * |

Note: Full model with 3-way interactions. *=P≤0.05, **=P≤0.01, ***=≤0.001, ns=not significant.

**Table 17. Mean Vehicle Speed and Standard Error for the Explanatory Variables in Winter.**

| **Explanatory variable** | **Mean** | **SE** | **N** |
|---|---|---|---|
| | | | |
| *Main effect* | | | |
| A: Direction | | | |
| Northbound | 41.72 | 0.33 | 513 |
| Southbound | 45.69 | 0.32 | 547 |
| | | | |
| *2-way interaction* | | | |
| Day, off | 43.23 | 0.38 | 396 |
| Day, on | 44.31 | 0.69 | 120 |
| Night, off | 45.14 | 0.40 | 351 |
| Night, on | 42.13 | 0.54 | 193 |
| | | | |
| *3-way interaction* | | | |
| Northbound, day, off | 41.59 | 0.55 | 189 |
| Northbound, day, on | 41.95 | 1.01 | 56 |
| Northbound, night, off | 42.47 | 0.58 | 172 |
| Northbound, night, on | 40.88 | 0.77 | 96 |
| Southbound, day, off | 44.87 | 0.52 | 207 |
| Southbound, day, on | 46.67 | 0.94 | 64 |
| Southbound, night, off | 47.82 | 0.56 | 179 |
| Southbound, night, on | 43.39 | 0.77 | 97 |

## Discussion

Vehicle speed was substantially lower in winter (44.91 mi/h) than in summer (55.01 mi/h) and autumn (51.92 mi/h), regardless of whether the warning signs were activated. This suggests that drivers to reduce their speed when road and weather conditions are challenging.

In summer, activated warning signs did not result in lower vehicle speeds. However, in autumn activated warning signs resulted in 0.69 mi/h speed reduction. In winter during the night, vehicle speed was 3.01 mi/h lower with warning signs on than with warning signs off, but during the day, vehicle speed was higher with warning signs on than with warning signs off. In winter, the effect of treatment (warning signs off vs. warning signs on) on vehicle speed was also significant in interaction with travel direction (northbound vs. southbound) and light conditions (day vs. night). During the night, vehicle speed was lower (1.59 mi/h for northbound traffic, 4.43 mi/h for southbound traffic) with warning signs on than with warning signs off. However, during the day, vehicle speed was higher (0.35 mi/h for northbound traffic, 1.80 mi/h for southbound traffic) with warning signs on than with warning signs off. Southbound traffic entered a curve before being able to observe the warning sign. Apparently, this caused southbound traffic to have higher speeds at the location of the radar in the detection zone. It seems that southbound drivers may not have been able to observe the activated warning sign until they were already close to the warning sign, the detection area and the radar in the detection area. This could explain the higher speed for southbound traffic, despite having gone through a curve just before their speed was measured.

The researchers conclude that the effect of activated warning signs on vehicle speed was greatest when road conditions were challenging (e.g., freezing temperatures and snow- and ice-covered road) and when visibility was reduced (night). In summer, there was no measurable benefit of activated warning signs, at least not as far as vehicle speed is concerned. Note that drivers may still have benefitted from activated warning signs through reduced reaction time (see Chapter 1, Figure 1). Depending on the conditions in autumn and winter, the activated warning signs resulted in a speed reduction of between 0.69 and 4.43 mi/h.

# Chapter 7
# Stopping Distance and Maximum Vehicle Speed

## Introduction

This chapter contains calculations on vehicle stopping distance given a certain vehicle speed and the maximum speed of vehicles that still allow drivers to come to a complete stop before hitting a large mammal on the highway in the dark. The calculations in this chapter relate to passenger vehicles on a level road surface that may be wet.(15)

## Methods

Drivers need time to interpret an activated warning sign, or to process that there is a large animal on the highway in front of them, before they can start braking. Once drivers start breaking they reduce the speed of their vehicle, and eventually they come to a complete stop. This suggests that the warning signs, at least the first ones, should be at some distance from the detection area. The distance required to stop a passenger vehicle on a level roadway that may be wet is calculated as follows:(15)

1. Stopping distance = brake reaction distance + braking distance.
2. Brake reaction distance: The distance traveled from the moment a driver sees an object that requires a stop to the moment the driver starts to brake. For the calculations in this chapter, the researchers used a brake reaction time of 0.7 seconds (for drivers that have been warned), 1.5 seconds (drivers that have not been warned but that have a fast reaction time) and 2.5 seconds (recommended design criterion by the American Association of State Highway and Transportation Officials).(15)
3. Braking distance: The distance required to stop the vehicle from the moment the braking starts. For the calculations in this chapter the researchers used a deceleration of 3.4 $m/s^2$ as recommended by the American Association of State Highway and Transportation Officials.(15) Note that a downhill slope, heavier vehicle weight (e.g, semi-trucks), and an icy road surface can result in longer braking distances. An uphill slope, lighter vehicle weight (e.g, very light passenger car), and a dry road surface with high friction can result in shorter braking distances.

## Results

Given the maximum speed limit of 60 mi/h (96.5 km/h, 26.8 m/s) along U.S. Hwy 95, north of Bonners Ferry, the brake reaction distance for a vehicle traveling at 60 mi/h is 132.0-220.5 ft (40.2-67.2 m), and the braking distance is 345.5 ft (105.3 m). This totals to 477.5-566.0 ft (145.5-172.5 m) for the stopping sight distance (Figure 25). This calculation is based on a brake reaction time of 1.5-2.5 seconds and the drivers deciding to stop the vehicle after seeing the activated warning signs (rather than having seen the large mammal on or near the highway).[15] Thus, the minimum distance between the first activated warning sign and an animal in the detection zone should be 477.5-566.0 ft (145.5-172.5 m).

If drivers do not attempt to stop the vehicle until they see the animal on or near the highway, they may decide to continue to travel at high speed (presumably 60 mi/h (96.5 km/h, 26.8 m/s) after seeing the activated warning sign. But when these drivers see the animal, their reaction time may be reduced to about 0.7 seconds instead of 1.5 or 2.5 seconds because they have been warned about the large animal on or near the highway.[15,16] This means that the brake reaction distance may be reduced from 132.0-220.5 ft (40.2-67.2 m) to 61.6 ft (18.8 m). The braking distance remains identical though (345.5 ft (105.3 m)), resulting in a stopping distance of 407.1 (124.1 m).

The stopping distance depends on brake reaction time as well as vehicle speed (Figure 25). For drivers to be able to stop in time in their travel lane for a large mammal that does not move out of that travel lane, they must have a stopping distance that is shorter than the distance at which they detect the animal (Figure 25).

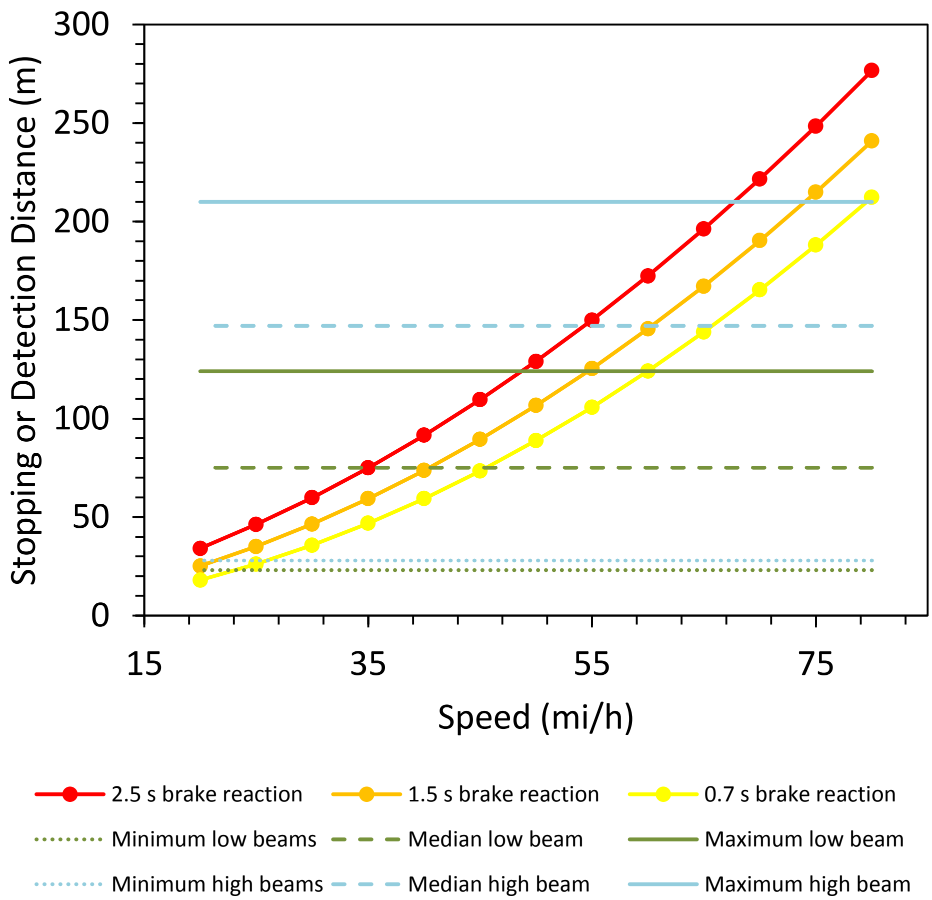



**Figure 25. Stopping Distances and Detection Distances for Large Mammals**

The median detection distance for a moose decoy on or adjacent to a highway for drivers with a vehicle with low beam head lights was 246.1 ft (75 m), range 75.5-406.8 ft (23-124 m).(17) This means that a driver that has been warned for a large animal on the road but that still drives 60 mi/h (96.5 km/h) would likely still hit the moose because the required stopping distance of 407.1 (124.1 m) is much longer than the median detection distance with low beam head lights (246.1 ft (75 m)). Drivers that are not warned require a stopping distance of 477.5-566.0 ft (145.5-172.5 m) which is much longer than the detection distance with the best performing low beam headlights 406.8 ft (124 m).

The median detection distance for a moose decoy on or adjacent to a highway for drivers with a vehicle with high beam head lights was 482.3 ft (147 m), range 91.9-689.0 ft (28-210 m).(17) This means that many of the drivers that have been warned for a large animal on the road would be able to stop in time because the required stopping distance of 407.1 (124.1 m) is shorter than the median detection distance with high beams (482.3 ft (147 m)). However, drivers of vehicles with poor high beam head lights will likely still hit the animal as the worst high beam head lights only allowed for 91.9 (28 m) detection distance. Drivers that are not warned require a stopping distance of 477.5-566.0 ft (145.5-172.5 m) which is about the same as the 482.3 ft (147 m) median detection distance for high beam head lights. Therefore, even with high beam head lights, the drivers of about half the vehicles would still not be able to stop in time if they are not warned for a large animal on the road.

Based on the graph, drivers should have already reduced vehicle speed to a maximum of about 45 mi/h (72 km/h) when they approach the detection zone after an animal has been detected. This is based on the driver using a low beam setting to not blind oncoming traffic, and on a “fast” brake reaction time (0.7 s) assuming the drivers have been warned for a large mammal on the road already. Drivers of cars with poor low beam head lights may need to reduce their speed to 25-30 mi/h (40-48 km/h) to be able to stop in time.

## Discussion

Assuming a vehicle speed of 60 mi/h (96.5 km/h), the minimum distance between the first activated warning sign and the near end of the detection zone should be 477.5-566.0 ft (145.5-172.5 m). Warning signs that are closer to the detection area do not allow drivers to stop their vehicles sufficiently early. Furthermore, the spacing of the warning signs should be such that drivers should not be able to pass a warning sign without being able to see and interpret the next warning sign until the end of the detection zone. At the time of the study, this was not the case; there was only one warning sign for each travel direction. This means that if a driver has passed a warning sign that was not activated, the driver can no longer be warned for large mammals on or near the highway for a road length of 656 ft (200 m) or 7.5 seconds at 60 mi/h for southbound traffic, or 1,109 (338 m) or 12.6 seconds at 60 mi/h for northbound traffic. The font size of the text and the size of the symbols on the signs determines the distance at which drivers can read and interpret the signs.(18) This distance is equivalent to the interval between the warning signs leading up to the detection zone through the end of the detection zone.

The posted speed limit of 60 mi/h (96.5 km/h) does not allow the driver of a vehicle with low beam head lights with a median detection distance of 246.1 ft (75 m) to stop in time after the driver has observed a large mammal on the road.(17) The researchers suggest experimenting with advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) at a maximum, in association with activated warning signs. Note that drivers with poor low beam head lights may still drive too fast to be able to come to a stop before hitting the animal. Drivers of cars with poor low beam head lights may need to reduce their speed to 25-30 mi/h (40-48 km/h) to be able to stop in time.

The researchers recognize that the recommendations for the number and placement of warning signs and the advisory or mandatory speed limit reductions associated with activated warning signs may not be consistent with current policy and practice of transportation agencies. The researchers recognize that more study and evaluation by transportation agencies may be required before the recommendations can be considered or implemented. For example, a series of signs at short intervals can result in sign saturation. Therefore, the researchers suggest not using standard warning signs that are always visible. The researchers suggest using LED signs that do not display any message when there is no detection of large animals.(12) Only when a large animal is detected will the LED signs display the warning message and associated advisory or mandatory speed limit reduction.

In summary, the researchers recommend the following for the configuration of the warning signs:

1. Regardless of the location, consider increasing the time the warning signs are activated after the last detection or change the configuration of the radar so that it detects large mammals earlier, and have shorter gaps between consecutive detections of animals that approach the highway. Note that for other types of systems (e.g. break-the beam systems) animals may be detected closer to the highway resulting in even shorter warning time before the enter the pavement.
2. Regardless of the location, and regardless of the type of animal detection system, the researchers recommend the following for the configuration of the warning signs:
    a. Consider placing the first warning sign at least 477.5-566.0 ft (145.5-172.5 m) before the near end of the detection zone. At the study location, north of Bonners Ferry, during the time of the study, the northern warning sign (for southbound traffic) was too close to the near end of the detection zone.
    b. Consider placing additional warning signs after the first warning sign until the end of the detection zone. The font size of the text and the size of the symbols on the signs determines the distance at which drivers can read and interpret the signs. This distance should be equivalent to the interval between the warning signs leading up to the detection zone through the end of the detection zone. Note that curves may reduce the sight distance for drivers and that curves may thus result in a shorter distance between the warning signs. Currently, drivers cannot be warned after they have passed the first warning sign as there are no additional warning signs.
    c. Consider using LED signs that do not display a message unless a large animal is detected. Only when a large animal is detected should the LED signs display the warning message.
    d. At the study location, north of Bonners Ferry, during the time of the study, the warning signs only result in relatively small reductions in vehicle speed under some circumstances. The

absolute vehicle speeds were too high for most drivers to be able to stop in time for a large mammal on the highway. Therefore, consider experimenting with advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) or lower in association with activated warning signs.

e. Consider installing informational signs at the beginning and end of the detection zone: "START DETECTION ZONE" and "END DETECTION ZONE."

Note: If the stopping distance exceeds the detection distance, there is still a chance for drivers to avoid a collision. However, this would require the animal to move out of the travel lane. Alternatively, drivers can initiate an evasive maneuver with the associated risk of losing control of the vehicle and departing the roadway. The researchers suggest designing the warning signs in such a way that the driver does not depend on wildlife to move out of the travel lane and that the driver does not have to initiate an evasive maneuver.

Note: Many of the calculations in this chapter were based on the stopping distance calculations in relation to the detection distance which depends on the head lights of the cars. These calculations assume that the vehicles and the animals are on a straight road section. If the animals are in or around a curve, drivers may not detect the animals until they are much closer and it is too later to stop the vehicle. Similarly, if animals run on the roadway at distances shorter than the detection distance of the headlights, drivers may not be able to avoid a collision.

# Chapter 8
# Crashes and Carcasses

## Introduction

This chapter reports on the number of crashes with large mammals before and after the installation of the animal detection system, both inside and outside the detection area. In addition, the researchers investigated the occurrence of wildlife-vehicle crashes during the day versus the night. Note that the wildlife-vehicle crash and carcass removal data presented in this chapter only included one full calendar year of data after the system was installed. Combined with the short road length protected by the system (371 ft (113 m)), and the variability in the wildlife-vehicle crash and carcass removal data, no definite conclusions can be drawn on the effectiveness of the system in reducing the number of collisions with large animals. The purpose of this chapter is mostly to document the large mammal-vehicle collisions through 2016 so that they can be included in potential future analyses that are based on data from a longer time.

## Methods

The researchers obtained both wildlife-vehicle crash data (typically collected by law enforcement agencies) and carcass removal data (typically collected by road maintenance personnel) from the Idaho Transportation Department. These data were for the road section between mile reference post 510.0 (near the junction with U.S. Hwy 2) and mile reference post 538.0 (near the Canadian border). This included the road section with the animal detection system. The north end of the detection area is at mile reference post 514.45, and the south end of the detection area is at mile reference post 514.38. The data covered the period 1 January 2000 through 31 December 2016 (crash data) and 1 January 2003 through 31 December 2016 (carcass data), though the carcass data for 2011 through 2015 were not available for this analysis. Based on the spatial data provided, the researchers categorized each crash or carcass record as "definitely inside the detection area" (between mile reference post 514.38 and 514.45), "definitely outside the detection area" (<514.0 or >514.5), or "either inside or outside the detection area" (514.0-514.5). The latter category included records for which the mile reference post was 514 without any decimals. Records with a mile reference post of 515 were always assumed to relate to collisions outside the detection area as the researchers expected these locations to be north of mile reference post 514.5. Based on the accident dates, the researchers also categorized each crash or carcass record as before, after or during the installation of the animal detection system. The *before* data related to 2000 through 2013, the *during* data related to 2014 and 2015 (the system was moved to its current location in April 2014 and became "permanently" operational from 2 October 2015 onwards), and the *after* data related to 2016.

The researchers had to standardize the number of wildlife-vehicle crashes and carcasses to a road length unit to be able to compare the road section with the animal detection system to the adjacent road sections that served as a control. We calculated the mean number of wildlife-vehicle crashes and large wild mammal carcasses per mile. Since the road section with the system covered only about 7 percent of a mile (371 ft (113 m)), the number of wildlife-vehicle crashes or large wild mammal carcasses in the road section with the system had to be multiplied by a factor 14.24. As a consequence, one or a few collisions in the detection zones results in a very high number of collisions per mile. However, such extreme values for the number of (potential) collisions per mile in the detection zone are more likely to be associated with the short length of the road section equipped with the system and the associated multiplication factor, rather than an indication of the system resulting in a more dangerous situation than the adjacent control road sections.

The wildlife-vehicle crash data included the hour of day the crashes occurred. The researchers classified the accident time into two categories: day (sunrise-sunset) and night (sunset-sunrise).

## Results

### Collisions

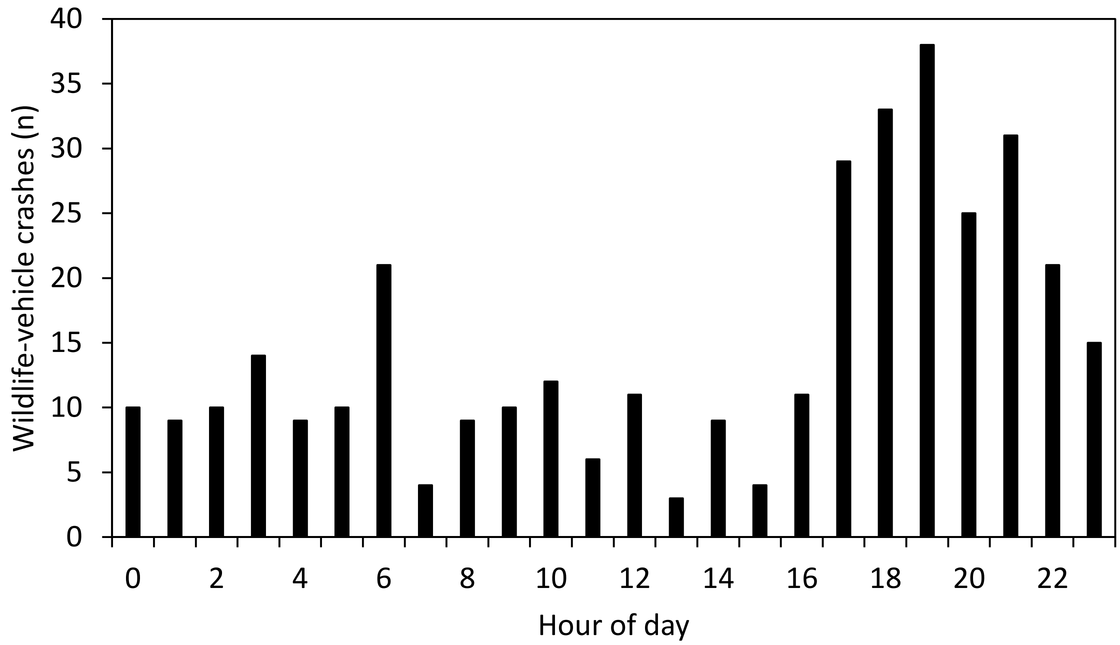
The mean number of wildlife-vehicle crashes and carcasses per mile per year inside the detection area before the animal detection system was installed was between 1.02 and 6.12 (crash data) and between 0.00 and 105.36 (carcass removal data) (Table 18). We presented a range for the averages as some of the collisions may or may not have been inside the detection area because of spatial imprecision of the crash and carcass removal data. After the animal detection system was installed, these numbers were between 0.00 and 57.14 (crash data) and between 0.00 and 85.71 (carcass removal data). The number of crashes per mile per year outside the detection area was 0.75 (before) and 0.36 (after). For carcass removal data, these numbers were 3.90 (before) and 2.15 (after). Note that the before data were based on multiple years (2000 through 2013 for carcass data and 2003 through 2010 for carcass removal data) and that the after data were only based on one year (2016).

**Table 18. Wildlife-Vehicle Collisions per Mile per Year In- and Outside Detection Area.**

| | Before | | | After | | |
|---|---|---|---|---|---|---|
| | **Mean (N)** | **SD** | **Years with data (N)** | **Mean (N)** | **SD** | **Years with data (N)** |
| *Crash data* | | | | | | |
| Definitely inside detection area | 1.02 | 3.82 | 13 | 0.00 | n/a | 1 |
| Definitely inside and potentially inside detection area | 6.12 | 12.17 | 13 | 57.14 | n/a | 1 |
| Definitely outside detection area | 0.75 | 0.26 | 13 | 0.36 | n/a | 1 |
| | | | | | | |
| *Carcass removal data* | | | | | | |
| Definitely inside detection area | 0.00 | 0.00 | 8 | 0.00 | n/a | 1 |
| Definitely inside and potentially inside detection area | 105.36 | 49.45 | 8 | 85.71 | n/a | 1 |
| Definitely outside detection area | 3.90 | 0.91 | 8 | 2.15 | n/a | 1 |

**Time of Day**

Most wildlife-vehicle crashes occurred in the late afternoon until midnight (Figure 26). A smaller peak in crashes occurred in the early morning. Most crashes (74.01 percent) occurred during the night, only 25.99 percent occurred during the day.




Note: The data relate to U.S. Hwy 95 (between mile reference posts 510 and 538).

**Figure 26. The Distribution of Wildlife-Vehicle Crashes over the Hours of the Day.**

## Discussion

The short length of the road section equipped with the animal detection system (0.07 mi) and the short time the system has been fully operational (since 2 October 2015), make it not possible to conclude whether the system has resulted in fewer wildlife-vehicle collisions. However, we can conclude that most of the crashes (74.01 percent) occurred during the night and that only 26 percent occurred during the day. This information is important because it means that most of the collisions occur when visibility is low (night time) when drivers cannot stop in time after the driver has observed a large mammal on the road; vehicles with low beam head lights only have a median detection distance of 246.1 ft (75 m) (see Chapter 7).[17]. The fact that most wildlife-vehicle collisions occur in the dark, supports the suggestion for a mandatory speed limit reduction when the warning signs are activated (Chapter 7).

Recommendations:

1. Should the animal detection system remain in place, continue collecting wildlife-vehicle crash and carcass removal data, both inside and outside the road section with the animal detection system. Note that the wildlife-vehicle crash and carcass removal data presented in this chapter only included one full calendar year of data after the system was installed. Combined with the short road length protected by the system (371 ft (113 m)), and the variability in the wildlife-vehicle crash and carcass removal data, no definite conclusions can be drawn on the effectiveness of the system in reducing the number of collisions with large animals. The

effectiveness of the system in reducing collisions with large mammals can only be evaluated if wildlife-vehicle crash and carcass removal data are collected for a longer period.

2. Increase the spatial precision of the wildlife-vehicle crash and carcass removal data. It is especially important to know for sure whether a collision occurred just inside or just outside the road section with the animal detection.
3. Since the road length covered by an animal detection system is almost always relatively short, and because wildlife-vehicle collisions are relatively variable from year to year at any specific location, it will remain a challenge to be able to conclude whether a particular animal detection system at a particular location has resulted in a reduction in wildlife-vehicle collisions. Therefore, the researchers suggest conducting meta-analyses using wildlife-vehicle collision data from multiple locations that have an animal detection system installed.

# Chapter 9
# Operation, Maintenance, and Financial Perspectives

ITD personnel has emphasized the importance of the animal detection system being mobile. Moving the equipment to a different location would be based on changes in the location of large mammal activity (especially deer) near the highway. Agricultural activities and the availability of food (e.g., crops, hay) seem to have a substantial influence on deer activity, including road crossings. In this context, ITD stresses the following (Pers. Com. Mike Hartz and George Shutes, Idaho Transportation Department):

1. Having the equipment be mounted on the trailer allows them to move the system with relatively little effort to a different location. Fortunately, this is exactly how the current system was designed.
2. It is not possible or viable to have a power drop (i.e., connect the system to the electrical grid) at all locations. Therefore, ITD stresses the importance of the system having its own power source. The generator has proven to be too maintenance intensive (i.e., it required a fuel refill about once a month), and this has resulted in periodic outages of the system. Therefore, ITD personnel suggests powering the system with solar panels. Note that solar panels may have their own issues with power outages (e.g., shade from trees, snow cover during certain periods in winter).
3. When the system is moved to a new location, the Doppler radar and thermal camera need to be adjusted. ITD personnel stresses it is not practical to raise and lower the pole with the radar and camera multiple times, or using a lift truck. ITD personnel suggest having remote control over the radar and camera angle from the ground.
4. The sensitivity of system needs to be adjusted for each location through the software. ITD personnel does not necessarily have the time and expertise to make these specialized adjustments. ITD personnel suggests making the interface more user friendly. Alternatively, transportation agencies could consider having operation and maintenance contracts with the manufacturers of animal detection systems. Then the manufacturers could potentially move the system, adjust the settings of the system given the site-specific conditions, and monitor the functionality of the system remotely, including potential issues with the power supply to the system.

The manufacturer, Sloan Security Technologies, stresses that it is important to have regular maintenance of the system and to monitor its functionality (Pers. Com. Brice Sloan, Sloan Security Technologies). The manufacturer suggests having an operation and maintenance contract in place between the transportation agency and the manufacturer to ensure the systems' functionality. Continuous monitoring of the system can be partially automated conducted remotely. When problems are detected and the cause is identified, action can be taken to restore the functionality of the system. Not monitoring the functionality of the system can result in a non-operational system without anyone being aware of it.

The manufacturer, Sloan Security Technologies, currently estimates that the costs for a deployment are about $50,000-$70,000 per 820 ft (250 m) road section with an additional $3,000 per year for monitoring and calibration of the system and data collection.

The researchers used the indicative costs for the animal detection system and associated maintenance provided by Sloan Security Technologies to conduct cost-benefit analyses (Pers. Com. Brice Sloan, Sloan Security Technologies). Investing in an animal detection system that has continuous coverage (i.e., not combined with wildlife fences or other mitigation measures) would cost $240,000 per km ($60,000 per 250 m). The researchers assumed that the equipment would have to be replaced once every 10 years.[5] In addition, the researchers assumed $12,000 per km per year ($3,000 per 250 m) for operation and maintenance by the manufacturer. The cost benefit analyses were conducted for a 75-year long time period with a discount rate of 3% following the model developed by Huijser et al. (2009).[5] Apart from the specific equipment costs and operation and maintenance costs associated with the system north of Bonners Ferry, all other parameters and values were the same as Huijser et al. (2009). [5] Note that this model is primarily based on human safety based parameters. Should passive use values also be included, it would result in lower thresholds for the implementation of effective mitigation measures.

If a road section has wildlife-vehicle collision numbers that exceed the threshold values (see Table 19), then the benefits of that mitigation measure exceed the costs over a 75-year period. In other words, if a road section has more than 5.5 deer hit per km per year, then installing the animal detection system developed by Sloan Security Technologies generates higher benefits than costs. The threshold values for elk and moose are lower as the costs associated with a collision with larger mammals are higher. Thus, the savings associated with reducing collisions with larger mammals are higher too, and fewer larger mammal-vehicle collisions are required to make it financially advantageous to invest in effective mitigation measures. Note that the thresholds for wildlife fences in combination with wildlife crossing structures are lower than those for the animal detection system. This is primarily because of the relatively short projected life span of animal detection systems (10 years) compared to that of fences (25 years) and concrete structures (75 years). For a discussion on other pros and cons of the different types of mitigation measures, please see Chapter 1.

**Table 19. Threshold Values for Individual Mitigation Measures.**

| | ADS Bonners Ferry | Fence, underpass, jump-outs[5] | Fence, under- and overpass, jump-outs[5] |
|---|---|---|---|
| Deer/km/yr | 5.5 | 3.2 | 4.3 |
| Elk/km/yr | 2.1 | 1.2 | 1.6 |
| Moose/km/yr | 1.2 | 0.7 | 0.9 |

# Chapter 10
# Conclusions and Recommendations

The researchers conclude and recommend the following:

## Operation and Maintenance

The researchers recommend the following for operation and maintenance:

1. As the system appears to be sufficiently reliable in detecting large mammals, consider keeping the current system in place or moving it to another location with a concentration of large mammal-vehicle collisions. Note that the authors of this report do not recommend a particular system type or manufacturer. Instead, the researchers emphasize the importance of using minimum norms for system reliability and selecting a system that best fits the specific conditions at a site, including environmental conditions. The researchers encourage ITD to keep using the current system as the system appears to be sufficiently reliable in detecting large mammals, and the system is already in ITD's possession.
2. Regardless of the location, if the system is kept in in operation, consider conducting system maintenance.
3. Regardless of the location, consider increasing the time the warning signs are activated after the last detection or change the configuration of the radar so that it detects large mammals earlier, and have shorter gaps between consecutive detections of animals that approach the highway. Note that for other types of systems (e.g. break-the beam systems) animals may be detected closer to the highway resulting in even shorter warning time before the enter the pavement.
4. Regardless of the location, and regardless of the type of animal detection system, the researchers recommend the following for the configuration of the warning signs:
    a. Consider placing the first warning sign at least 477.5-566.0 ft (145.5-172.5 m) before the near end of the detection zone. At the study location, north of Bonners Ferry, during the time of the study, the northern warning sign (for southbound traffic) was too close to the near end of the detection zone.
    b. Consider placing additional warning signs after the first warning sign until the end of the detection zone. The font size of the text and the size of the symbols on the signs determines the distance at which drivers can read and interpret the signs. This distance should be equivalent to the interval between the warning signs leading up to the detection zone through the end of the detection zone. Note that curves may reduce the sight distance for drivers and that curves may thus result in a shorter distance between the warning signs. Currently, drivers cannot be warned after they have passed the first warning sign as there are no additional warning signs.
    c. Consider using LED signs that do not display a message unless a large animal is detected. Only when a large animal is detected should the LED signs display the warning message.

   d. At the study location, north of Bonners Ferry, during the time of the study, the warning signs only result in relatively small reductions in vehicle speed under some circumstances. The absolute vehicle speeds were too high for most drivers to be able to stop in time for a large mammal on the highway. Therefore, consider experimenting with advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) or lower in association with activated warning signs.
   e. Consider installing informational signs at the beginning and end of the detection zone: "START DETECTION ZONE" and "END DETECTION ZONE."
5. The components of animal detection systems (all types) continue to improve (e.g., hardware, software). Therefore, system reliability and the equipment's level of sophistication of this and other systems will likely become higher in the future. Consider upgrading components when better equipment becomes available.

## Research Activities

Regardless of the location, and regardless of the type of animal detections system, the researchers recommend considering the following in association with potential future research activities:

1. When video images are used to investigate the reliability of an animal detection system, ensure that the camera view includes the entire detection zone. At the study location, north of Bonners Ferry, during the time of the study, the thermal camera did not cover the entirety of the detection zone. Should the entire detection zone have been covered by the thermal camera, the "possible false positives" would have been classified as either "false positives" or "correct detections".
2. Investigate what type of warning sign (e.g., message, symbols) may be most effective in having drivers avoid a collision with large mammals (through either reduced vehicle speed, greater alertness, or a combination of the two). For example "Caution, animal detected".[(13)]
3. Investigate the effectiveness of advisory or mandatory speed limit reduction to 45 mi/h (72 km/h) or lower when the warning signs are activated.
4. Continue to document wildlife-vehicle crashes and large mammal carcasses. Many years of data are required for an individual location with an animal detection system to generate sufficient data. This is because the road length covered by an animal detection system is typically very short, e.g., a few hundred yards. In addition, consider installing additional animal detection systems at other locations and use the collision data from multiple locations to conduct meta-analyses. This will allow for a more rapid assessment of the effectiveness of the systems in reducing large mammal-vehicle collisions compared to studying one system only along a relatively short road section. Note that, in this context, there is an advantage to keeping the system at the same location north of Bonners Ferry as there is already a few years of crash and carcass removal data available after the system was installed.
5. Increase the spatial accuracy for crash and carcass data, specifically around the edges of the detection area. It should always be clear whether a collision occurred inside or just outside the road section covered by the animal detection system.

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