

**The Comparison of Animal Detection Systems in a Test-Bed:
A Quantitative Comparison of System Reliability and Experiences
with Operation and Maintenance**

Final report

by

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16. Abstract The reliability of nine different animal detection systems from five different manufacturers was evaluated at the same site under similar circumstances. For this purpose a test facility (RADS test-bed) was constructed near Lewistown, MT. The animal detection systems were installed and evaluated for their ability to detect horses and llamas (models for large wild ungulate species) that roamed in an enclosure. The data loggers recorded the date and time of each detection for each system. The animal movements were also recorded by six infrared cameras with a date and time stamp. By analyzing the images and the detection data, researchers were able to evaluate the system for a range of reliability parameters. In addition, the effect of system modifications, weather conditions, and animal species (llamas vs. horses) on the reliability of the systems was investigated. Furthermore, three stakeholder groups (employees of transportation agencies, employees of natural resource management agencies, and the traveling public) were surveyed with regard to their expectations on the reliability and effectiveness of animal detection systems. Based on the results, the researchers recommended minimum performance requirements for the reliability and effectiveness of animal detection systems. Finally, the researchers presented a concept of operation and a review of ITS architecture and infrastructure for animal detection systems, and reviewed seven sites in Montana for the potential installation of an animal detection system.					
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EXECUTIVE SUMMARY

Animal–vehicle collisions affect human safety, property, and wildlife, and the number of animal–vehicle collisions has been increasing in many regions across North America. For this project The Western Transportation Institute at Montana State University (WTI/MSU) evaluated a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape. WTI/MSU evaluated different types of animal detection systems from different manufacturers with regard to system reliability and operation and maintenance aspects. Animal detection systems detect large animals (e.g., deer, elk, moose, or pronghorn) as they approach the road. When an animal is detected, signs are activated warning drivers that large animals may be on or near the road at that time. Previous research has shown that, depending on road and weather conditions, the warning signs can cause drivers to reduce their speed. Warning signs may also result in more alert drivers, which can lead to a substantial reduction in stopping distance: 20.7 m (68 ft) at 88 km/h (55 mi/h). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82 percent.

The main objective of this project was to evaluate the reliability of different animal detection systems from different manufacturers at the same site under similar circumstances and to recommend minimum standards for system reliability. A test facility (Roadside Animal Detection System (RADS) test-bed) was constructed near Lewistown, Montana. Nine different animal detection systems from five different manufacturers were installed to detect horses and llamas that roamed in an enclosure. Data loggers recorded the date and time of each detection for each system. The animal movements were also recorded by six infrared cameras with a date and time stamp. By analyzing the images and the detection data, researchers were able to evaluate the system for a variety of reliability parameters.

The results of the reliability tests showed that different detection technologies detect large animals more or less frequently as an animal passes through the detection area or line of detection. The percentage of false positives (i.e., a detection is reported by a system but there is no large animal present in the detection zone) and the average number of false positives per hour was relatively low for all systems ($\leq 1\%$; $\leq 0.10/\text{hr}$). The percentage of false negatives (i.e., an animal is present in the detection zone but a system failed to detect it) and the average number of false negatives per hour was highly variable (0–31%; 0–1.61/h) (all types of false negatives combined). The percentage of intrusions (i.e., animal movements across the detection line) that were detected varied between 73 and 100 percent. The results suggest that some animal detection systems are quite reliable in detecting large mammals with few false positives and false negatives, whereas other systems have relatively many false negatives.

The reliability of animal detection systems is influenced by a range of environmental conditions. High winds were associated with an increase in different types of false negatives for most passive infrared area-cover systems (i.e. systems that detect an animal within a certain range of a sensor, mostly through passive infrared or radar technology). High winds were associated with both an increase in false positives and a decrease in false positives for different types of systems, suggesting that passive infrared area-cover systems become less sensitive with high winds whereas break-the-beam systems (i.e. systems that detect an animal when the animal blocks or reduces a signal (active infrared, laser or radar) transmitted by a sensor and received by another sensor) that rely on a very narrow beam may start generating false positives, presumably because

the sensors sway slightly in and out of alignment. The latter suggests the importance of a stable foundation and pole for break-the-beam systems. Stable foundations and poles may also be beneficial to passive infrared area-cover systems, but it is unclear if the increase in false negatives for such systems is caused by movement of the sensors that tend to be higher up on a pole than sensors for break-the-beam systems, or by vegetation or pockets of hot and cold air that move in the wind across the detection zone. The effects of wind direction are hard to interpret, but it may be that winds oriented perpendicular to the systems caused vegetation or pockets of hot and cold air to trigger systems more often than winds oriented more parallel to the systems. Higher temperatures are generally associated with higher error rates. This could be due to temperature causing reduced performance of the equipment. In addition, passive infrared systems may not be able to distinguish clearly between pockets of hot air and moving animals. However, higher temperatures are concentrated in time (summer) and it is possible that factors other than temperature caused more errors in summer. Animal behavior and possible effects on the likelihood of correct detections and errors may have also been influenced by temperature. Three systems had fewer false negatives during the night compared to during the day. This may be related to lower temperatures or higher contrasts in temperatures of the animals and their surroundings during the night. However one system had more false negatives during the night compared to during the day. Excellent visibility was associated with fewer false positives for a break-the-beam system, which suggests that relatively low visibility may block or reduce the narrow signal path of optical break-the-beam systems. It is unclear why excellent visibility was associated with an increase in false negatives for one of the area-cover systems. Precipitation was rarely observed during the test periods and its effect on system reliability is unclear. However, higher relative humidity was mostly associated with an increase in errors, and to a lesser extent with a decrease in errors. Finally, llamas were substantially harder to detect for most systems, especially passive infrared area-cover systems, than horses, probably because of their smaller body size.

Three stakeholder groups—employees of transportation agencies, employees of natural resource management agencies, and the traveling public—were surveyed with regard to their expectations on the reliability and effectiveness of animal detection systems. There was considerable agreement in the responses of the three groups. Based on the results from the survey, the researchers recommend the following performance requirements for the reliability and effectiveness of animal detection systems:

- Animal detection systems should detect at least 91 percent of all large animals that approach the road.
- Animal detection systems should have fewer than 10 percent of all detections be false.
- Animal detection systems should result in at least 71 percent reduction of wildlife–vehicle collisions.

The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests. Five of the nine systems tested met the recommended performance requirements for reliability. However, experiences with installation, operation and maintenance showed that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

This report also presented a concept of operation and a review of Intelligent Transportation System (ITS) architecture and infrastructure for animal detection systems. Currently, roadside

animal detection systems present drivers with warnings displayed on road signs. In the future, roadside animal detection systems may also transmit warning signals to traffic approaching a location where a large animal has been detected on or near the road. This procedure would require a two-way GPS-based communication system. With animal detection system deployments becoming more numerous, standards for communication and ITS integration will have to be further developed and accepted.

Finally, the researchers reviewed seven sites in Montana for the potential installation of an animal detection system.

Based on the results of the study, the researchers concluded:

- Different detection technologies detect large animals more or less frequently as an animal passes through the detection area or line of detection. This implies that care must be taken in evaluating the reliability of different technologies, and in comparing them to other systems or minimum performance requirements.
- The percentage of false positives and the average number of false positives per hour was relatively low for all systems ($\leq 1\%$; $\leq 0.10/\text{hr}$). False positives do not appear to be a major concern with regard to the reliability of animal detection systems.
- The percentage of false negatives (all types of false negatives combined) and the average number of false negatives per hour under the test circumstances was highly variable (0–31%; 0–1.61/hr). The percentage of intrusions (i.e., situations where at least one animal was present in the detection area) that were detected varied between 73 and 100 percent. The results suggest that false negatives are a major concern for some animal detection systems, but not for others.
- Environmental conditions influence the reliability of animal detection systems. Therefore the environmental conditions at a site should be carefully evaluated before selecting a suitable system. In addition, since the size of the species affects the reliability of some of the systems, it is also important to consider the size target species and how that may affect the reliability of a particular system. Besides system reliability, system robustness (i.e. consistent performance over time, low monitoring and maintenance effort), size of the equipment (landscape aesthetics), and the road length that the sensors are able to cover needs to be considered.
- The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests. Five of the nine systems tested met the recommended performance requirements for reliability. However, experiences with installation, operation, and maintenance show that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.
- Currently, roadside animal detection systems present drivers with warnings displayed on road signs. In the future, roadside animal detection systems may also transmit warning signals to traffic approaching a location where a large animal has been detected on or near the road. With animal detection system deployments becoming more numerous, standards for communication and ITS integration will have to be further developed and accepted.

1. INTRODUCTION

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1.1. Background

Animal–vehicle collisions affect human safety, property, and wildlife. In the United States, more than 90 percent of animal–vehicle collisions involve deer (Hughes et al., 1996), with the total number of deer–vehicle collisions estimated at more than one million per year (Conover et al., 1995). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries, and over \$1 billion in property damage a year (Conover et al., 1995). These numbers are likely to have increased even further over the last decade (Hughes et al., 1996; Romin & Bissonette, 1996; Anonymous, 2003). In most cases, the animals die immediately or shortly after the collision (Allen & McGullough, 1976). In some cases, it is not just the individual animals that suffer; some species are also affected on the population level and may even be faced with a serious reduction in population survival probability (e.g., van der Zee et al., 1992; Huijser & Bergers, 2000; Proctor, 2003). In addition, for some species a monetary value (e.g., hunting, recreation) is lost to society once an individual animal dies (Romin & Bissonette, 1996; Conover, 1997).

Historically, animal–vehicle collisions have been addressed through signs warning drivers of potential animal crossings. In other cases, wildlife warning reflectors, mirrors or wildlife fences have been installed to keep animals away from the road (e.g., de Molenaar & Henkens, 1998; Clevenger et al., 2001). However, conventional warning signs appear to have only a limited effect because drivers are likely to habituate to them (Pojar et al., 1975). Also, wildlife warning mirrors or reflectors may simply not be effective (Reeve & Anderson, 1993; Ujvári et al., 1998). Furthermore, wildlife fences can isolate populations. Wildlife fencing has been combined with wildlife crossing structures to address these limitations (e.g., Foster & Humphrey, 1995; Clevenger et al., 2002) but, primarily due to their high cost, such crossing structures are limited in number and size.

For this project, the Western Transportation Institute at Montana State University (WTI/MSU) evaluated a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape. WTI/MSU evaluated different types of animal detection systems from different manufacturers with regard to system reliability and operation and maintenance aspects. Animal detection systems detect large animals (e.g., deer, elk, moose, or pronghorn) as they approach the road. When an animal is detected, signs are activated warning drivers that large animals may be on or near the road at that time. Previous research has shown that, depending on road and weather conditions, the warning signs can cause drivers to reduce their speed (see review in Huijser & McGowen, 2003; Kinley et al., 2003; Dodd & Gagnon, 2008). Warning signs may result in more alert drivers (Green, 2000), which can lead to a substantial reduction in stopping distance: 20.7 m (68 ft) at 88 km/h (55 mi/h) (Huijser et al., 2006a). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82 percent (Kistler, 1998) or 81 percent (Romer et al., 2003). Similar results come from Arizona (91 percent; Dodd & Gagnon, 2008) and Montana (58–67 percent; Huijser et al., 2009).

While projects that evaluate individual animal detection systems remain valuable and continue to contribute to the existing knowledge, the ongoing development and implementation of animal detection system technologies can benefit by expanding beyond this limited scope. Huijser et al. (2006a) identified the remaining research questions for the emerging field of animal detection systems. Two of the most important questions that remain are how reliable the different animal detection systems really are and what the minimum standards for system reliability should be. In addition, the efforts and costs related to installation, operation, and maintenance are generally not available, and it is currently impossible to compare different systems from different vendors with regard to this important parameter.

1.1.1. Related Studies

Huijser et al. (2006a) listed all known animal detection system sites throughout Europe and North America. They also summarized experiences with the operation and maintenance of these systems. In addition, WTI/MSU has ongoing projects that evaluate the reliability and effectiveness of animal detection systems in roadside environments. WTI/MSU also documents driver opinions and experiences with operation and maintenance. One system, installed in the fall of 2002, is located along U.S. Highway 191 in Yellowstone National Park in Montana. This WTI/MSU Pooled Fund Study is funded by the Federal Highway Administration (FHWA) and 15 departments of transportation: the Alaska Department of Transportation and Public Facilities, and the California, Indiana, Iowa, Kansas, Maryland, Montana, Nevada, New Hampshire, New York, North Dakota, Oregon, Pennsylvania, Wisconsin, and Wyoming Departments of Transportation.

As of August 2006, only some of the vendors of animal detection systems have actually installed their animal detection systems at one or more sites (Huijser et al., 2006a). In addition, some systems that have been installed are not yet operational and others have been abandoned for various reasons (Huijser et al., 2006a). Few animal detection systems have been studied with regard to system reliability and system effectiveness. Examples include the area-cover systems in Switzerland (Kistler, 1998; Romer et al., 2003) and Finland (Muurinen & Ristola, 1999; Taskula, 1999), the systems in Wyoming (Gordon et al., 2001; Gordon & Anderson, 2002) and the area-cover system in Kootenay National Park, Canada (Kinley et al., 2003). Some studies have not yet been completed (e.g., Huijser et al., 2006a), but most systems have never been evaluated properly, and the information with regard to those systems remains anecdotal at best.

1.2. Project Outline

In order to select the most reliable animal detection system and to gain insight in the cost–benefit ratio of different systems, it is important to compare the different systems with regard to system reliability and operation and maintenance aspects. Until now, this comparison has been problematic due to the following factors:

- a. Most systems have not been properly studied, or the results have not been published;
- b. Different studies have evaluated systems with regard to different parameters;
- c. Different studies used different methods; and
- d. Different systems have been evaluated under varying conditions (e.g., varying road and climate conditions).

Therefore, WTI/MSU evaluated different types of animal detection systems from different vendors at the same site and under similar circumstances. Phase 1 of the project involved designing and implementing the backbone of the “Roadside Animal Detection Systems” (RADS) test-bed in a controlled access environment, followed by the installation of selected animal detection systems. During Phase 2, WTI/MSU measured the reliability and the costs and benefits of the systems. For the final phase, Phase 3, several sites in Montana were reviewed for possible installation of the best performing animal detection system. Finally, the project provided tech transfer to transportation agencies, including FHWA and the Montana Department of Transportation (MDT), vendors of animal detection systems, the general public, and the scientific community.

1.3. Project Goals and Objectives

The objectives of this project were to:

- Develop a high-level concept of operations that includes transportation agencies, the traveling public, vendors of animal detection systems, and researchers.
- Design and implement the RADS test-bed backbone utilizing a systems engineering approach.
- Install selected animal detection systems in the RADS test-bed backbone.
- Measure and compare the reliability of the different types of animal detection systems from different vendors included in the RADS test-bed.
- Document the experiences with installation and operation and maintenance, including system costs.
- Review the animal detection systems included in the RADS test-bed with regard to National ITS Architecture standards.
- Develop standards for recommended performance requirements of animal detection systems.
- Promote cooperation and communication between transportation agencies and vendors.
- Provide feedback to vendors to help them build systems that meet national ITS architecture standards and recommended performance requirements.
- Review one or more sites in Montana for possible installation of an animal detection system.
- Provide the study results to the funders, including FHWA and MDT, and advise them on future investments in animal detection systems and their potential applications.
- Provide the study results to other transportation agencies, the scientific community, and the general public.

The goals, objectives, and measures of effectiveness for this project are defined in Table 1.1. The report has been organized according to these goals and objectives. The measures of effectiveness will allow us to answer the main research questions and tie back into the goals and objectives.

Table 1.1: Goals, objectives, and measures of effectiveness.

Goals	Objectives	Measures of Effectiveness
Provide a vision to transportation agencies and participating vendors of how animal detection systems may work in the future, and what criteria should be included in the RADS test-bed	Develop a high-level concept of operations	Acceptance by transportation agencies (FHWA and MDT) and vendors
Provide advice to transportation agencies on the selection of animal detection systems that are reliable and that minimize installation, operation, and maintenance costs	Design and implement RADS test-bed backbone, facilitating integration of animal detection systems	Must meet requirements
	Install selected animal detection systems in the RADS test-bed backbone	Must meet requirements
	Identify the most reliable animal detection systems	1. The percentage of false detections (false positives) for each system 2. The percentage of missed animal (or model) crossings (false negatives) for each system 3. Downtime of the system (time that the system is not operational or time that the system does not function according to the specifications of the vendor and the expectation of the researchers)
	Identify the systems that require the least installation, operation, and maintenance efforts	Document the experiences with installation, operation, and maintenance (expressed in terms of time and money, if possible)
Help develop animal detection systems that are integrated into national ITS architecture and standards, and that meet certain minimum performance requirements	Review the animal detection systems included in the RADS test-bed with regard to national ITS architecture and standards	Compare national ITS architecture and standards with that of the systems included in the RADS test-bed
	Develop recommended performance requirements	Acceptance by transportation agencies (FHWA and MDT), vendors, the general public, and researchers
	Promote cooperation and communication between transportation agencies and vendors	Document the lessons learned from public-private partnerships
	Provide feedback to vendors to help them build systems that meet national ITS architecture and standards and recommended performance requirements	Acceptance by vendors leading to modifications to their products on the long-term
Promote informed decisions on the selection and use of animal detection systems that are reliable and that minimize installation, operation, and maintenance costs	Review one or more sites in Montana for possible installation of an animal detection system	One or more sites will be evaluated with respect to a range of parameters, including historic road-kill, road characteristics, terrain characteristics, vegetation characteristics, etc.
	Provide the study results to the funders, including FHWA and MDT, and advise them on future investments in animal detection systems and their potential applications	Acceptance of the final report by the funders (FHWA and MDT)
	Provide the study results to other transportation agencies, the scientific community, and the general public	Outreach through speaking at selected conferences, the publication of peer-reviewed scientific articles in international journals, and exposure in popular media (newspapers, radio, television)

1.4. Project Location

The RADS test-bed was installed in a controlled access environment near Lewistown, Montana. WTI/MSU is using models for wildlife (i.e., domesticated species—horses and llamas) rather than wild animals. The reasons for using a controlled access environment and models for wildlife are:

- A controlled access environment reduces or eliminates vandalism, theft, and accidents. The reduction or elimination of such events minimizes operation and maintenance costs as well as liability risks during the project.
- A controlled access environment allows for a better comparison of the reliability of the different animal detection systems by reducing or eliminating vandalism, theft, and accidents that may confound the results of the study. Although a “real world” setting could potentially result in new or additional experiences with operation and maintenance, it may not result in a fair comparison of these aspects as not all systems may suffer equally from vandalism, theft, or accidents. A controlled access environment is the best guarantee for similar circumstances for a comparison of the reliability of the different animal detection systems.
- A controlled access environment reduces the number of parties involved in the project. This makes the project easier to manage and improves adherence to the schedule.
- A controlled access environment allows the project to direct the majority of the resources to the actual comparison of the animal detection systems rather than to incident management.
- By using models for wildlife, rather than wild animals, WTI/MSU can control the number and location of “animal movements.” This allows for a shorter test-bed and testing period. A shorter test-bed greatly reduces the costs for sensors, poles, other equipment, and operation and maintenance. A shorter testing period allows us to complete the project in a shorter time frame.
- Vendors are more likely to donate equipment for the duration of the study if the risk of vandalism or theft is reduced, and the number of sensors and other equipment required is minimized.

However, there are some drawbacks to a controlled access environment and working with models for wildlife. WTI/MSU has addressed these issues as follows.

- A controlled access environment is not the same as a real roadside environment. However, other systems installed in real roadside environments have already given insight into problems that may be encountered there (see review in Huijser et al., 2006a). Furthermore, a project such as this is already challenging from a technical perspective making it wise to eliminate unnecessary risks. The project is primarily aimed at comparing different technologies rather than exploring the hazards of a roadside environment.

- Models for wildlife may differ from wild animals, so WTI/MSU has selected models (llamas and horses) that are relatively similar in size to the “target” species (e.g., deer, pronghorn, elk, or moose).

WTI/MSU installed the RADS test-bed on the grounds of Lewistown airport in Montana. Since part of the airport is being transformed into a cold region and rural transportation research, maintenance and operations test-bed (“TRANSCEND”), it provides an ideal location for the RADS test-bed as this project aims to test technology under a range of weather conditions, especially cold weather. Furthermore, animal detection systems typically find their applications in rural settings. However, the following challenges had to be addressed:

- Poles and equipment had to be installed next to a paved road section that one can drive on to mimic traffic for potential future research efforts. This causes potential conflicts with other uses that may not allow for any obstacles near the paved sections. However, since the test-bed is relatively short (91 m (300 ft)), the researchers were able to find a suitable location. To reduce safety risks, all poles for the detection equipment were equipped with a break-away system.
- The location had to be relatively close to existing power lines (110 V). Using power from the grid rather than solar panels or generators allowed the researchers to focus on the comparison of the different technologies, rather than potential challenges with different power sources.
- Because domesticated animals (horses and llamas) were used as wildlife models, an enclosure had to be constructed. Arrangements were made for the feeding and care of the animals, and permits were obtained to have the animals be part of an experiment.

2. CONCEPT OF OPERATIONS

Author: Marcel P. Huijser, Western Transportation Institute, College of Engineering, Montana State University

2.1. Systems Concepts Studied

This study deals with animal detection systems based along the road only. It does not deal with animal warning systems or vehicle-based detection systems. Animal warning systems detect vehicles or trains and then alert large animals through a range of audio and visual signals from stations placed in the right-of-way (for details and discussion see Bushman et al., 2001; Huijser and McGowen 2003; Hunin 2005; Mulka 2008). Vehicle-based systems (e.g., Bendix, 2002; General Motors, 2003; Hirota et al., 2004; Honda, 2004) only inform drivers of the possible presence of animals in vehicles equipped with such a detection system. Road-based animal detection systems, however, are designed to inform all drivers, regardless of what equipment their vehicle may or may not have.

2.2. Concept of Operation

A road-based animal detection system consists of two parts: one part detects large animals as they approach the road, and the other part warns the drivers after detection has occurred (Figure 2.1). A transportation agency or natural resource management agency usually takes the initiative for site- and species-specific mitigation measures. Site selection is often based on accident reports and road mortality data for large animal species. The transportation agency and natural resource management agencies then decide on the appropriate mitigation measure, in this case an animal detection system. After a detection technology and vendor have been selected, an animal detection system is built and delivered by the vendor. An installation contractor then puts the system in place.

Once the system is installed and working according to the agreed-upon specifications, the transportation agency may operate and maintain the system. In some cases natural resource management agencies may assist with checking up on the system. Currently most systems have to be checked at the site regularly to verify that the system is indeed operating correctly. In some cases there is remote access to the detection data and system diagnostics through land-based phone lines, or cellular or satellite phone. In the future there may be algorithms in place that screen the data continuously for unusual patterns that may indicate that there is a problem with the system or parts thereof. Once a problem with the system is detected, a person may be notified through an automated system. Figure 2.1 shows the concept of operations for animal detection systems. Arrows indicate the direction of output and processes. Solid lines indicate output and processes that exist already. Dotted lines indicate output and processes that may be developed in the future.

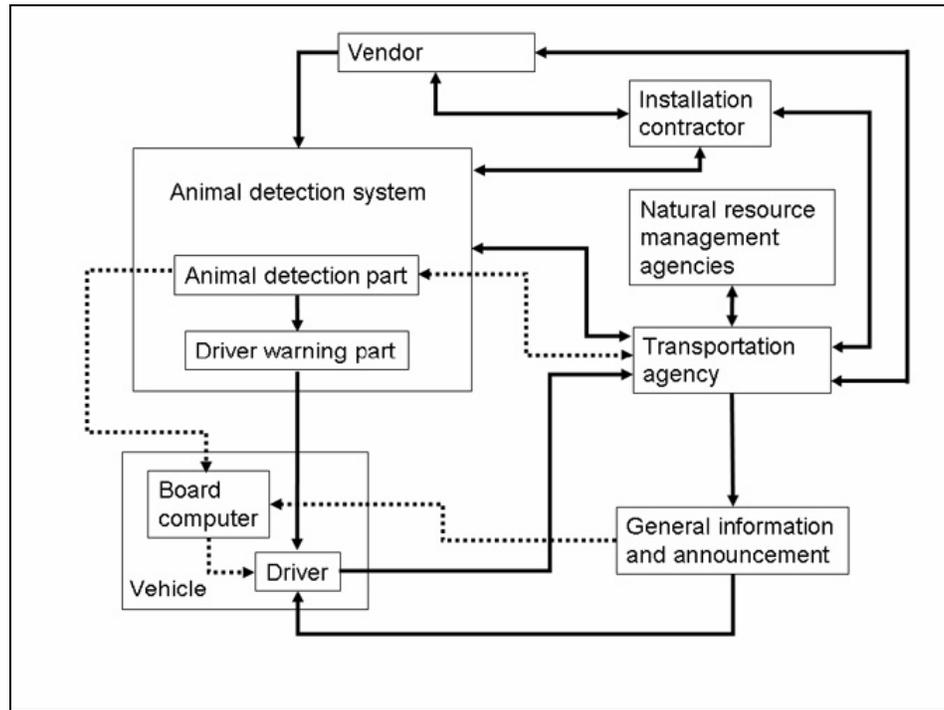


Figure 2.1: Concept of operations

The transportation agency provides information to the traveling public about the purpose and the location of the animal detection system. This information should be provided just before drivers get to the area covered by the animal detection system. Road signs and highway advisory radio messages are the most obvious ways to deliver this information to the driver. When approaching the animal detection system a driver may be confronted with an activated warning signal indicating that a large animal has been detected and is present on or near the road at that time.

In the future the information about the purpose and the location of the animal detection system may also be delivered to an on-board computer inside the vehicle. The information would be provided as soon as the vehicle gets within a certain radius of the animal detection system. This procedure would require a two-way GPS-based communication system. The warning signal may also be delivered to an on-board computer inside the vehicle.

2.3. System Reliability and Effectiveness

In order 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 there is no animal present. Numerous false positives may result in drivers regarding the system no differently than a permanently flashing warning light not connected to sensors, thus failing to convey the warning for acute danger. False negatives should be avoided or kept to an absolute minimum, as drivers expect an animal detection system to detect all or nearly all large animals that approach the road. False positives should also be minimized, but it is probably more acceptable to have a few false positives than a few false negatives. Nevertheless, it is important that animal detection systems are reliable, 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. Figure 2.2 splits driver response into two components: increased driver alertness and lower vehicle speed.

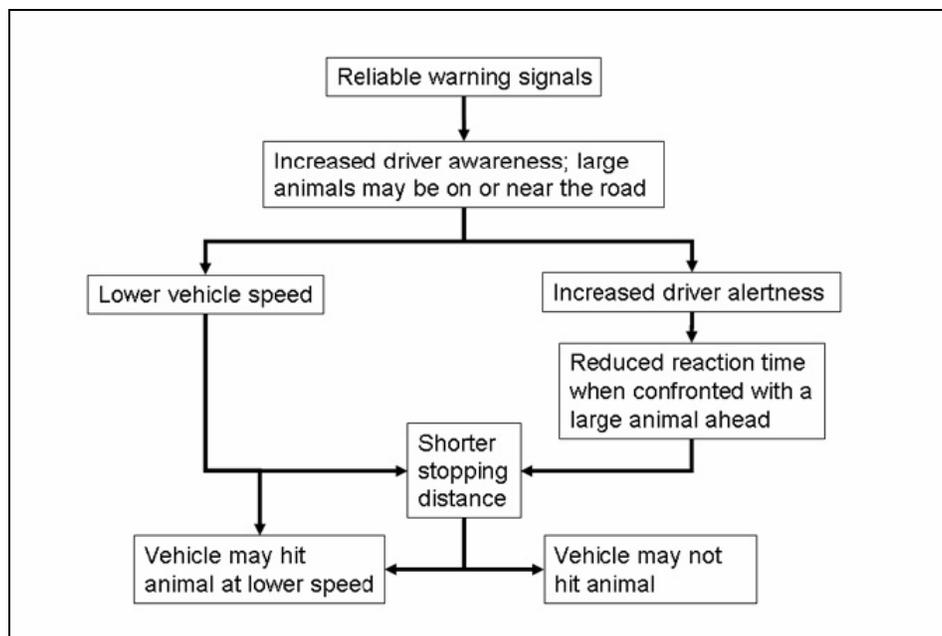


Figure 2.2: Warning signals and driver response

A higher state of alertness of the driver, lower vehicle speed, or a combination of the two can result in a reduced risk of a collision with the large animal or less severe collisions. A 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 will have to be removed, transported, and disposed of by road maintenance crews.

3. TEST-BED DESIGN, DETECTION SYSTEMS, AND TEST ANIMALS

Authors: Marcel P. Huijser, Tiffany D. Holland, Matt Blank & Shaowei Wang, Western Transportation Institute, College of Engineering, Montana State University

3.1. Test-Bed Location and Design

The RADS test-bed is part of the TRANSCEND cold region rural transportation research facility and is located along a former runway at the Lewistown Airport in central Montana (Figure 3.1). The test-bed location experiences a wide range of temperatures, and precipitation ranges include mist, heavy rain, and snow; the topography is flat, and the rocky soil does not sustain much vegetation that may obstruct the signals transmitted or received by the sensors. The test-bed consists of an animal enclosure, nine different animal detection systems, and six infrared cameras with continuous recording capabilities (Figures 3.2 through 3.5). The distance covered by the systems (except for System 9) was 91 m (300 ft) (from the left to the right side of the enclosure).



Figure 3.1: The location of the test-bed along a former runway at the Lewistown Airport in central Montana. The current municipal airport is located on the upper right of the photo.

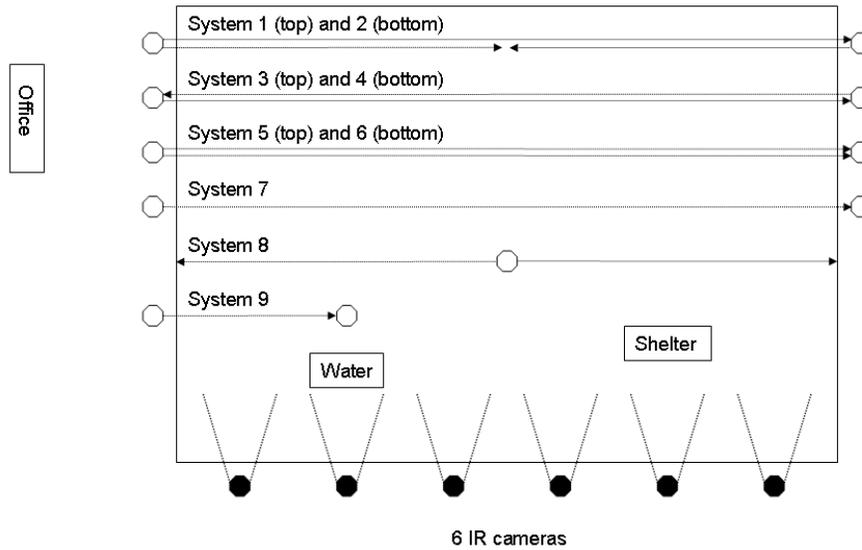


Figure 3.2: Test-bed design including an animal enclosure, the nine detection systems (open circles represent the sensors), the six infrared (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. The arrows show the direction towards which each sensor or transmitter is pointed.



Figure 3.3: The test bed with the remote office, poles with animal detection systems attached to them, the shelter, and a llama (Photo: Marcel Huijser, WTI/MSU).



Figure 3.4: Some of the sensors of the animal detection systems (Photo: Marcel Huijser, WTI/MSU).



Figure 3.5: The infrared cameras that monitor animal movements in the enclosure (Photo: Marcel Huijser, WTI/MSU).

The animal enclosure includes shelter, water, and several areas alongside the fence designated for feeding. These three resources are located in different parts of the enclosure to maximize animal movement through the detection areas.

3.2. Animal Detection Systems

During the first five tests, which were conducted from January through May 2007, there were eight systems, all installed parallel to each other (Table 3.1). Five of these were area-cover systems and the other three systems were break-the-beam systems (Table 3.1). A second STS break-the-beam system was installed on July 19, 2007, resulting in a total of nine systems. Two of the systems required two detectors to cover the 91 m (300 ft) distance. One of these systems (System 8, Xtralis 1-2) had its two sensors installed on a pole in the middle of the 91 m (300 ft) distance, with the sensors facing opposite directions (Figure 3.2). The other system (System 2, Xtralis 5-6) had a detector installed at each end with the sensors facing each other (Figure 3.2). In addition, there was one system that did not cover the 91 m (300 ft) and for which only one set of sensors was available (System 9, Goodson). This system was installed across a shorter section, equivalent to the maximum distance for this particular system 27 m (90 ft) (Figure 3.2).

Table 3.1: The characteristics of the nine animal detection systems. See appendix A for manufacturer contact details.

System number (Figure 3.2)	Manufacturer and system name	ID number	System type	Signal type	Maximum range	Installation date
1	Xtralis (ADPRO)	7	Area cover	Passive IR	500 ft (152 m)	Sep 21, 2006
2	Xtralis (ADPRO)	5-6	Area cover	Passive IR	200 ft (61 m) (one detector on each side)	Sep 21, 2006
3	STS (RADS I)	1	Break-the-beam	Microwave radio (± 35.5 GHz)	¼ mi (402 m)	Oct 19, 2006
4	STS (RADS II)	2	Break-the-beam	Microwave radio (± 35.5 GHz)	Well over ¼ mi (402 m)	Jul 19, 2007
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	Break-the-beam	Laser	984 (built-up areas) –1148 ft (open areas) (300–350 m)	Sep 21-22, 2006
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	Area cover	Passive IR	328 ft (100 m)	Sep 21-22, 2006
7	Camrix (A.L.E.R.T.)		Area cover	IR ITS Camera Technology	300 ft (91 m) (Note: 1 unit detects both sides of a road)	Oct 19-31, 2006
8	Xtralis (ADPRO)	1-2	Area cover	Passive IR	200 ft (61 m) (2 detectors, one facing each way)	Aug 8, 2006
9	Goodson		Break-the-beam	Active IR	90 ft (27 m)	Dec 2006

The six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection systems on November 8–9, 2006. These cameras and a video recording system record all animal movements within the enclosure continuously, day and night. The animal detection systems saved their individual detection data with a date and time stamp. These data were compared to the images from the infrared cameras, which also had a date and time stamp, to

investigate the reliability of each system. Cones within the enclosure defined the detection zone for each system (Figure 3.6).



Figure 3.6: The detection zones and detection lines were marked with cones to be able to record the position of the animals (Photo: Marcel Huijser, WTI/MSU).

Area-cover systems are designed to detect animals within a certain area and range from a sensor. This area is typically cone-shaped—narrow close to the sensor and wider as the distance from the sensor increases (Figure 3.7). All area-cover systems tested in this study detect animals based on body heat and motion. Break-the-beam systems consist of a transmitter that transmits a signal to a receiver. Break-the-beam systems detect animals when their body blocks the signal or when the signal received by the receiver is greatly reduced. The break-the-beam systems tested in this study use infrared, laser or microwave radio signals.

The detection area is the area within which area-cover systems should detect large animals, and the detection line is the line between sensors where break-the-beam systems should detect large animals (Figure 3.7). The detection areas and detection lines were indicated by the manufacturers and were marked with cones that were visible on the images from the individual cameras. Area-cover systems have relatively large, cone-shaped detection areas, whereas break-the-beam systems have a detection line that is linear or mostly linear in shape, although the STS 1 system that used microwave signals had a 3° angle from the transmitter, which resulted in a detection area that was 2.4 m (7.8 ft) wide at 91.4 m (300 ft) from the transmitter (Pers. com., Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007).

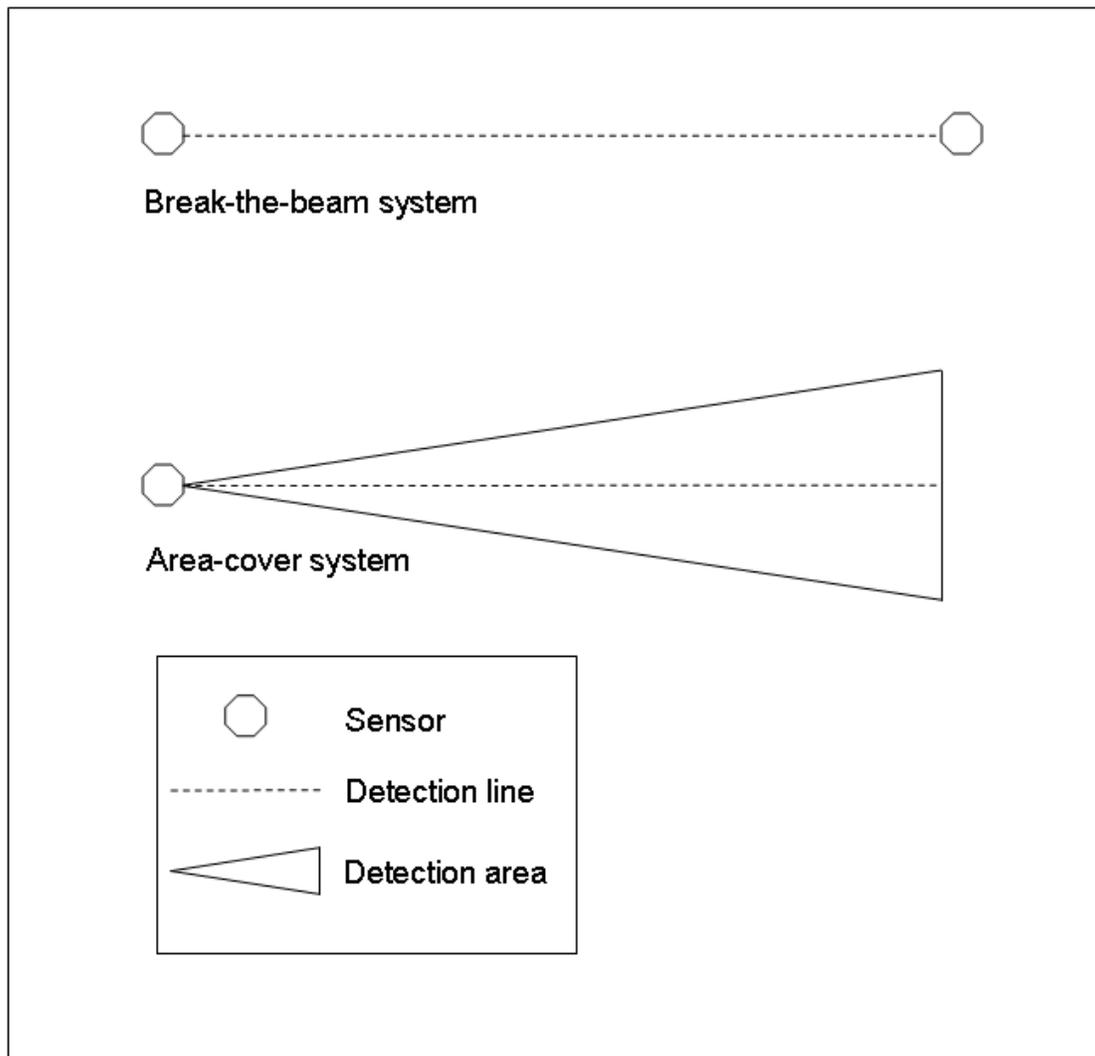


Figure 3.7: Schematic representation of break-the-beam and area-cover systems showing the detection line (or center line) for break-the-beam and area-cover systems, and the detection area for area-cover systems.

The detection technology of the different systems is described below. Photos of the systems are in Figures 3.8 through 3.14).

The Xtralis systems detect changes in infrared radiation (8–13 μm) (Pers. com., Andreas Hartmann, Xtralis, October 1, 2007), which allows the system to detect the motion of an object against a stationary background. Such motion leads to changes in infrared radiation, which are processed by the system. Filtering and algorithms help distinguish between large animals and other objects to help reduce or prevent false detections. The STS RADS systems transmit microwave radio signals (around 35.5 GHz) (Huijser et al., 2006b; Salsman & Wilson, 2006). These signals are received by a sensor on the other end, and whenever an animal or object passes

between the sensors, the signal is reduced. If certain thresholds are met, the reduction in signal strength results in a detection. RADS II is more compact than RADS I and has parts integrated into fewer components. The detection line of the STS 1 system is about 2.4 m (7.8 ft) wide at 91.4 m (300 ft) from the transmitter (Pers. com. Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). For the STS 2 system the detection line is 40.6 cm (16 in) wide consistently (Pers. com. Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). In addition, both the STS 1 and STS 2 systems have a wider detection area 4.5 m (15 ft) close to the sensors (Pers. com., Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). Calonder Energy 1 transmits a laser signal that is received by a sensor on the other end. Whenever an animal or object blocks the laser signal, the system reports a detection. Calonder Energy 1 was installed at 105 cm (41.34 in) above the ground. Calonder Energy 2 detects changes in infrared radiation as a result of objects moving 0.2–5 m/s (8 in/s – 16.4 ft/s) (Pers. com., Giacomo Calonder, Calonder Energy, September 22, 2006; Calonder Energy, not dated). Algorithms help distinguish between large animals and other objects to help reduce or prevent false detections. This system was installed 3 m (9.8 ft) above the ground, pointing downwards at a 3–5° angle. There is a blind spot of approximately 10-12 m (32.8-39.4 ft) directly under the sensor, and the detection area is about 3 m (9.8 ft) wide at 100 m (328 ft) from the sensor (Pers. com., Giacomo Calonder, Calonder Energy, October 10, 2007). This blind spot is normally covered by another passive infrared sensor with a range of 18 m (59.1 ft) (Pers. com. Giacomo Calonder, Calonder Energy, October 10, 2007). The Calonder Energy 2 system (IR-204-319/M3) was discontinued in 2007 and Calonder Energy now offers an ADPRO unit from Xtralis (Pers. com., Giacomo Calonder, Calonder Energy, October 9, 2007). The Animal Location Evasive Response Technology (A.L.E.R.T.) system from Camrix uses a camera, optics, infrared illumination, and a computer to gather and analyze digital imagery (Pers. com., Mike Doyle, Camrix, October 3, 2007). Advanced proprietary machine vision algorithms process the images and decide whether a detection should be declared. The Goodson system (TM 1550) transmits an infrared signal that is received by a sensor on the other end. Whenever an animal or object blocks the infrared signal, the system reports a detection.



Figure 3.8: System 1 (Xtralis 7) and System 2 (Xtralis 5-6) mounted on the same pole (Photo: Matt Blank, WTI/MSU).



Figure 3.9: System 3 (STS I; black tube behind pole) and System 4 (STS II; white sensor in front of pole) mounted on the same pole (Photo: Tiffany Holland, WTI/MSU).



Figure 3.10: System 5 (Calonder Energy 1) (Photo: Marcel Huijser, WTI/MSU).



Figure 3.11: System 6 (Calonder Energy 2) (Photo: Marcel Huijser, WTI/MSU).



Figure 3.12: System 7 (Camrix) (Photo: Matt Blank, WTI/MSU).



Figure 3.13: System 8 (Xtralis 1-2) (Photo: Marcel Huijser, WTI/MSU).



Figure 3.14: System 9 (Goodson) (Photo: Marcel Huijser, WTI/MSU).

3.3. System Costs

The costs for the systems are summarized in Table 3.2. The costs are for one sensor (area-cover systems) or one sensor pair (break-the-beam systems) and associated electronics. The costs are indicated and based on quotes in the years indicated. Animal detection systems can be combined with other mitigation measures such as wildlife fencing (see conceptual drawings in Huijser et al., 2006). Dependent on the road length that needs to be covered by a system and the range of the sensors, one may calculate a price for two units (to cover both sides of a road) or a price per meter road length.

Note: ICx Radar Systems (formerly STS) has developed a new generation system (RADS III) which is quoted for \$11,616 (2009) (one transmitter and one receiver, including associated electronics, excluding installation, warning signs) (Pers. com. Dan Bjerck, ICx Radar Systems, March 18, 2009).

Note: Goodson (Trailmaster) indicated that a unit that would be customized for animal detection along roadways is likely to cost around \$1,200 (2009) (one transmitter and one receiver, including associated electronics, excluding installation, warning signs). This customized unit would have a range of about 183-305 m (600-1,000 ft) and could be powered through solar panels or connected to the grid. The unit would have the ability to be daisy chained with other units to cover longer road sections (Pers. com. Bill Goodson, Trailmaster, February 26, 2009)

Table 3.2: The characteristics of the nine animal detection systems. See appendix A for manufacturer contact details.

System number (Figure 3.2)	Manufacturer and system name	ID number	Indicative equipment costs (US\$) (yr of quote)	Included/excluded	Maximum range
1	Xtralis (ADPRO)	7	\$1,101 (2009)	Incl.: 1 sensor and (wall) mounting. Excl.: warning signs, installation materials (foundations, poles) and installation labor.	500 ft (152 m)
2	Xtralis (ADPRO)	5-6	\$844 (2009)	Incl.: 1 sensor (range 61 m) and (wall) mounting. Excl.: warning signs, installation materials (foundations, poles) and installation labor.	200 ft (61 m) (one detector on each side)
3	STS (RADS I)	1	\$13,136 (2005)	Incl.: 1 transmitter and 1 receiver and associated electronics. Excl: warning signs, installation materials (foundations, poles) and installation labor.	¼ mi (402 m)
4	STS (RADS II)	2	\$17,314 (2006)	Incl.: 1 transmitter and 1 receiver and associated electronics. Excl: warning signs, installation materials (foundations, poles) and installation labor.	Well over ¼ mi (402 m)
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	\$12,737 (2006) \$9,000 (2009)	Incl.: 1 transmitter and 1 receiver and associated electronics. Excl: warning signs, installation materials (foundations, poles) and installation labor. Incl.: 1 laser unit, wiring, control box, and pole. Excl.: installation.	984 (built-up areas)–1148 ft (open areas) (300–350 m)
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	\$8,000 (2009)	Incl.: 1 sensor unit, wiring, control box, and pole. Excl: installation.	328 ft (100 m)
7	Camrix (A.L.E.R.T.)		\$14,400	Incl: 1 camera, computer, enclosure, solar panel, and battery. Excl: installation hardware (pole, associated hardware) signage, labor.	300 ft (91 m)
8	Xtralis (ADPRO)	1-2	\$844 (2009)	Incl.: 1 sensor (range 61 m) and (wall) mounting. Excl.: warning signs, installation materials (foundations, poles) and installation labor.	200 ft (61 m) (2 detectors, one facing each way)
9	Goodson		\$260 (2009)	Incl.: 1 transmitter and 1 receiver and associated electronics. Excl: warning signs, installation materials (foundations, poles) and installation labor.	90 ft (27 m)

3.4. Wildlife Target Species and Models

In a North American setting, animal detection systems are typically designed to detect white-tailed deer (*Odocoileus virginianus*) and/or mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*) or moose (*Alces alces*). For this study, which took place within an enclosure, two horses and two llamas were used as models for these wildlife target species. Horses are similar in body shape and size to moose, whereas the body shape and size of llamas is similar to deer (Tables 3.3 and 3.4). The body size and weight of the individual horses and llamas used in this experiment are shown in Table 3.5.

Table 3.3: Height and length of wildlife target species and horses and llamas.

Species	Height at shoulder	Length (nose to tip of tail)	Source
Target species			
Moose	195-225 cm (6'5"-7'5")	206-279 cm (6'9"-9'2")	Whitaker (1997)
Elk	137-150 cm (4'6"-5')	203-297 cm (6'8"-9'9")	Whitaker (1997)
White-tailed deer	68-114 cm (2'3"-3'9")	188-213 cm (6'2"-7')	Whitaker (1997)
Mule deer	90-105 cm (3'-3'5")	116-199 cm (3'10"-7'6")	Whitaker (1997)
Pronghorn	89-104 cm (2'11"-3'5")	125-145 cm (4'1"-4'-9")	Whitaker (1997)
Models			
Feral horse	142-152 cm (4'8"-5')		Whitaker (1997)
Quarter horse	150-163 cm (4'11"-5'4")		UHS (2007), Wikipedia (2007)
Llama	91-119 cm (3'-3'11")		Llamapedia (2007)

Table 3.4: Body weight of wildlife target species and horses and llamas.

Species	Weight male	Weight female	Source
Target species			
Moose	400-635 kg (900-1400 lbs)	315-500 kg (700-1,100 lbs)	Whitaker (1997)
Elk	272-494 kg (600-1089 lbs)	204-295 kg (450-650 lbs)	Whitaker (1997)
White-tailed deer	68-141 kg (150-310 lbs)	41-96 kg (90-211 lbs)	Whitaker (1997)
Mule deer	50-215 kg (110-475 lbs)	32-73 kg (70-160 lbs)	Whitaker (1997)
Pronghorn	41-64 kg (90-140 lbs)	34-48 kg (75-105 lbs)	Whitaker (1997)
Models			
Feral horse	360-390 kg (795-860 lbs)	270-340 kg (595-750 lbs)	Whitaker (1997)
Quarter horse	386-540 kg (850-1200 lbs)		UHS (2007), Wikipedia (2007)
Llama	113-204 kg (250-450 lbs)		Llamapedia (2007)

Table 3.5: Body size and weight of the horses and llamas used in the experiment (Pers. com., Lethia Olson, livestock supplier).

Individual	Height at shoulder	Weight
Horse 1	152 cm (5')	513 kg (1,130 lbs)
Horse 2	160 cm (5'3'')	658 kg (1,450 lbs)
Llama 1	104 cm (3'5'')	168 kg (370 lbs)
Llama 2	110 cm (3'7½'')	213 kg (470 lbs)

3.5. Research

The research at the TRANSCEND test facility focused on two main questions, which are addressed in subsequent chapters:

- How reliable are the animal detection systems in detecting large mammals (horses and llamas) (Chapter 4)?
- Is the reliability of the animal detection systems influenced by environmental conditions (Chapter 5)?

4. RELIABILITY TESTS

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4.1. Test Periods, Data Selection, and Data Storage

There were eight test periods with test animals between January 10, 2007 and December 9, 2007 (Table 4.1). Each test period with animals lasted 7–11 days.

Table 4.1: Test periods with animals present.

Test period	Start	End
1	January 10, 2007	January 17, 2007
2	February 19, 2007	February 28, 2007
3	March 16, 2007	March 25, 2007
4	April 22, 2007	May 2, 2007
5	May 24, 2007	June 3, 2007
6	July 20, 2007	July 30, 2007
7	August 23, 2007	September 3, 2007
8	November 30, 2007	December 9, 2007

Camera images were recorded on site on a hard drive that is capable of storing 10–14 days of data. Camera images from three types of time periods were reviewed and compared to the detection logs of the individual systems to measure the reliability of each system:

- Stratified random with animals present: Three, one-hour-long sections of video were randomly selected for each test day for review.
- Non-random with animals present: These time periods were chosen based on the occurrence of unusual detection patterns (i.e., times with an unusually high or low number of detections) and certain weather events. Some of these weather events included the occurrence of precipitation (i.e., rain, snow or sleet), extreme temperatures (hot or cold), and low visibility (i.e., fog, heavy rain or snow). The length of time reviewed depended upon the length of the event itself; the time period analyzed varied in length.
- Non-random without animals present: After each test with horses and llamas present, images were recorded for an additional 12–14 days (during these days there were no

domesticated animals present). This is the maximum number of days that could be stored on the hard drive. Additional non-random time periods were selected from these days. These time periods were also chosen based on unusual detection patterns and certain weather conditions.

The images that were analyzed were all saved on DVD. Time periods that were not analyzed were not saved. The number of hours from which images were analyzed for each system is listed in Table 4.2.

Table 4.2: The number of hours from which images were analyzed for each system.

System number (Figure 3.2)	Manufacturer and system name	ID number	Stratified random with animals present (hours)	Non-random with animals present (hours)	Non-random without animals present (hours)	Total (hours)
1	Xtralis (ADPRO)	7	225.0	16.9	28.0	269.9
2	Xtralis (ADPRO)	5-6	225.0	16.9	28.0	269.9
3	STS (RADS I)	1	225.0	16.9	28.0	269.9
4	STS (RADS II)	2	91.0	5.5	20.2	116.7
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	225.0	16.9	28.0	269.9
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	225.0	16.9	28.0	269.9
7	Camrix (A.L.E.R.T.)		225.0	16.9	28.0	269.9
8	Xtralis (ADPRO)	1-2	225.0	16.9	28.0	269.9
9	Goodson		225.0	16.9	28.0	269.9

A modification to the Camrix system towards the end of the field tests (29 November 2007, see Table 5.2, Chapter 5) resulted in a significant change in the reliability performance of the system (see Table 5.4, Chapter 5). Therefore, the reliability parameters for the Camrix system presented in this current chapter are not only presented as totals for the entire study period, but they are also presented separately before and after system modification took place. The number of hours

from which images were analyzed for the Camrix system before and after system modification are:

- Stratified random with animals present: before: 197.0; after: 28.0.
- Non-random with animals present: before: 13.4; after: 3.5.
- Non-random without animals present: before: 15.5; after: 12.5 (8.0 with detection data available and 4.5 with no detection data available).
- Total: before: 225.9; after: 44.0 (39.5 with detection data available and 4.5 with no detection data available).

4.2. Video Review and Reliability Parameters

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

- *Valid detections* – A valid detection was defined as “the presence of an animal within the detection zone of the system in conjunction with a corresponding detection recorded by the system’s data logger.” The number of valid detections depends on the frequency with which a system “scans” for the presence of an animal. Sensors that sense an area typically sense continuously and have, by definition, more detections than break-the-beam systems that only sense the presence of an animal when it crosses the detection line (which is a much smaller “area”). Some break-the-beam systems also have a “reset” period after a detection before the system can report the next detection. For the time periods reviewed, the date, time, and species were recorded for all valid detections.

Cases in which humans, birds, dogs, or other non-target species entered the enclosure were not considered in evaluating valid detections. However, in the rare circumstance when a deer happened to enter the enclosure, the incident was included in the analysis, and it was evaluated for valid detections in the same manner as described above.

- *False positives* – A false positive was defined as “when the system reported the presence of an animal, but there was no animal in the detection zone.” Thus, each incident in which a system’s data logger recorded a detection, but there was no animal present in the detection zone of that system, was recorded as a false positive. The date and time were recorded for all false positives.

Cases in which humans, birds, dogs, or other non-target species entered the enclosure were considered a valid explanation for a detection and were not recorded as a false positive.

- *False negatives* – A false negative was defined as “when an animal was present but was not detected by the system.” However, due to animal behavior and the design of some detection systems (i.e., some systems are desensitized by the continuous presence of an animal), there are several ways for a false negative to occur. Therefore, various types of false negatives were distinguished and these were recorded separately. The date, time, and species were recorded for each type of false negative.

The simplest type of false negative, recorded as “false negative,” occurred when an animal completely passed through “the line of detection” without lingering but was not detected by the system. The line of detection was defined by the straight line between either end of the system (in the case of break-the-beam systems, or area-cover systems that are relatively narrow— up to 4.6 m (15 ft) or a line through the center (or close to the center) of a wide detection area (wider than 4.6 m (15 ft); System 7 (Camrix A.L.E.R.T.)) (see Figure 3.7). If an animal lingered in the detection zone but did not completely cross the line of detection or centerline, it was not deemed a false negative. After a valid detection at least three minutes had to pass before another animal movement across the centerline could be viewed as a false negative. However, if two or more animals passed the centerline within three minutes of each other, and if they were all detected, all passages were considered a valid detection across the centerline. The three minute “reset” period was put in effect because:

- Some sensors are desensitized after a detection and need some time before they can detect another animal. For example, the vendor of the STS 1 system recommends three minutes reset time for the sensors to become fully sensitive again after a detection.
- The warning signs of an animal detection system need to stay activated for a certain amount of time after a detection anyway. Therefore it is not essential to have an animal detection system detect multiple animals within a short time. Based on an analysis of patterns in the detection data from a field site it was concluded that it seemed appropriate to have warning signs be activated for three minutes after a detection had occurred. The three minute time period was found to be an appropriate balance between warning the drivers for animals that may still linger on or close to the road and not exposing drivers to unnecessary warnings.

Another type of false negative, recorded as “false negative 1,” occurred when an animal lingered in the detection zone before completely passing through the line of detection without a detection by the system. If the system did not detect the animal as it completely passed through the line of detection, and if it was three minutes or longer since the system last detected an animal, it was considered a false negative. If the system did not detect the animal as it completely passed through the line of detection, and it was less than three minutes since the system last detected an animal, it was considered neither a false negative nor a valid detection.

A third type of false negative, recorded as “false negative 2,” occurred when one animal lingered in the detection zone without a detection by the system, while a second animal (or multiple animals) completely passed through the line of detection. If the system did not detect the second animal as it completely passed through the line of detection, and it was three minutes or longer since the system last detected an animal, it was considered a false negative. If the system did not detect the animal as it completely passed through the line of detection, and it was less than three minutes since the system last detected an animal, it was considered neither a false negative nor a valid detection.

In addition to valid detections, false positives and false negatives, the total number of times an animal should have been detected was recorded. The number of times an animal should have

been detected was the sum of the number of times an animal crossed the line of detection and was detected and the total number of false negatives, regardless of the type of false negative.

Cases in which humans, birds, dogs, or other non-target species entered the enclosure were not considered in evaluating false negatives. However, when deer entered the enclosure, the incident was included in the analysis.

- *Intrusions in detection area* – An intrusion was defined as “the presence of one or multiple animals in the detection zone.” An intrusion began when one or more animals entered the detection zone and ended when all animals left the detection zone. Each intrusion resulted in one of the three event types described below. The event types were hierarchical—while an intrusion was in progress, the classification could change from E2 to E1, from E3 to E2, or from E3 to E1, but not from E1 to E2 or E3 or from E2 to E3.

The first type of event, classified as “event 1” or “E1,” occurred when an animal entered the detection zone and was detected by the system.

The second type of event, classified as “event 2” or “E2,” occurred when an animal completely crossed the line of detection but was not detected by the system. After each valid detection, there was a reset time of three minutes before evaluating that system for an event 2.

The third type of event, classified as “event 3” or “E3,” occurred when an animal entered the detection zone but did not fully pass through the line of detection and was not detected by the system. After each valid detection, there was a reset time of three minutes before evaluating that system for an event 3. If an animal entered the detection zone within three minutes of the last valid detection and if it remained in the detection zone after the three-minute reset time had expired, it was evaluated for an event 3. Date, time, and species were recorded for each event 3.

Event 3 was only analyzed with regard to System 7 (Camrix A.L.E.R.T.). This was the only system that had a large enough detection area on either side of the detection line to accurately analyze for an event 3. For all other systems, if the animal was at the centerline or in the narrow detection zone, and it did not fully cross the centerline (e.g., it turned back), and the animal was not detected, it was not an event. In addition, event 3 applied only to System 7 (Camrix A.L.E.R.T.) because all other area sensors that were tested acted more like break-the-beam systems (i.e., they were more sensitive to movement near the centerline), whereas System 7 (Camrix A.L.E.R.T.) was equally sensitive to movement in all areas of the detection zone.

- *Downtime* – Downtime was defined as “the time when the system was not working at all or when it was not working according to the expectations of the researchers or the specifications of the vendor.” Date, time, and duration of downtime were recorded for each system.

4.3. Data Analyses

Since this chapter focuses on the reliability of the animal detection systems, only the stratified random time periods were selected for the data analyses. Non-randomly selected time periods would result in a bias for one or more systems because the non-random periods were selected, in

part, because of unusual detection patterns for one or more systems. The data were combined for all test periods. However, time periods that were classified as downtime or time periods for which no detection data were available due to external circumstances (e.g., power outage) were excluded from the analyses.

The following parameters were calculated for each system:

- The average number of valid detections per hour:

$$\bar{N}_{t(\text{valid detections})} = \frac{N_{t(\text{valid detections})}}{N_{h(\text{with data available})}}$$

Where:

$N_{t(\text{valid detections})}$ = total number of valid detections

$N_{h(\text{with data available})}$ = total number of hours for which detection data were available

- The percentage of false positives for each system:

$$F^+ = \frac{F_N^+}{N_{t(\text{detections recorded by system})}} * 100 = \frac{F_N^+}{N_{t(\text{valid detections})} + F_N^+} * 100$$

Where:

F_N^+ = total number of false positives

$N_{t(\text{detections recorded by system})}$ = total number of detections recorded by a system

$N_{t(\text{valid detections})}$ = total number of valid detections

- The average number of false positives per hour for each system:

$$\bar{F}^+ = \frac{F_N^+}{N_{h(\text{with data available})}}$$

Where:

F_N^+ = total number of false positives

$N_{h(\text{with data available})}$ = total number of hours for which detection data were available

- The percentage of false negatives for each system:

$$F^- = \frac{F_N^-}{N_{t(\text{center line})}} * 100 = \frac{F_N^-}{N_{d(\text{center line})} + F_N^-} * 100$$

Where:

F_N^- = total number of false negatives (false negatives, false neg. 1, and false neg. 2)

$N_{t(\text{center line})}$ = total number of times an animal crossed the centerline and should have been detected

$N_{d(\text{center line})}$ = total number of times an animal crossed the centerline and was detected

Note that the percentage was calculated for false negatives, false negatives 1, and false negatives 2 individually. Since the total number of false negatives varied between these categories, the sum of the percentages for false negatives, false negatives 1, and false negatives 2 do not equal the percentage of the total number of false negatives.

- The average number of false negatives per hour for each system:

$$\bar{F}^- = \frac{F_N^-}{N_{h(\text{with data available})}}$$

Where:

F_N^- = total number of false negatives

$N_{h(\text{with data available})}$ = total number of hours for which detection data were available

Note that the percentage of false negatives was also calculated for false negatives, false negatives 1, and false negatives 2 individually.

- The percentage of intrusions detected for each system (i.e., animal presence in the detection area):

$$I_{\% \text{ detected}} = \frac{I_d}{I_t} * 100 = \frac{E_1}{E_1 + E_2} * 100$$

For System 7 (Camrix) the percentage of intrusions detected for each system was also calculated in a different way. This second calculation was possible because the detection area for system 7 was large enough for the researchers to distinguish between different types of intrusions. The detection area for the other systems was linear in shape and did

not allow the researchers to distinguish between certain types of intrusions. The alternative way to calculate intrusions for system 7 (Camrix) was:

$$I_{\% \text{ detected (Camrix)}} = \frac{I_{d(\text{Camrix})}}{I_{t(\text{Camrix})}} * 100 = \frac{E_1}{E_1 + E_2 + E_3} * 100$$

Where:

I_d = total number of intrusions detected

I_t = total number of intrusions

E_1 = total number of event 1

E_2 = total number of event 2

E_3 = total number of event 3

The values for the reliability parameters can be compared between the individual systems (this chapter) and recommended norms for system reliability (chapter 8). However, it is important to note that, although the test conditions were standardized as much as possible, the reliability values for the individual systems were not measured under the exact same conditions:

- The number of hours on which the reliability parameters are based was not the same for each system as the systems were not all installed at the same time, and hours classified as downtime or hours for which no data were available were excluded from the analyses.
- Even when the number of hours was the same for some of the systems and when the observations related to the same hours, the animals did not trigger the different systems at the same time. Therefore the conditions under which the reliability of the individual systems were evaluated were similar, but not exactly the same.
- Even when the number of hours was the same for some of the systems and when the observations relate to the same hours, the number of times that an animal was present in the detection area or the number of times that an animal crosses the detection line and thus should or could have been detected was different for each system.
- Even when the number of hours was the same for some of the systems and even when the observations related to the same hours, some technologies resulted in multiple detections as an animal entered the detection area or crossed the detection line, whereas other technologies would have one detection for an animal that passed through the line of detection.

Therefore, some caution should be used when comparing the values of the reliability parameters between individual systems or to recommended norms for system reliability.

4.4. Results

The number of hours that detection data were available for analyses for each system is shown in Table 4.3. The data in the table show that the reliability parameters calculated for STS II and

Calonder Energy 2 were based on relatively few hours compared to the other systems, indicating that the reliability parameters for these two systems may be less robust than for the other systems. Furthermore, Calonder Energy 2 had relatively much downtime compared to the other systems, STS I and Camrix had some downtime, and the other systems had no downtime. The number of hours for which no detection data were available due to external circumstances (e.g., power outage) is also shown in Table 4.3.

Table 4.3: The number of hours that detection data were available for analyses for each system.

System number (Figure 3.2)	Manufacturer and system name	ID number	Downtime (hours)	No detection data available (hours)	Detection data available for analyses (hours)	Total (hours)
1	Xtralis (ADPRO)	7	0	46	179	225
2	Xtralis (ADPRO)	5-6	0	46	179	225
3	STS (RADS I)	1	28	81	116	225
4	STS (RADS II)	2	0	34	57	91
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	0	76	149	225
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	134	63	28	225
7	Camrix (A.L.E.R.T.)		18	0	207	225
8	Xtralis (ADPRO)	1-2	0	46	179	225
9	Goodson		0	0	225	225

Figure 4.1 shows the average number of valid detections per hour for each system. Camrix had much higher numbers of valid detections compared to the other systems. The Xtralis systems also had relatively high numbers of valid detections. The other systems (STS I, STS II, Calonder Energy 1, Calonder Energy 2, and Goodson) had relatively low numbers of valid detections.

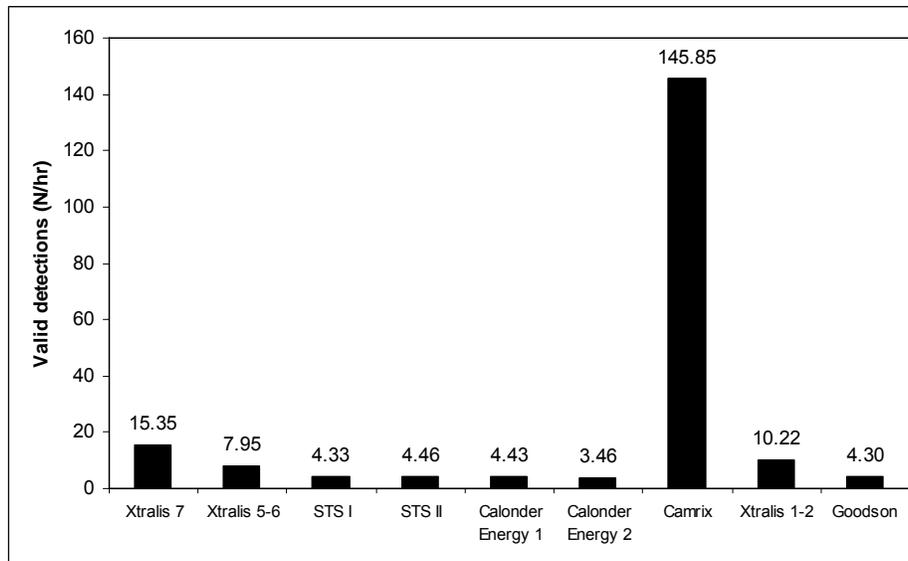


Figure 4.1: The average number of valid detections per hour for each system (Camrix: before (157.28) and after (72.79) system modification).

The percentage of false positives was relatively low for all systems. Xtralis 1-2, Goodson, Calonder Energy 1, and Camrix had some false positives while the other systems had no false positives.

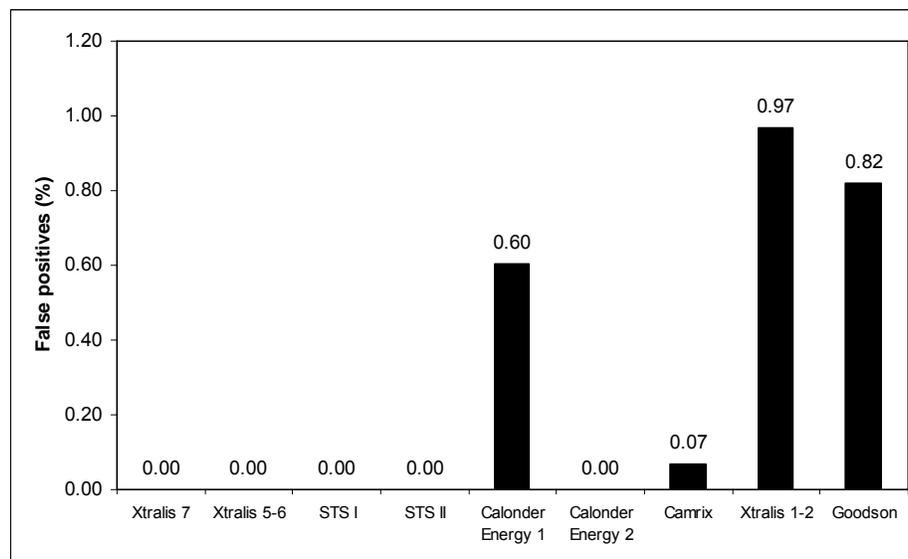


Figure 4.2: The percentage of false positives for each system (Camrix: before (0.07) and after (0.00) system modification).

The average number of false positives per hour was relatively low for all systems (Figure 4.3). Xtralis 1-2, Goodson, Calonder Energy 1, and Camrix all had fewer than 0.1 false positives per hour while the other systems had no false positives.

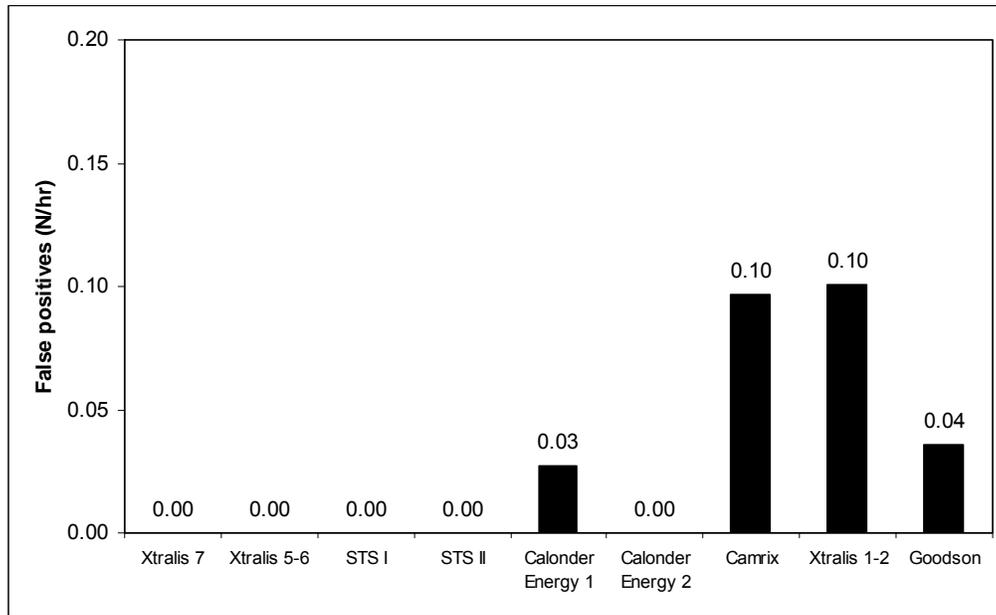


Figure 4.3: The average number of false positives per hour for each system (Camrix: before (0.11) and after (0.00) system modification).

The percentage of false negatives was lowest for Calonder Energy 1, Calonder Energy 2, and Goodson (Figure 4.4). The percentage of false negatives was highest for STS I and Camrix.

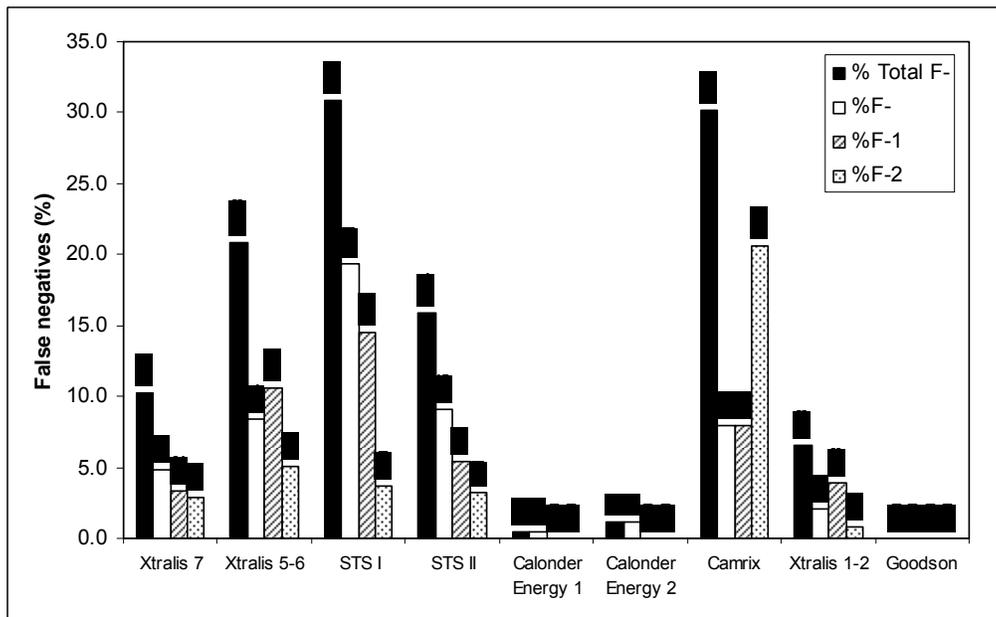


Figure 4.4: The percentage of false negatives for each system (Camrix: before (30.41; 7.00; 8.44; 21.22 respectively) and after (27.00; 20.59; 0.00; 10.00 respectively) system modification).

The average number of false negatives per hour was lowest for Calonder Energy 1, Calonder Energy 2, and Goodson (Figure 4.5). The highest values occurred for STS I and Xtralis 1-2.

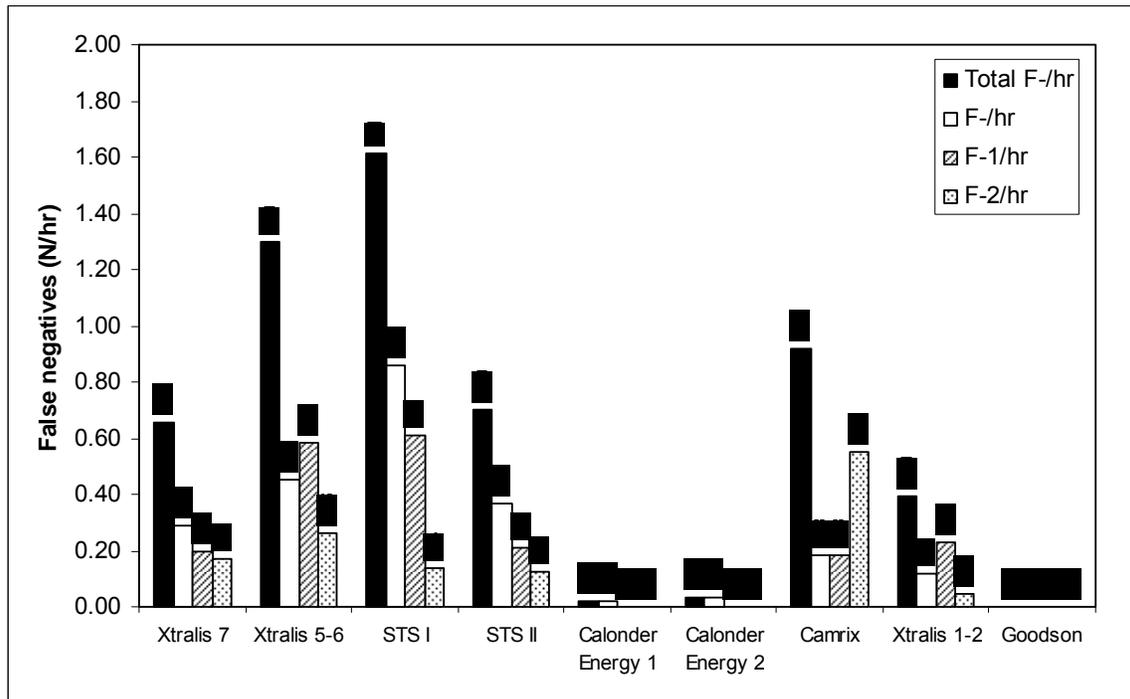


Figure 4.5: The average number of false negatives per hour for each system (Camrix: before (1.01; 0.17; 0.21; 0.62 respectively) and after (0.36; 0.25; 0.00; 0.11 respectively) system modification).

The following systems detected all or nearly all intrusions (i.e., animal movements across the detection line): Goodson, Calonder Energy 1, and Calonder Energy 2 (Figure 4.6). STS I showed the lowest detection percentage (Figure 4.6). For Camrix an additional analysis that included the detection area (see section 5.3) showed this system detected 81.2 percent of all intrusions in the detection area.

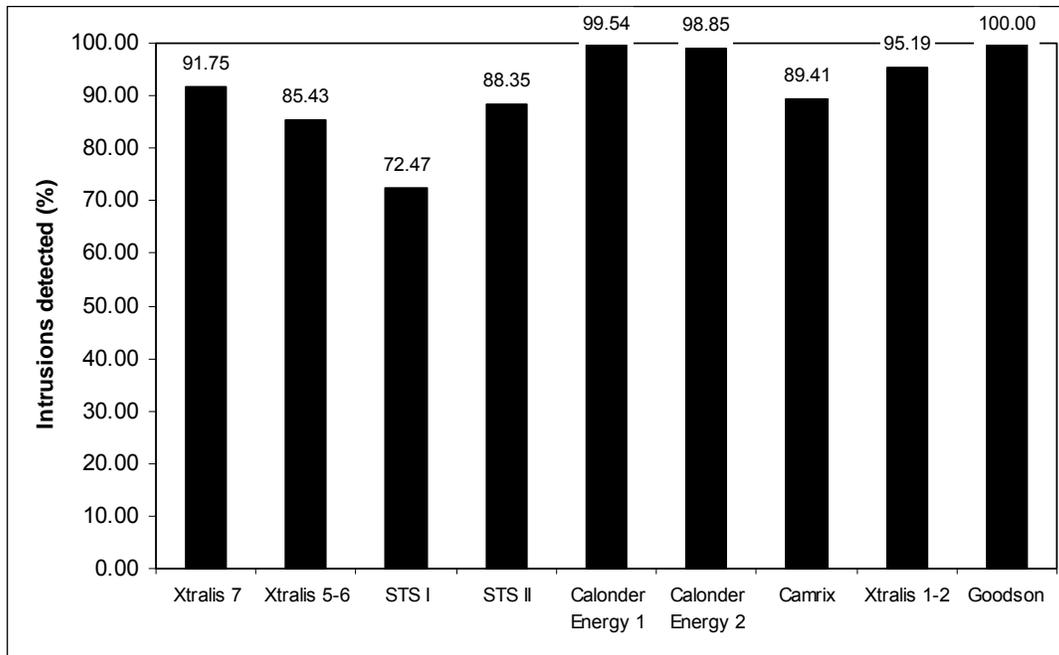


Figure 4.6: The percentage of intrusions that were detected for each system (Camrix: before (89.33; additional analysis 81.82) and after (90.24; additional analysis 75.51) system modification).

4.5. Discussion and Conclusions

Downtime for most of the systems was low or non-existent. For more information about the causes of downtime for Calonder Energy 2, STS I and Camrix, see chapter 6.

Different detection technologies detect large animals more or less frequently as an animal passes through the detection area or line of detection. This implies that care must be taken in evaluating the reliability of different technologies, and in comparing them to other systems or minimum performance requirements.

The average number of valid detections per hour was highest for Camrix, followed by the Xtralis systems. The detection technologies of these systems all allow for multiple detections when an animal passes the line of detection or walks into the detection area. Such detections typically are highly clustered in time, and a relatively high number of valid detections per hour does not necessarily imply that such systems would result in warning signs that are activated all or most of the time. In addition, the number of valid detections per hour was heavily depended ion the test conditions; i.e. the number of animals present in the enclosure. The number of valid detections of wild ungulates (e.g. deer, pronghorn, elk, or moose) along a real roadside may be very different.

The percentage of false positives and the average number of false positives per hour was relatively low for all systems ($\leq 1\%$; $\leq 0.10/\text{hr}$). False positives do not appear to be a major concern with regard to the reliability of animal detection systems.

The percentage of false negatives (all types of false negatives combined) and the average number of false negatives per hour was highly variable (0-31%; 0-1.61/hr). Note that the number of false negatives per hour was heavily depended ion the test conditions; i.e. the number of animals present in the enclosure. The number of false negatives per hour of wild ungulates (e.g. deer, pronghorn, elk, or moose) along a real roadside may be very different. The results suggest that false negatives are a major concern for some animal detection systems, but not for others.

The percentage of intrusions (i.e., animal movements across the detection line) that were detected varied between 73 and 100 percent. The results suggest that false negatives are a major concern for some animal detection systems, but not for others.

In conclusion, the results suggest that some animal detection systems are quite reliable in detecting large mammals with few false positives and false negatives, whereas the reliability of other systems suffers from relatively many false negatives.

5. INFLUENCE OF ENVIRONMENTAL CONDITIONS ON SYSTEM RELIABILITY

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5.1. Introduction

This chapter is aimed at investigating if and how environmental conditions influence the reliability of animal detection systems. For details on the nine systems tested see chapter 3. For details on the start and end date of each test period with animals present and details on how system reliability was measured see chapter 4.

5.2. Detection Data Selection

For this chapter all three detection data types were included (see also chapter 4, Table 4.2):

- Stratified random with animals present: Three, one-hour-long sections of video were randomly selected for each test day for review.
- Non-random with animals present: These time periods were chosen based on the occurrence of unusual detection patterns (i.e., times with an unusually high or low number of detections) and certain weather events. Some of these weather events included the occurrence of precipitation (i.e., rain, snow or sleet), extreme temperatures (hot or cold), and low visibility (i.e., fog, heavy rain or snow). The length of time reviewed depended upon the length of the event itself; the time period analyzed varied in length.
- Non-random without animals present: After each test with horses and llamas present, images were recorded for an additional 12–14 days (during these days there were no domesticated animals present). This is the maximum number of days that could be stored on the hard drive. Additional non-random time periods were selected from these days. These time periods were also chosen based on unusual detection patterns and certain weather conditions.

The data from non-randomly selected time periods increased the range of values for different environmental condition parameters (see next paragraph), and increased the probability that an effect of environmental conditions could be detected.

5.3. Environmental Variables

Environmental variables consisted of weather data and the animal species (llama or horse) present in the detection area or crossing the detection line. Detections caused by species other than llamas or horses were excluded from the analyses.

Weather data from the Lewistown Municipal Airport weather station, about 2.4 km (1.5 mi) distant, was entered in the database and, based on the date and time, linked to each valid detection, false positive, and false negative. Weather reports were typically available in one-hour intervals. The data generated by the weather station included:

- Date of report
- Time of report
- Station type
- Sky conditions
- Visibility—surface statute miles
- Weather type (at time of report)
- Dry bulb temperature
- Wet bulb temperature
- Dew point temperature
- Relative humidity
- Wind speed
- Wind direction
- Wind gusts
- Station pressure
- Pressure tendency
- Net three-hour change
- Sea level pressure
- Report type
- Precipitation total (since the last regular hourly report)
- Altimeter

In addition, the researchers recorded whether it was day or night at the time of each valid detection, false positive, or false negative. “Day” was defined as 30 minutes before sunrise through 30 minutes after sunset. “Night” was 30 minutes after sunset through 30 minutes before sunrise. Sunrise and sunset times were reported by the Lewistown Municipal Airport weather station.

5.4. Statistical Analyses

The effect of environmental conditions on the reliability of the nine individual animal detection systems was investigated through a multinomial logistic regression model with Akaike’s “An Information Criterion” (AIC) (Akaike, 1973) with a stepwise model selection procedure to select the most appropriate model.

For this chapter the researchers distinguished two types of situations:

- An animal is in the detection area or crosses the detection line (see chapter 3); and
- A system erroneously indicates an animal (denoted as a False Positive or FP).

When an animal is in the detection area or crosses the detection line, then the system can:

- Correctly detect the animal; or
- Fail to detect it (False Negative or FN).

Three different types of false negatives were distinguished (see chapter 4 for details):

- Regular false negative (FN): the animal completely crosses the detection line and is not detected;
- False negative 1 (FN1): the animal lingers in the detection zone before passing through the line of detection and is not detected; and
- False negative 2 (FN2): one animal lingered in the detection zone and other animals passed through the line of detection without being detected.

Thus there were five different possible response categories:

- Correct detection
- False positive
- Regular false negative
- False negative 1
- False negative 2

However, not all responses were observed for all systems.

Overall rates of errors were not used in this analysis for three reasons:

- The rate that each system “fires” or “detects” is different for each system (see chapter 4);
- The detection areas differ in size and location for the different systems (see chapter 3), and;
- Non-randomly selected times were included in the analyses for this chapter to increase the range of values for parameters describing the environmental conditions.

Instead, system errors were related to correct detections through logistic regression models. Logistic regression models use categorical responses to model probabilities of success using the logistic link function ($\log(\pi/(1-\pi))$), which leads to modeling on the log-odds scale. If a random sample of a certain number of events was considered and the different systems produced the same number of events per time, then the probability of each type of event could be considered. However, the different sampling rates of the systems (see chapter 4) could lead a system with a higher rate to record a single animal crossing 10 times whereas another system might only record one animal crossing. Even if the success rate is the same in both systems, the opportunities for correct or incorrect detections would be different in the different systems. Also, since the correct detection rate depends on the animal’s path through the enclosure, comparing probabilities

between systems is not reasonable. However, an advantage of logistic models is that log-odds scale slope coefficient is unaffected by varying sampling rates either in the explanatory or response categories.

Consider the following exaggerated and unrealistic example in Table 5.1 where the odds of correct detection between day and night are the same in both systems, in that they are twice as high during the day than during the night. But for some reason, ten times more correct identifications were observed in one system, either due to animal path choices or system “firing” or detection rates. Using a logistic regression model, $\log(\pi/(1-\pi))=\beta_0 + \beta_1\text{Day}$, both tables result in the same estimate of β_1 but different estimates of β_0 and different estimates of π based on the different intercept values. β_1 provides the log-odds of success during the day compared to the night and $\exp(\beta_1)$ provide the odds ratio comparing day and night. The estimate of the intercept term, β_0 , depends on the number of correct identifications observed. This simple example motivates the focus throughout the modeling process only on slope coefficients, as this same argument applies to all the multinomial models considered. Another feature of this example is that the standard error associated with the second data set is smaller than for the first example, so there is a benefit to including additional information even though it would not change the point estimates for the coefficients.

Table 5.1: The number of hours that detection data were available for analyses for each system.

	System 1		System 2	
	False positives	Correct detections	False positives	Correct detections
Day	5	10	5	100
Night	5	5	5	50

Multinomial logistic regression models were used due to the multi-category nature of the response variable that had up to five possible categories. One version of these models is called the baseline category model (Agresti, 2007) where one category is chosen as a baseline or reference category and then up to four typical logistic regression models are estimated to predict the difference between the category of interest and the baseline category. Positive (or negative) coefficients provide higher (or lower) log-odds of being the category of interest relative to the baseline category. Here the baseline category was chosen to be a correct identification and each sub-category logit model is focused on predicting each type of error relative to a correct identification.

A simple example using only Day/Night as an explanatory variable leads to the following multinomial logit model:

$$\log\left(\frac{\pi_0}{\pi_4}\right) = \alpha_{00} + \beta_{01}Day$$

$$\log\left(\frac{\pi_1}{\pi_4}\right) = \alpha_{10} + \beta_{11}Day$$

$$\log\left(\frac{\pi_2}{\pi_4}\right) = \alpha_{20} + \beta_{21}Day$$

$$\log\left(\frac{\pi_3}{\pi_4}\right) = \alpha_{30} + \beta_{31}Day.$$

In the previous model, π_0 corresponds to FN, π_1 to FN1, π_2 to FN2, π_3 to FP, and π_4 to a correct detection. Each row in the model is a “sub-category” logistic regression model. The only coefficients of interest in interpreting this model would be for the effect of day in the transition or comparison between log-odds of errors in the night versus the day. On the log-odds scale, positive-valued effects correspond to higher rates of an error for day than night and negative coefficients flip the effect around. A coefficient close to 0 would suggest that there is negligible day/night effect. We can judge closeness to 0 using a test statistic instead of the magnitude of the coefficients since it adjusts for the variability in the estimate. If the test statistic is small, then there is little evidence that that coefficient should be different from 0. A cut-off of ± 2 was used below to focus the interpretation on coefficients that look to be different from 0. Note, however, that it is possible to have an overall effect that is significant in an ANOVA (here it would be an analysis of deviance) type test where all of the coefficients involved in that effect would not meet this cut-off.

Based on the assumed multinomial distribution for the response variable, a multinomial distribution is used to define a likelihood. This likelihood is maximized to provide parameter estimates and associated standard errors of those estimated coefficients. These are interpreted without reference to specific probabilities of events to allow equal comparison across systems and allow for some non-randomly selected times to be used to augment the randomly sampled information.

An additional advantage of this modeling perspective is that it is possible to consider different models for each sub-category model. This is particularly important when false positives are considered along with the explanatory variable of type of animal. It is only possible to get false positives where there are no animals present to be detected and this uninformative model must not be considered. This implementation of multinomial logit models is available via the VGAM package (Yee, 2008) in R with the interface to these methods performed using the Zelig package (Imai, 2008).

The following variables were considered in step-down AIC-driven model selection to generate a set of candidate models to compare AIC values. Models within two AIC units of the top model were considered for selection. Within these constraints, the selection process focused on the simplest model that contained the variables that were present in most of the models within two AIC units of the top model. The units or categories for each variable are given between brackets.

For categorical variables the effect is calculated in relation to a “standard” category). For example, for wind direction, the effect of northern, southern or western winds is calculated compared to eastern winds). Similarly, the effect of high winds is calculated by comparing the presence of high winds to the absence of high winds.

- Wind direction (split into 4 categories for N, S, W / E)
- Wind speed (mi/h)
- High wind (winds over 15 mph) (present/absent)
- Wind gust (present/absent)
- Temperature (°C)
- Day or night (Day: 30 min before sunrise until 30 min after sunset; Night: 30 min after sunset until 30 min before sunrise)
- Visibility (excellent: ≥ 10 mi, less-than excellent: < 10 mi)
- Relative humidity (%)
- Precipitation (present/absent)
- Animal (none, horse or llama)

The three variables related to wind velocity (wind speed, high wind, and wind gust) were considered individually in each model. Considering wind speed and high wind and wind gust together is unreasonable as they are highly correlated and can be considered as different transformations of similar information. Animal is problematic for typical multinomial logistic models as noted above as the “none” category is associated with false positives by definition. But the difference in “animal” is important to consider for the other types of events. To incorporate this effect only where it is reasonable, it is only used for the subcategory logit models for false negatives (FN, FN1, FN2), and not for false positives (FP).

In some situations, wind direction was not defined due to low wind speeds. In these situations, a randomly selected direction from the observed directions was generated to impute each missing observation. This retains approximately the same distribution of wind directions that were observed but prevents the models from encountering missing information. Multiple runs through the imputation were considered for some of the systems and the differences in the model selection and coefficient estimates were negligible across the runs, with coefficients changing in the second decimal point generally characterizing those results. By randomly imputing those missing values, wind direction should have less of a chance of being a useful explanatory variable, but it was included in the model for many of the systems even with the imputation.

Since each variable is retained across all sub-category models (except for “animal”), the effect must either be large in one model or somewhat useful across the different models to be selected by AIC. Further simplification would be possible if this condition would be relaxed, but the complexity of the model selection process would be exponentially higher for modeling each system if model selection was considered for each sub-category logit model. Since typical multinomial models do not allow this degree of flexibility in modeling, this choice retains comparability to more conventional multinomial logit modeling with the only difference from these typical models involved in the false positive sub-category logit and the animal explanatory variable.

Models for systems that had their settings or sensitivity modified at some point between the test periods had a variable included to address such changes, as the purpose of such modifications was to reduce the occurrence of errors. The inclusion of this “modification” variable

(before/after) in the models was mandatory (forced) (Table 5.2). Systems that did not have their settings or sensitivity modified between the test periods did not have the “modification” variable included in their models.

Some systems had very low numbers for certain types of errors or did not display certain types of errors at all. If the frequency of a certain type of error was ≤ 3 , the type of error concerned was excluded from the models.

To simplify the interpretation of the vast number of parameters in the models, only coefficients that have z test statistics over two ($P \leq 0.05$) are considered for interpretation. This is not a testing-based approach to interpret the coefficients, as a variable could be significantly included in the model and not have any significant coefficients. It is simply used to highlight the most important features of the models.

Table 5.2: Dates modifications were made to each system (see also chapter 6).

System number (Figure 3.2)	Manufacturer and system name	ID number	Dates modifications
1	Xtralis (ADPRO)	7	29 November 2007
2	Xtralis (ADPRO)	5-6	29 November 2007
3	STS (RADS I)	1	No modifications
4	STS (RADS II)	2	No modifications
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	No modifications
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	No modifications
7	Camrix (A.L.E.R.T.)		29 November 2007
8	Xtralis (ADPRO)	1-2	29 November 2007
9	Goodson		No modifications

With this experiment running over time, there is some concern about clustered or correlated responses. Highly correlated responses can cause overdispersion, which is where the variability in the generalized linear model exceeds the amount that was assumed based on the model. In those situations, the likelihood and standard errors are not accurate. It is possible to incorporate an adjustment to the likelihood based on an estimate of overdispersion leading the QAIC (Burnham & Anderson, 2003) and to inflate standard errors in a similar way. Adjustments for overdispersion are suggested when Pearson's X^2 or the residual deviance test for lack of fit for the "fullish" model are much larger than their respective degrees of freedom. The "fullish" model is based on the most complicated model considered in the candidate models before any model reduction is considered. The degrees of freedom for the k category multicategory logit models are $(n*(k-1)-\text{total \# parameters in the model})$. The deviance was compared to its df for each system.

5.5. Results

The number of errors and correct detections included in the analyses are shown in Table 5.3. As discussed in the methods section, some systems had very low numbers for certain types of errors or did not display certain types of errors at all. If the frequency of a certain type of error was ≤ 3 , the type of error concerned was excluded from the models. Note that this left insufficient data to conduct the analysis for the Calonder Energy 2 system. Also note that the errors listed in Table 5.3 are based on a combination of randomly and non-randomly selected time periods and that the error counts in the table cannot be used to compare systems.

Table 5.3: The number of errors and correct detections for each system.

System number (Figure 3.2)	Manufacturer and system name	ID number	False negatives (FN)	False negatives 1 (FN1)	False negatives 2 (FN2)	False positives (FP)	Correct detections
1	Xtralis (ADPRO)	7	51	36	30	0	1,020
2	Xtralis (ADPRO)	5-6	81	104	47	2	879
3	STS (RADS I)	1	100	71	16	0	418
4	STS (RADS II)	2	21	12	7	0	211
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	3	0	0	30	622
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	1	0	0	0	100
7	Camrix (A.L.E.R.T.)		38	38	114	190	439
8	Xtralis (ADPRO)	1-2	21	41	8	42	1,002
9	Goodson		1	0	0	666	643

The model selected for each system is indicated in Table 5.4. Shaded cells indicate the parameter concerned was included in the selected model whereas unshaded cells indicate the parameter concerned was excluded in the selected model. None of the selected models for the systems required an adjustment for overdispersion.

Table 5.4: The effect of environmental conditions on system reliability (see text).

	Excluded	System modifications (aft./bef.)	Wind speed (mi/h)	High wind (> 15 / ≤ 15 mi/h)	Wind gust (present/absent)	Wind direction (N,W,S / E)	Temperature (°C)	Day or night (N/D)	Visibility (excellent/not excel.)	Relative humidity (%)	Precipitation (present/absent)	Animal (llama/horse)
Xtralix 7			+FN				+FN					
			+FN1									+FN1
			+FN2				+FN2			-FN2		
	FP											
Xtralix 5-6			+FN				+FN	-FN		+FN		+FN
						+FN1 (N/E)		-FN1				+FN1
			+FN2			-FN2 (N/E)	+FN2					+FN2
	FP											
STS 1							+FN	-FN		+FN		
								-FN1				
	FP											
STS 2												+FN
						+FN1 (S/E)	+FN1					
							+FN2			+FN2		+FN2
	FP											
Calonder Energy 1	FN											
	FN1											
	FN2											
					+FP		+FP		-FP	+FP		
Camrix			+FN					+FN				
							-FN1	+FN1				
		-FN2						+FN2	+FN2			
			-FP			+FP (N/E)	-FP			+FP		
Xtralix 1-2							+FN			+FN		+FN
						-FN1 (N/E)		-FN1				+FN1
												+FN2
										-FP		
Goodson	FN											
	FN1											
	FN2											
					-FP	+FP (N+W+S/E)	-FP			-FP		

Table 5.4 has four rows for each system. Each row relates to a specific type of error. The first row relates to regular false negatives (FN), the second to false negatives 1 (FN1), the third to false negatives 2 (FN2), and the fourth to false positives (FP). If a shaded cell contains a symbol for one of these error types (FN, FN1, FN2, FP), the environmental parameter concerned had a significant effect ($P \leq 0.05$) on that type of error. The direction of the effect is indicated through – and + symbols. The results for each system are discussed in detail below.

5.5.1. System 1 (Xtralis (ADPRO) 7)

The selected model excluded false positives. System modification did not have a significant effect on the reliability of the system. An increase in wind speed was associated with an increase in FN, FN1, FN2 (log-odds of a FN, FN1 and FN2 relative to a correct identification increase by 0.08, 0.13, and 0.07 respectively for each mi/h increase). An increase in temperature was associated with an increase in FN and FN2 (log-odds of a FN and FN2 relative to a correct identification increase by 0.05 and 0.06 respectively for each 1°C increase). An increase in relative humidity was associated with a decrease in FN2 (log-odds of a FN2 relative to a correct identification decrease by -0.05 for each 1% increase in relative humidity). Finally, llamas (compared to horses) were associated with an increase in FN1 (log-odds of a FN1 relative to a correct identification increase by 1.86 for a llama compared to a horse).

5.5.2. System 2 (Xtralis (ADPRO) 5-6)

The selected model excluded false positives. System modification did not have a significant effect on the reliability of the system. An increase in wind speed was associated with an increase in FN and FN2 (log-odds of a FN and FN2 relative to a correct identification increase by 0.10 and 0.11 respectively for each mi/h increase). Wind coming from the north (compared to wind from the east) was associated with more FN1 and fewer FN2 (log-odds of a FN1 relative to a correct identification increase by 0.56 with northern winds compared to eastern winds; log-odds of a FN2 relative to a correct identification decrease by -1.49 with northern winds compared to eastern winds;). An increase in temperature was associated with an increase in FN and FN2 (log-odds of a FN and FN2 relative to a correct identification increase by 0.10 and 0.11 respectively for each 1°C increase). Nights (compared to days) were associated with fewer FN and FN1 (log-odds of a FN and FN1 relative to a correct identification decreased by -0.84 and -1.02 during the night). An increase in relative humidity was associated with an increase in FN (log-odds of a FN relative to a correct identification increase by 0.06 for each 1% increase in relative humidity). Finally, llamas (compared to horses) were associated with an increase in FN, FN1, and FN2 (log-odds of a FN, FN1, and FN2 relative to a correct identification increase 1.70, 1.33, and 1.11 respectively for a llama compared to a horse).

5.5.3. System 3 (STS (RADS) 1)

The selected model excluded false positives. Higher temperatures and higher relative humidity were associated with an increase in FN (log-odds of a FN relative to a correct identification increase by 0.03 for each 1°C increase; log-odds of a FN relative to a correct identification increase by 0.02 for each 1% increase in relative humidity). Nights (compared to days) were associated with fewer FN and FN1 (log-odds of a FN and FN1 relative to a correct identification decrease by -1.57 and -1.86 during the night). The species (llama or horse) did not have a significant effect on the reliability for this system.

5.5.4. System 4 (STS (RADS) 2)

The selected model excluded false positives. Wind coming from the south (compared to wind from the east) was associated with more FN1 (log-odds of a FN1 relative to a correct identification increase by 2.69 with southern winds compared to eastern winds). Higher temperatures were associated with an increase in FN1 and FN2 and higher relative humidity was associated with an increase in FN2 (log-odds of a FN1 and FN2 relative to a correct identification increase by 0.28 and 0.30 respectively for each 1°C increase; log-odds of a FN2 relative to a correct identification increase by 0.28 for each 1% increase in relative humidity). Finally, llamas (compared to horses) were associated with an increase in FN and FN2 (log-odds of a FN and FN2 relative to a correct identification increase by 1.67 and 2.77 respectively for a llama compared to a horse).

5.5.5. System 5 (Calonder Energy 1 (CAL 92, LS-WS-WE 45))

The selected model excluded all types of false negatives. Since the model only related to false positives, the animal species variable was excluded from the model. The presence of wind gusts, an increase in temperature, and an increase in relative humidity were all associated with an increase in false positives (log-odds of a FP relative to a correct identification increase by 1.92 with wind gusts compared to no wind gusts; log-odds of a FP relative to a correct identification increase by 0.11 for each 1°C increase; log-odds of a FP relative to a correct identification increase by 0.06 for each 1% increase in relative humidity). Excellent visibility (compared to less-than-excellent visibility) was associated with a decrease in false positives (log-odds of a FP relative to a correct identification decrease by -4.29 with excellent visibility compared to less-than-excellent visibility).

5.5.6. System 6 (Calonder Energy 2 (CAL 92, IR-204-319/M3))

There were insufficient data to conduct an analysis for this system (see table 5.3).

5.5.7. System 7 (Camrix (A.L.E.R.T.))

System modifications were associated with a decrease in FN2 (log-odds of a FN2 relative to a correct identification decrease by -1.52 after system modification). An increase in wind speed was associated with an increase in FN, and a decrease in FP (log-odds of a FN relative to a correct identification increase by 0.07 for each mi/h increase; log-odds of a FP relative to a correct identification decrease by -0.19 for each mi/h increase). Wind coming from the north (compared to wind from the east) was associated with more FP (log-odds of a FP relative to a correct identification increase by 1.51 with northern winds compared to eastern winds). An increase in temperature was associated with a decrease in FN1 and FP (log-odds of a FN1 and FP relative to a correct identification decrease by -0.06 and -0.08 respectively for each 1°C increase). Nights (compared to days) were associated with an increase in FN, FN1, and FN2 (log-odds of a FN, FN1, and FN2 relative to a correct identification increase by 2.27, 1.05, and 1.94 respectively during the night). Excellent visibility (compared to less-than-excellent visibility) was associated with an increase in FN2 (log-odds of a FN2 relative to a correct identification increase by 2.46 with excellent visibility compared to less-than-excellent visibility). An increase in relative humidity was associated with an increase in FP (log-odds of a

FP relative to a correct identification increase by 0.07 for each 1% increase in relative humidity). The species (llama or horse) did not have a significant effect on reliability for this system.

5.5.8. System 8 (Xtralis (ADPRO) 1-2)

System modification did not have a significant effect on the reliability of the system. Wind coming from the north (compared to wind from the east) was associated with a decrease in FN1 (log-odds of a FN1 relative to a correct identification decrease by -1.09 with northern winds compared to eastern winds). An increase in temperature was associated with an increase in false negatives (log-odds of a FN relative to a correct identification increase by 0.14 for each 1°C increase). Nights (compared to days) were associated with a decrease in FN1 (log-odds of a FN1 relative to a correct identification decrease by -1.75 during the night). An increase in relative humidity was associated with an increase in FN and a decrease in FP (log-odds of a FN relative to a correct identification increase by 0.06 for each 1% increase in relative humidity; log-odds of a FP relative to a correct identification decrease by -0.05 for each 1% increase in relative humidity). Finally, llamas (compared to horses) were associated with an increase in FN, FN1, and FN2 (log-odds of a FN, FN1, and FN2 relative to a correct identification increase 1.35, 1.29, and 2.88 respectively for a llama compared to a horse).

5.5.9. System 9 (Goodson)

The selected model excluded all types of false negatives. Since the model only related to false positives, the animal species variable was excluded from the model. The presence of wind gusts, an increase in temperature, and an increase in relative humidity were all associated with a decrease in FP (log-odds of a FP relative to a correct identification decrease by -1.36 with wind gusts compared to no wind gusts; log-odds of a FP relative to a correct identification decrease by -0.18 for each 1°C increase; log-odds of a FP relative to a correct identification decrease by -0.02 for each 1% increase in relative humidity). However, the effect of wind gusts is likely an artifact of the sampling design as the majority of the false positives happened to occur when wind gusts were not present. Wind coming from the north, south, and west (compared to wind from the east) was associated with an increase in FP (log-odds of a FP relative to a correct identification increase by 1.23, 1.41, and 1.11 respectively with northern, southern, and western winds compared to eastern winds).

5.6. Discussion and Conclusions

Wind gusts or wind speed were included in all models, suggesting wind is an important factor in the reliability performance of the systems. High winds were associated with an increase in different types of false negatives for most passive infrared area-cover systems (except Xtralis 1-2). High winds were associated with both an increase in false positives (Calonder Energy 1) and a decrease in false positives (Camrix). This suggests that passive infrared area-cover systems become less sensitive with high winds whereas break-the-beam systems that rely on a very narrow beam (in this case a laser beam) may start generating false positives, presumably because the sensors sway slightly in and out of alignment. The latter suggests the importance of a stable foundation and pole for break-the-beam systems. Stable foundations and poles may also be beneficial to passive infrared area-cover systems, but it is unclear if the increase in false negatives for such systems is caused by movement of the sensors that tend to be higher up on a

pole than sensors for break-the-beam systems, or by vegetation or pockets of hot and cold air that move in the wind.

Wind direction was present in six of the eight models, suggesting wind direction is an important factor in the reliability performance of the systems. The effects are hard to interpret, but it may be that winds oriented perpendicular to the systems caused vegetation or pockets of hot and cold air to trigger systems more often than winds oriented more parallel to the systems.

The temperature variable was present in all selected models suggesting temperature is an important factor in the reliability performance of the systems. Higher temperatures are generally associated with higher error rates. This could be due to temperature causing reduced performance of the equipment. In addition, passive infrared systems may not be able to distinguish clearly between pockets of hot air and moving animals. However, higher temperatures are concentrated in time (summer) and it is possible that factors other than temperature caused more errors in summer. Animal behavior and possible effects on the likelihood of correct detections and errors may have also been influenced by temperature.

The day and night variable was present in six of the eight selected models suggesting the effect of day and night is an important factor in the reliability performance of the systems. Three systems (Xtralis 5-6, STS 1, and Xtralis 1-2) had fewer false negatives during the night compared to during the day. This may be related to lower temperatures or higher contrasts in temperatures of the animals and their surroundings during the night. However, Camrix had more false negatives during the night compared to during the day.

The visibility variable was included in four of the eight selected models suggesting visibility is an important factor in the reliability performance of some systems. Excellent visibility was associated with fewer false positives for a break-the-beam system (Calonder Energy 1), which suggests that relatively low visibility may block or reduce the narrow signal path of optical break-the-beam systems. It is unclear why excellent visibility may have caused the Camrix system to increase false negatives 2.

Precipitation was rarely observed during the test periods. Thus the fact that this variable was only present in two of the eight selected models is probably more related to the local conditions (generally dry climate) than the actual effect of precipitation. This can be contrasted by the importance of relative humidity as that parameter was included in all selected models suggesting humidity (and thus probably also precipitation) is an important factor in the reliability performance of the systems. Higher relative humidity was generally associated with an increase in errors. However, some systems showed a decrease in errors with increased relative humidity.

The animal species parameter (llamas vs. horses) was included in all models that included false negatives suggesting that the size of the target species is an important factor in the reliability performance of the systems. Llamas were substantially harder to detect for most systems, especially passive infrared area-cover systems, than horses, probably because of their smaller body size.

6. EXPERIENCES WITH INSTALLATION, OPERATION, AND MAINTENANCE

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6.1. System 1 (Xtralis (ADPRO) 7)

Xtralis 7 was installed on September 21, 2006.

On July 3, 2007, two error messages were observed when the computer in Lewistown was accessed remotely from the WTI/MSU office in Bozeman. The error messages read: “Integer-Überlauf” and “Exception EIntOverflow im Modul ASIM-S.exe bei 000498BC. Integer-Überlauf.” The system was restarted, and when researchers were in Lewistown on July 18, 2007, the system was operating properly. However, there was no data available from June 30, through July 18, 2007.

The system stopped recording detections on September 29, 2007. The system was restarted on November 16, 2007 and began detecting properly.

At the request of Xtralis, the system was upgraded and made more sensitive on November 29, 2007.

Xtralis sensor 1 was not detecting properly on January 18, 2008. While trouble-shooting, an error message appeared, and the computer was restarted. After restarting the computer, Xtralis 7 was not found or recognized by the computer, and another error message appeared. It read “Information: Sorry no Detector found!” On January 22, 2008, the system was accessed via the remote connection in Bozeman. Xtralis 7 was previously assigned to COM port 2. However, the system was automatically reassigned to COM port 10. Settings were adjusted to accommodate the new COM port, and the computer was then able to locate the sensor.

After power outages unrelated to the system itself, the data logger shut down and there were no data available for the following dates: February 21–27, 2007, March 23–26, 2007, April 21–23, 2007, and April 26– May 4, 2007. There were also no data available February 19–20, 2007, March 2–9, 2007, November 21–29, 2007, and December 12, 2007– January 18, 2008. This was likely due to power outages.

6.2. System 2 (Xtralis (ADPRO) 5-6)

Xtralis 5–6 was installed on September 21, 2006.

On April 19, 2007, during a routine check, researchers noticed the Xtralis 6 sensor was not detecting properly. Snow was cleared off the lens of the sensor, and it began operating properly again.

On July 3, 2007, two error messages were observed when the computer in Lewistown was accessed remotely from Bozeman. The error messages read: “Integer-Überlauf” and “Exception EIntOverflow im Modul ASIM-S.exe bei 000498BC. Integer-Überlauf.” The system was

restarted, and when researchers were in Lewistown on 18 July 2007, the system was operating properly. However, there was no data available from June 30 through July 18, 2007.

The system stopped recording detections on September 29, 2007. The system was restarted on November 16, 2007 and began operating properly again.

At the request of Xtralis, the system was upgraded and made more sensitive on November 29, 2007.

Xtralis sensor 1 was not detecting properly on January 18, 2008. While trouble-shooting, an error message appeared, and the computer was restarted. After restarting the computer, neither sensor (Xtralis 5 or Xtralis 6) was found or recognized by the computer, and another error message appeared. It read "Information: Sorry no Detector found!" On January 22, 2008, the system was accessed via the remote connection in Bozeman. Xtralis 5–6 was previously assigned to COM port 2. However, the system was automatically reassigned to COM port 10. Settings were adjusted to accommodate the new COM port, and the computer was then able to locate both sensors.

After power outages unrelated to the system itself, the data logger shut down and there were no data available for the following dates: February 21–27, 2007, March 23–26, 2007, April 21–23, 2007, and April 26–May 4, 2007. There were also no data available February 19–20, 2007, March 2–9, 2007, November 21–29, 2007, and December 12, 2007–January 18, 2008. This was likely due to power outages.

6.3. System 3 (STS (RADS) 1)

STS 1 was installed on October 19, 2006.

On April 19, 2007, researchers noticed during a routine check that STS 1 was not detecting properly, though it was still communicating with the computer and data storage software.

Also on April 19, 2007, a new antenna was installed outside of the office to improve communication between the system and the computer.

On August 31, 2007, while checking all systems via remote access from Bozeman, it was noted that the system was not recording data properly. The data logger software was restarted but still did not record data. When in Lewistown on September 4, 2007, an indicator light signifying that the entire system shut down due to a power interruption was observed. The memory card was changed, the system was restarted, and the system began operating and storing data properly again. As a result of this power interruption, there were no data available from August 22, 2007 through September 4, 2007.

On September 4, 2007, vegetation was removed from in front of the system to prevent false positives due to tall and moving vegetation.

The system stopped recording detections on November 4, 2007. The system was restarted on November 16, 2007, however, the system still did not detect properly.

On November 29, 2007, researchers attempted to repair the system by adjusting the gain and checking connections. On December 4, 2007, the Digital Signal Processor (DSP) card was replaced and voltages and the gain settings were checked. The Multi Media Card (MMC) card was also swapped, and the system was restarted. The "ribbon connections" were checked and

the Microcontroller (MTC) board was cleaned on January 18, 2007, and the system began operating properly.

After power outages unrelated to the system itself, the data logger shut down and there were no data available for the following dates: February 19–27, 2007, March 24–25, 2007, April 22–23, 2007, and April 26–May 4, 2007. There were also no data available November 4–16, 2007, November 20–29, 2007, and December 12, 2007– January 18, 2008. This was likely due to power outages.

6.4. System 4 (STS (RADS) 2)

STS 2 was installed on July 18–19, 2007.

On August 31, 2007, while checking all systems via remote access from Bozeman, it was noted that the system was not recording data properly. The data logger software was restarted but still did not record data. When in Lewistown on September 4, 2007, an indicator light signifying that the entire system shut down due to a power interruption was observed. The memory card was changed, the system was restarted, and the system began detecting and storing data properly again. As a result of this power interruption, there were no data available from August 22, 2007 through September 4, 2007.

On September 4, 2007, vegetation was removed from in front of the system to prevent false positives due to tall and moving vegetation.

The system stopped recording detections on November 4, 2007. The system was restarted on November 16, 2007, and the system began operating properly.

There were no data available November 4–16, 2007, November 20–29, 2007, and December 12, 2007–January 18, 2008. This was likely due to power outages.

No data were available for part of the day on December 4, 2007, due to work being done on the system to repair STS 1.

6.5. System 5 (Calonder Energy 1 (CAL 92, LS-WS-WE 45))

Calonder Energy 1, a laser break-the-beam system, was installed on September 21–22, 2006.

On July 18, 2007, researchers observed that the system was properly detecting, as indicated by the counter attached to the actual sensor. However, there was a communication problem between the system and the computer and data software, and researchers were unable to download detection data.

On August 22, 2007, it was determined that the communication problem between the system and the computer was caused by the data logger. The data logger was removed and was sent to Calonder for repair.

The data logger was reinstalled on November 16, 2007. The system began recording data and continued to detect properly. Due to this error, there are no detection data available from June 6 through November 16, 2007.

There are also no data available for April 22–25, 2007 and May 24–26, 2007. Researchers believe this may also be related to the data logger malfunction described above.

On January 18, 2008, the system was not detecting properly. Ice was melted off of the receiver, and the system then operated properly again.

6.6. System 6 (Calonder Energy 2 (CAL 92, IR-204-319/M3))

Calonder Energy 2, a passive infrared system, was installed on September 21–22, 2006.

On March 16, 2007, researchers noticed that CE 2 was not properly recording detections. It was left in place during the next test (March 16–25, 2007) to confirm that it was not properly detecting animals. The sensor was removed on April 19, 2007 and sent back to Switzerland for repairs, having not worked since January 2007. The cover on the original system was installed incorrectly, and water caused damage to the internal electronics. A replacement sensor was received by WTI/MSU in June 2007.

On July 18–19, 2007, the system was reinstalled; however, it was still not performing properly. The system was detecting in a 2.5–3.0 m (8.2–9.8 ft) window approximately 12 m (39 ft) from the sensor, as opposed to the expected 88–90 m (289–295 ft) detection area beginning 10–12 m (33–39 ft) from the sensor.

Also on July 18–19, 2007, researchers observed that, in addition to the system not properly detecting, there was also a communication problem between the system and the computer and data software. Researchers were unable to download detection data.

On July 30, 2007, without further attempt to install the system properly, the detection area had increased to approximately 60 m (197 ft), beginning about 12 m (39 ft) from the system. However, this was still not the expected detection area of 88–90 m (289–295 ft).

After receiving further installation instructions from Calonder, the system was properly reinstalled on August 22, 2007.

On August 22, 2007, it was determined that the communication problem between the system and the computer was caused by the data logger. The data logger was removed and was sent to Calonder for repair.

The data logger was reinstalled on November 16, 2007. The system began recording data and continued to detect properly. As a result of the data logger malfunction, there are no detection data available from August 22, 2007 through November 16, 2007.

The counter in the box was reset on January 18, 2008, as it was at its maximum capacity of 12,000 counts. However, the counter being at its maximum had no effect on the performance of the system.

6.7. System 7 (Camrix A.L.E.R.T.)

Camrix installation began on October 19, 2006 and was completed on October 31, 2006.

On March 21, 2007, during a test (March 16–25, 2007), the Camrix computer “froze” with an image of an animal. When the test was ended on March 26, 2007, the system was not detecting

properly, and the “frozen” image was observed. The computer, and therefore the Camrix software, was restarted and the system began operating properly again.

On June 5, 2007, though the system was detecting properly, a warning message was present. It stated “Microsoft Windows warning: the system has recovered from a serious error.” The computer, and therefore the Camrix software, was restarted, and the system continued operating properly.

On July 28, 2007, the Camrix system “froze” again during a test (July 20–30, 2007). On July 30, 2007, the system was not detecting properly, and a “frozen” image was observed. The computer, and therefore the Camrix software, was restarted, and the system began operating properly again.

On November 16, 2007, though the system was detecting properly, a warning message was present. It stated “Microsoft Windows warning: the system has recovered from a serious error.” The computer, and therefore the Camrix software, was restarted, and the system continued operating properly.

At the request of Camrix, an upgrade to the system was installed on November 29, 2007.

6.8. System 8 (Xtralis (ADPRO) 1–2)

Xtralis 1–2 was installed on August 8, 2006.

On July 3, 2007, two error messages were observed when the computer in Lewistown was accessed remotely from Bozeman. The error messages read: “Integer-Überlauf” and “Exception EIntOverflow im Modul ASIM-S.exe bei 000498BC. Integer-Überlauf.” The system was restarted, and when researchers were in Lewistown on July 18, 2007, the system was operating properly. However, there was no data available from June 30 through July 18, 2007.

The system stopped recording detections on September 29, 2007. The system was restarted on November 16, 2007 and then began operating properly again.

At the request of Xtralis, the system was upgraded and made more sensitive (lower thresholds for detections) on November 29, 2007.

Xtralis sensor 1 was not detecting properly on January 18, 2008. While trouble-shooting, an error message appeared and the computer was restarted. After restarting the computer, neither sensor (Xtralis 1 or Xtralis 2) was found or recognized by the computer, and another error message appeared. It read “Information: Sorry no Detector found!” On January 22, 2008, the system was accessed via the remote connection in Bozeman. Xtralis 1–2 was previously assigned to COM port 2. However, the system was automatically reassigned to COM port 10. Settings were adjusted to accommodate the new COM port, and the computer was then able to locate both sensors.

After power outages unrelated to the system itself, the data logger shut down and there were no data available for the following dates: February 21–27, 2007, March 23–26, 2007, April 21–23, 2007, and April 26– May 4, 2007. There were also no data available February 19–20, 2007, March 2–9, 2007, November 21–29, 2007, and December 12, 2007–January 18, 2008. This was likely due to power outages.

6.9. System 9 (Goodson)

Goodson was installed in December 2006.

On March 2, 2007, researchers noticed that the loose ends of the straps used to secure the system to the pole may have been blowing in front of the detection beam. This may have been the cause of false positives previously observed. These straps were secured so that no false positives could occur in this manner. As a result, the system was not analyzed for false positives prior to March 2, 2007.

On April 19, 2007, researchers noticed the Goodson system was detecting properly but was also recording many false positives. This may have been related to environmental conditions such as the angle of the sun, or other conditions; the temperature was about 2°C (35°F) with a varying wind of about 16 to 48 km (10 to 30 mi) per hour, and snowfall was reported.

On July 18, 2007, researchers observed the low battery indication, which was initially reported on July 3, 2007. New batteries were installed in both the transmitter and receiver.

On September 4, 2007, vegetation was removed from in front of the system to prevent false positives due to tall and moving vegetation.

On January 18, 2008, a low-battery indication was observed, which was initially reported on January 15, 2008. New batteries were installed in both the transmitter and receiver. In addition, ice was melted off of the transmitter.

From November 22 through November 29, 2007, the data logger on the receiver was at its maximum capacity. Therefore, no data were recorded during that time.

7. NATIONAL ITS ARCHITECTURE AND STANDARDS

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7.1. What is ITS Architecture?

The Transportation Equity Act for the 21st Century (TEA-21), requires that federally funded ITS projects conform to the National ITS Architecture standards. As defined in TEA-21, the term “intelligent transportation system” means “electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system” (AASHTO et al., 2002).

National ITS Architecture standards govern both the functions performed in implementing ITS, and the information flows between transportation subsystems. Key requirements of these regulations are that regional ITS architectures must be prepared, all ITS projects must follow a systems engineering process, and that ITS standards be used (AASHTO et al., 2002).

The ITS National Architecture’s purpose is to make sure that all intelligent transportation systems in the nation conform to the appropriate standards, such that where interconnects could be made, or communication infrastructure is shared, the system concerned will integrate with other ITS components.

7.2. ITS Architecture Levels

The ITS National Architecture is broken down into several levels, from conceptual to the equipment that is placed in the ground. Each of these levels is defined below.

7.2.1. Logical Architecture

“The Logical Architecture” presents a functional view of the ITS user services. This perspective is separated from those for implementations and physical interface requirements. It defines the functions or process specifications that are required to perform ITS user services, and the data flows that need to be exchanged between these functions (USDOT, 2007).” This essentially provides a framework for how different user services may work together and the general communication connections involved.

7.2.2. Physical Architecture

The physical architecture shows how different subsystems (i.e., travelers, field elements, centers, and vehicles) may be interconnected. The physical architecture is not a detailed design, but shows the current and potential communication links so that systems can be integrated and share communications infrastructure. From a high level, the physical architecture is commonly represented by the “sausage diagram” (Figure 7.1).

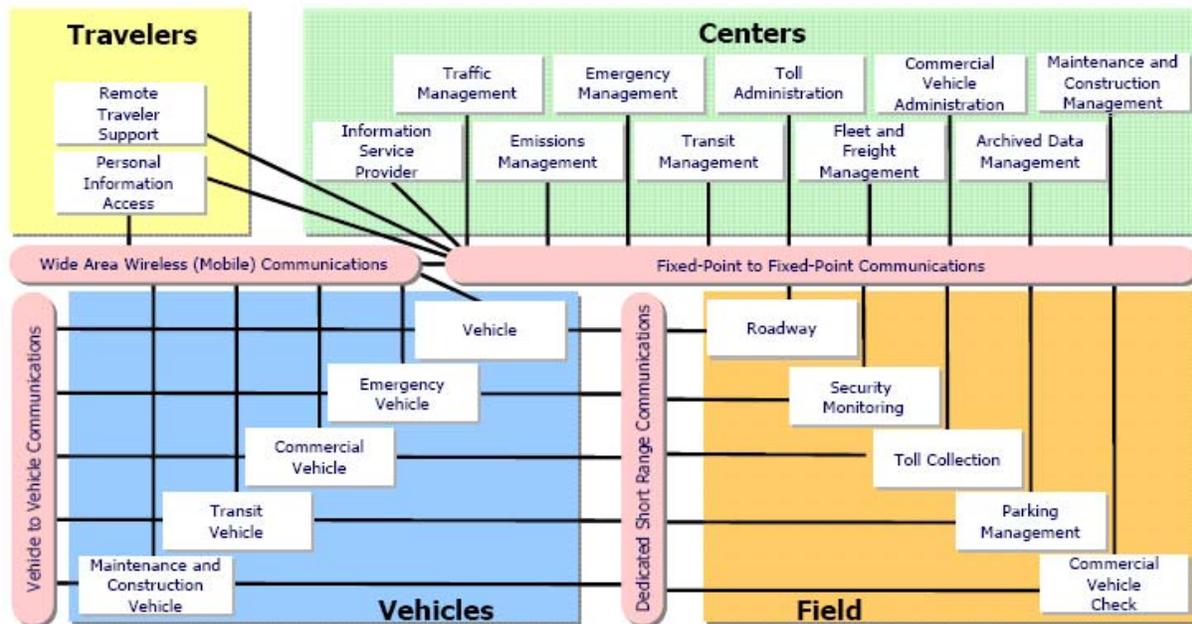


Figure 7.1: Physical Architecture (Source: USDOT 2007).

7.2.3. User Services

To avoid deploying technology for technology's sake, it is important to start with a properly defined need. User services define the purpose of a system from the user's level. ITS architectures are broken into user service bundles like traffic management and commercial vehicle operations. Within each of those bundles there are specific user services, which define how the ITS system will perform for each specific user. User services are broken down even further to market packages. Right now the user service for animal detection systems is not explicitly considered in the National ITS Architecture. An example of a user service defined in the National ITS Architecture standards is the intersection collision avoidance user service:

“3.6.3.3. Service Description

The intersection collision warning and control service is specifically aimed at providing vehicle operators with assistance in avoiding collisions at intersections. The situations addressed include those that arise when vehicles improperly violate the right-of-way of another vehicle, or when the right-of-way is not clear. The service will provide warnings of imminent collisions with crossing traffic, as well as warnings of stop control—either a stop sign or a traffic signal—in the intersection ahead.

There are many diverse causal factors involved in intersection collisions. Among the most common of these are driver inattention, failure to obey traffic control devices (red signal indications and stop signs), attempting to beat the yellow phase of traffic signals, proceeding against cross traffic due to faulty perception and obstructed view, and driver intoxication. A variety of countermeasures may

be devised depending on both crash type (SCP, CLT or other) and intersection traffic control type (signalized, stop signs, and uncontrolled).

3.6.3.4. Operational Concepts

The function of this service is to track the position and state of vehicles within a defined area surrounding an intersection. The systems may involve infrastructure-to-vehicle and/or vehicle-to-vehicle communications. For example, if a vehicle is waiting to cross a high-speed roadway, the driver of the crossing vehicle could be alerted when there is high-speed traffic approaching. In turn, once a vehicle begins crossing the intersection, the other vehicles could be warned and/or controlled to avoid a possible collision. One important operational approach is the Cooperative Intersection Collision Avoidance System, or CICAS. This system would include both vehicle-to-vehicle and vehicle-to-infrastructure links, incorporating both one-way and two-way communications. These communications technologies would provide various coverage zones and ranges. Several media can be used for this purpose, including spread spectrum, microwave, millimeter wave, and infrared.

A type of vehicle-based countermeasure for SCP collisions could utilize video and digital image processing to recognize traffic signs and signals and advise or warn the driver to stop the vehicle before it encroaches into the intersection in an unsafe manner. This concept could be integrated with the In-Vehicle Signing subservice, which is part of the En Route Driver Information user service (Section 3.1.2). In addition, several systems developed primarily for other collision categories, such as head-on collision warning and control, may also be useful in intersection collision situations. For additional information on HDS, please refer to Longitudinal Collision Avoidance (see Section 3.6.1)” (USDOT, 2005).

7.2.4. Market Packages and Equipment Packages

Market packages define the main components of an ITS application and how they are interconnected for possible implementation. In a sense, they define the physical architecture for a user service. Most user services have a market package, but there is not always a straight one-to-one relationship between user services and market packages. Again an example is provided from the National ITS Architecture—the intersection safety warning market package.

“This market package will determine the probability of a collision in an equipped intersection (either highway-highway or highway-rail) and provide timely warnings to drivers in response to hazardous conditions. Monitors in the roadway infrastructure assess vehicle locations and speeds near an intersection. Using this information, a warning is determined and communicated to the approaching vehicle using a short range communications system. Information can be provided to the driver through the market package ATIS9--In-Vehicle Signing” (USDOT 2002).

Figure 7.2 shows the schematic for the example market package. “Roadway” and “vehicle” are subsystems (note that both of these are in the overarching physical architecture depicted in Figure 7.1). The white text boxes within the subsystems describe the “equipment packages” or ITS elements needed within these subsystems for this market package to operate. “Basic

vehicle,” “potential obstacles,” and “driver” are external elements that participate in the market package. The arrows show the information flows.

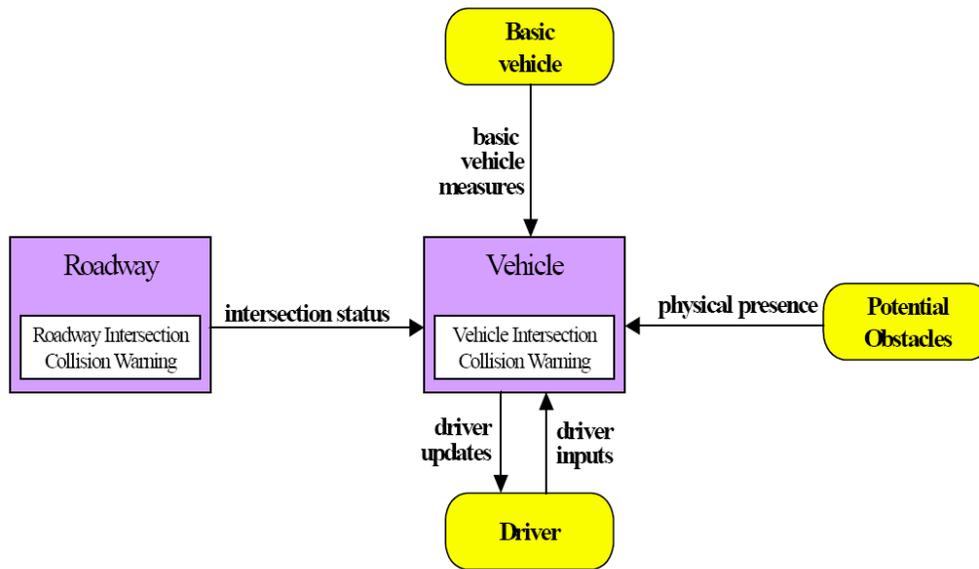


Figure 7.2: Market Package Example (Source: USDOT, 2002).

7.3. Purpose

The purpose of this chapter is to define how the systems used in the test bed for animal detection systems at the TRANSCEND facility near Lewistown relate to the National ITS Architecture. A regional ITS architecture was previously developed and summarized in two reports, which will be relied upon heavily in this report. The first report is the Greater Yellowstone ITS (GRYITS) report (Ice & Associates, 1999) which provided an ITS architecture for the region in and around Yellowstone National Park. The second is Montana Regional Architecture (Strong & Eidswick, 2005).

The intent of this chapter is not to recreate a regional architecture, but summarize and update the architecture elements that relate to animal detection systems. The following summarizes the purpose of the regional architecture.

“A regional architecture for the Greater Yellowstone Rural ITS Priority Corridor can guide ITS deployments in the region in a manner that is compatible with national efforts including the National ITS Architecture and ITS standards. Benefits of a regional architecture that demonstrates conformance with the National ITS Architecture include:

- Section 5206(e) of the Transportation Equity Act for the 21st Century (TEA-21) requires that ITS projects using funds from the Highway Trust Fund conform to the National ITS Architecture and standards. The GYRITS

regional architecture presented in this report meets or exceeds the interim policy guidance for architecture conformity from US DOT. It is anticipated that this report will also support the final conformity policy that will be published later in 1999.

- A regional architecture facilitates regional integration. It helps agencies and other stakeholders to identify and plan for the many integration and information sharing opportunities which ITS offers.
- A regional architecture that conforms with the National ITS Architecture and identifies ITS standards enables other ITS systems that will be developed for use throughout the U.S. to operate in the Yellowstone region. The regional architecture and project implementation guidance provided in this report addresses this national interoperability objective.
- Transportation improvements in the region will be made one project at a time. A regional architecture provides guidance for how these projects should fit together, improving interoperability between the projects, making efficient use of scarce resources, and facilitating future ITS expansion in the region.” (Ice, 1999).

7.4. Incorporating RADS into the National ITS Architecture

This section provides detail on how animal detection systems fit into the regional architecture including the physical architecture, the user service, the market package, and one equipment package. Since the user service is not likely to be combined with other user services within the ITS architecture, the logical architecture is not discussed.

7.4.1. Physical Architecture

Figure 7.3 shows the physical architecture for the region as defined in the GYRITS architecture. Notice “animal vehicle warning system” is depicted in the roadside subsystem. The physical architecture provides flexibility of communication infrastructure (wireless or wireline) depending on the specific implementation.

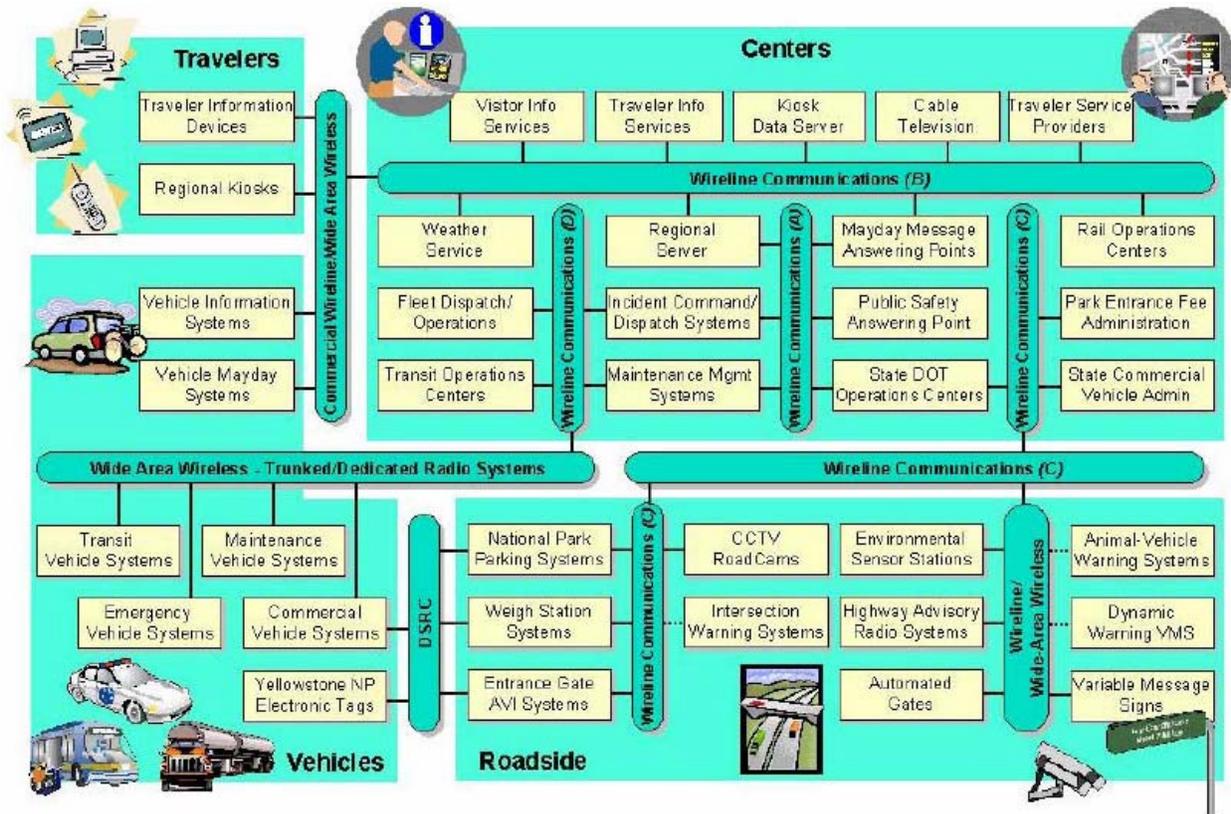


Figure 7.3: Sausage Diagram for GYRITS Regional Architecture (Source: Ice, 1999).

7.4.2. User Service

Animal detection systems provide drivers with a warning when an animal is on or near the roadway. A warning that large animals are on or near the road may result in fewer and less severe collisions. The need for animal detection systems, or for a reduction in collisions with large mammals, is based on the following facts:

- There are an estimated 1–2 million collisions with large mammals (deer and larger) in the United States per year, and their number is increasing (Huijser et al., 2007).
- Although “only” 4.6 percent of all reported animal–vehicle collisions result in human injury, and “only” 0.4 percent result in human fatality (Huijser et al., 2007), collisions with large mammals amount to an estimated 29,000 human injuries and 211 human fatalities in the United States per year (Conover et al., 1995).
- Collisions with large mammals are costly. The costs associated with the average deer–, elk–, and moose–vehicle collision is estimated at US\$6,617, US\$17,483, and US\$30,760, respectively (Huijser et al., submitted). These cost estimates include the following components: vehicle repair, human injuries, human fatalities, towing, accident attendance and investigation, hunting value of the animal, and carcass removal and disposal. Assuming that the vast majority of collisions with large mammals relate to deer (Huijser et al., submitted), the total costs associated with large mammal–vehicle collisions is estimated at US\$6,617,000,000–US\$13,234,000,000 per year.

7.4.3. Market Package

The market package for animal detection systems was previously developed for the Montana Regional ITS Architecture.

“Encroachment of animals on the roadway is a significant problem in rural areas in the United States. The Animal–vehicle Detection Market Package combines sensors that detect animals with a dynamic warning system that warns drivers of the animal’s presence on or near the roadway. While early implementations are likely to operate autonomously, future implementations may allow remote status reporting and calibration of the system to facilitate fault detection and maintenance of these potentially remote systems” (Strong & Eidswick, 2005).

Figure 7.4 shows the communication link between the roadside and a center, consistent with the national architecture. The system could be monitored by a traffic management center. The basic system is envisioned to warn the driver through roadside signing. If in-vehicle warning systems become more prevalent, the system could communicate with the vehicle to provide in-vehicle warning.

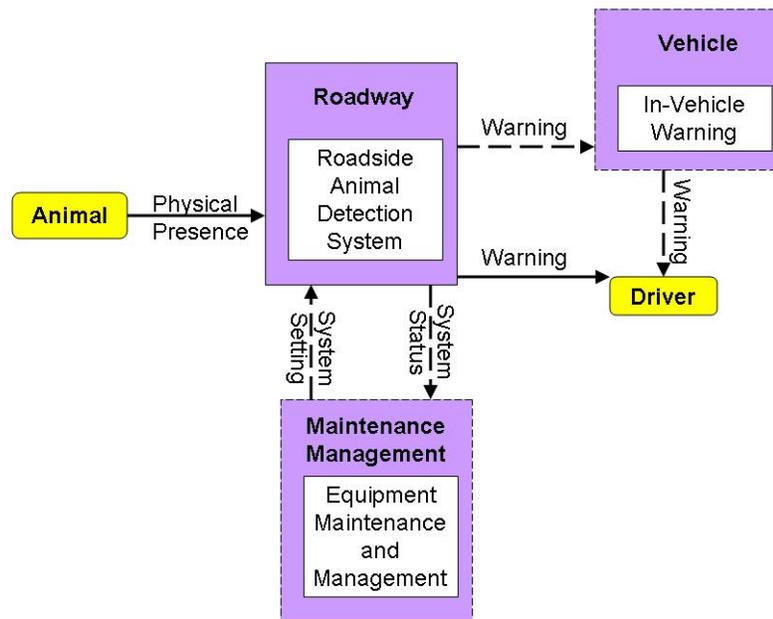


Figure 7.4: Animal detection system Market Package.

Figure 7.5 shows how each piece of the animal detection system equipment package, inside the dashed line, connects to each other and how the entire equipment package connects with the other elements of the market package. Within the equipment packages there is a wide variety of equipment to use, and different ways to get the information to the driver on the road. For example the detection system could be a motion sensor with infrared to detect the animals, or it could use a radar detection system. The detection system will provide data to the master controller. The data can be in terms of actual presence detection, or a raw signal that is processed by the master controller. The master controller must activate the warning sign when a presence is detected. A data storage unit is optional, but useful for evaluating and improving the system. The data storage unit will record the time and location of detections for future download and analysis.

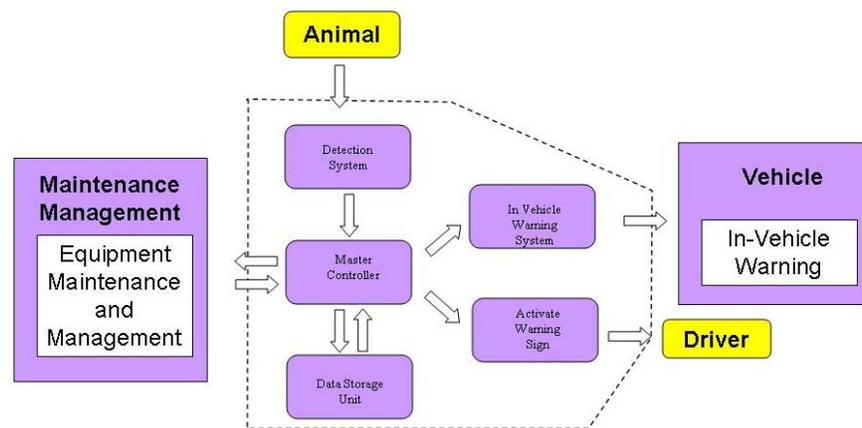


Figure 7.5: Potential equipment package.

7.5. Standards

Ideally, a single vendor will provide the entire system, in which case standards and requirements related to National ITS Architecture only pertain to the external communication links (the arrows in Figure 7.5 that cross the dotted line of the equipment package boundary). However, commonly these systems are delivered by several vendors, and a systems integrator must make all the pieces work together. The standards discussed in regard to the external communication links (master controller to management center) are highly important. Additional standards would allow interchangeability (use of several vendor products) within a single system. Depending on the exact nature of the detection system, standards between devices within the animal detection system equipment package may not be viable.

7.6. Master Controller to Management Center

The reality is that most locations where animal detection systems would be beneficial are in rural locations with limited power and communication. The exact system used to communicate between the Traffic Management Center and the master controller (e.g., satellite, cell phone, fiber, twisted pair) should be determined based on cost effectiveness for the specific location.

It is strongly encouraged that as a general specification, the animal detection system equipment package follow the National Transportation Communications for ITS Protocol (NTCIP). Of primary importance is the communication link between the master controller and the Traffic Management Center. This should follow the NTCIP communication protocols for “center-to-field” communication.

Because the bandwidth is not anticipated to be significant, Simple Network Management Protocol (SNMP) is recommended as the NTCIP communication standard. This standard allows more flexible implementation, but is not recommended for high-bandwidth applications.

For more information on NTCIP refer to www.ntcip.org.

8. RECOMMENDED PERFORMANCE REQUIREMENTS

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8.1. Introduction

Currently there are no generally agreed upon performance requirements for the reliability and effectiveness of animal detection systems. This chapter investigates the expectations of different stakeholders with regard to system reliability and effectiveness.

8.2. Methods

8.2.1. Stakeholders

The researchers surveyed employees of transportation agencies, natural resource management agencies, and the public. A minimum of one employee of each state or provincial transportation agency and each state or provincial natural resource management agency in the United States and Canada was asked to fill out a survey. The survey was also sent to employees of federal or natural transportation and natural resource management agencies in the United States and Canada. This survey was also sent to vendors and manufacturers of animal detection systems, non-governmental organizations and researchers involved with animal detection systems, but the number of respondents of these groups was too low (eight or less per group) to allow for inclusion in the analyses. In addition, the researchers surveyed the traveling public along a road section equipped with an animal detection system (US Hwy 191 between Big Sky and West Yellowstone, Montana) (see also Huijser et al., 2009). The surveys were anonymous, though respondents from agencies were asked to indicate what country their organization is based in.

8.2.2. Survey

The questions presented to transportation agencies and natural resource management agencies were formulated slightly differently from the questions presented to the public:

- Question 1:

For agencies: Animal detection systems are designed to warn drivers when animals are on or near the roadway. For your organization to implement such a system, approve of its installation or use, or to sell such a system, what percentage of large animals (deer and larger) that approach the road do you think should be detected by an animal detection system?

For public: Animal detection systems are designed to warn you when animals are on or near the roadway. For you to be confident in such a system, what percentage of large animals (deer and larger) that approach the road do you think should be detected by an animal detection system?

Potential answers: 60% or less, 61–70%, 71–80%, 81–85%, 86–90%, 91–95%, 96–99%, 100% (all large animals that approach the road are detected), I do not know, I do not wish to answer this question.

- Question 2:

For agencies: Depending on the technology used, certain weather conditions, low-flying birds, falling leaves or high vegetation can result in a “detection” and the activation of the warning signs. For your organization to implement an animal detection system, approve of its installation or use, or to sell such a system, what percentage of the total number of detections would you allow to be “false” (that is, the warning lights are on, but there is not really a large animal present)?

For public: Certain weather conditions, low-flying birds, falling leaves or high vegetation can result in a “detection” and the activation of the warning signs. What percentage of the total number of detections would you allow to be “false” (that is, the warning lights are on, but there is not really a large animal present)?

Potential answers: 41% or more, 31–40%, 21–30%, 11–20%, 6–10%, 1–5%, 0% (the warning signs are only activated when a large animal is really there), I do not know, I do not wish to answer this question.

- Question 3:

For agencies: For your organization to implement an animal detection system, approve of its installation or use, or to sell such a system, what percentage reduction in collisions with large wildlife (deer and larger) would you want to see or expect to see as a result of the presence of an animal detection system?

For public: What percentage reduction in collisions with large wildlife (deer and larger) would you want to see or expect to see as a result of the presence of an animal detection system?

Potential answers: 60% or less, 61–70%, 71–80%, 81–85%, 86–90%, 91–95%, 96–99%, 100% (all wildlife–vehicle collisions are prevented), I do not know, I do not wish to answer this question.

The survey for agencies was web-based and was conducted between February 20, 2008 and June 9, 2008. Employees of the agencies were sent an e-mail with an introductory letter and a link to the web site with the survey. The survey for the public was also web-based. The public was made aware of the survey in three different ways:

- Flyers with the web site address were distributed at gas stations and other locations in West Yellowstone and Big Sky (5 locations in each town). The flyers contained a brief background of the project and a link to a web site for the survey.
- Direct surveys were conducted at a gas station in Big Sky (Figure 8.1). If travelers wanted to participate in the survey but did not have time to complete the survey at that time, they were provided with the option to fill out the survey on the web site or fill out a hard copy of the survey and return it by mail.
- The web site for the survey was advertised in local and regional media.

The survey for the public was conducted between August 24, 2007 and August 3, 2008.



Figure 8.1: Booth set up for taking surveys at a gas station in Big Sky, Montana (Photo: Angela Kociolek, WTI/MSU).

8.2.3. Data analyses

Responses from the three stakeholder groups were investigated to recommend minimum performance requirements for the reliability and effectiveness of animal detection systems. The researchers calculated cumulative percentages for the number of respondents from each stakeholder group for each potential answer to a question, starting from the category with the lowest requirement. For example, for question 1, the percentage of respondents that selected 60% or less was calculated. Then the percentage of respondents who selected 60% or less or 61–70% was calculated, and so on, until the last category (100%), which brought the cumulative percentage to 100% by definition. Respondents who selected “I do not know,” “I do not wish to answer this question,” or that chose to not answer a question at all were excluded from the analyses. The calculations were carried out for each of the three questions and for each of the three stakeholder groups, and the results were plotted in graphs. The researchers recommend that the minimum performance requirements for the reliability and effectiveness of animal detection systems should satisfy the majority (50% or more) of each of the three stakeholder groups.

8.3. Results

The number of respondents was similar for transportation agencies and natural resource management agencies, while the number of respondents from the public was much greater (Table

8.1). Most of the respondents from agencies were from the United States; relatively few were from Canada. The public survey did not ask for country information, so that breakdown is not known.

Table 8.1: The number of respondents by group and location.

Stakeholder group	United States	Canada	Total
Transportation agencies	37	6	43
Natural resource management agencies	35	2	37
Public	Unknown	Unknown	160

The majority ($\geq 50\%$) of all three stakeholder groups would be satisfied with animal detection systems detecting 91–95% or more of all large animals that approach the road (Figure 8.2).

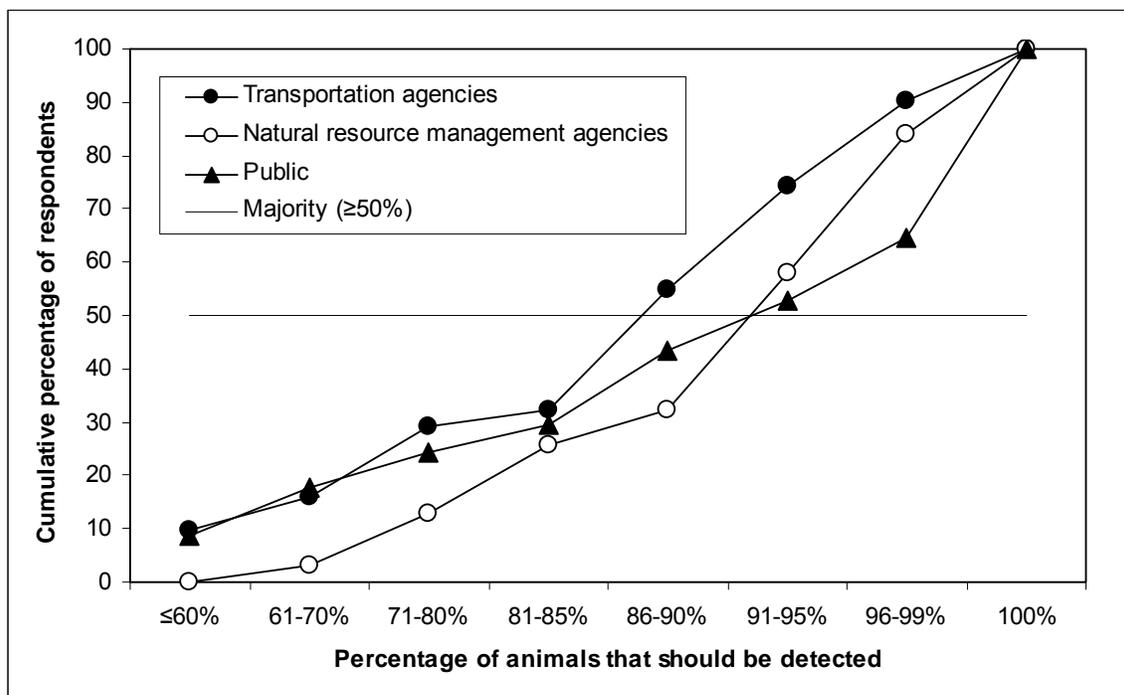


Figure 8.2: The percentage of large animals approaching the road that survey respondents said should be detected by animal detection systems. The number of respondents included in the analysis was 31 for transportation agencies, 31 for natural resource management agencies, and 136 for the public.

The majority ($\geq 50\%$) of all three stakeholder groups would be satisfied with animal detection systems for which 6–10% or less of all detections be are false (Figure 8.3).

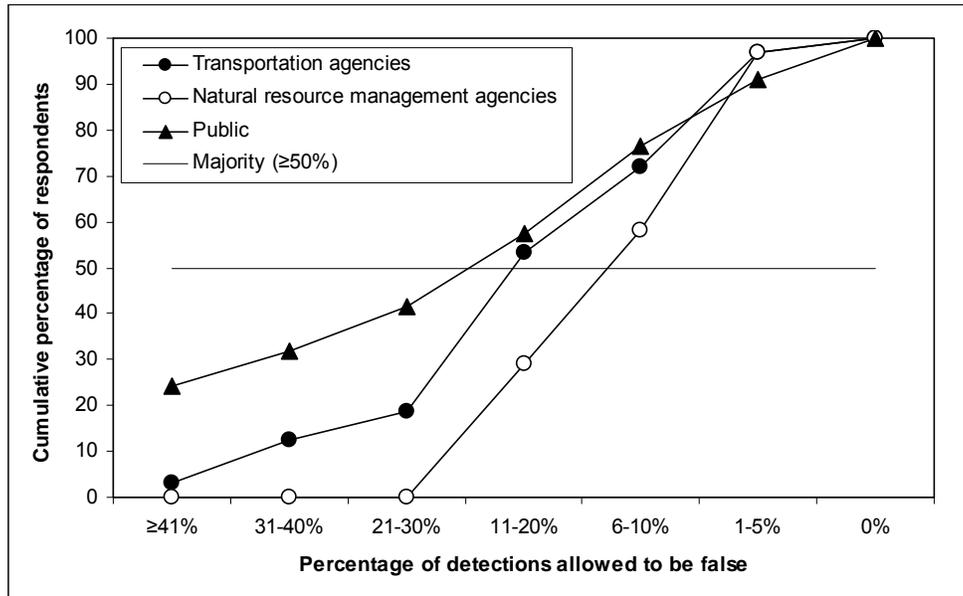


Figure 8.3: The percentage of detections by animal detection systems respondents would allow to be false. The number of respondents included in the analysis was 32 for transportation agencies, 31 for natural resource management agencies, and 132 for the public.

The majority ($\geq 50\%$) of all three stakeholder groups would be satisfied with animal detection systems that provide a reduction of 71–80% or more in wildlife–vehicle collisions (Figure 8.4).

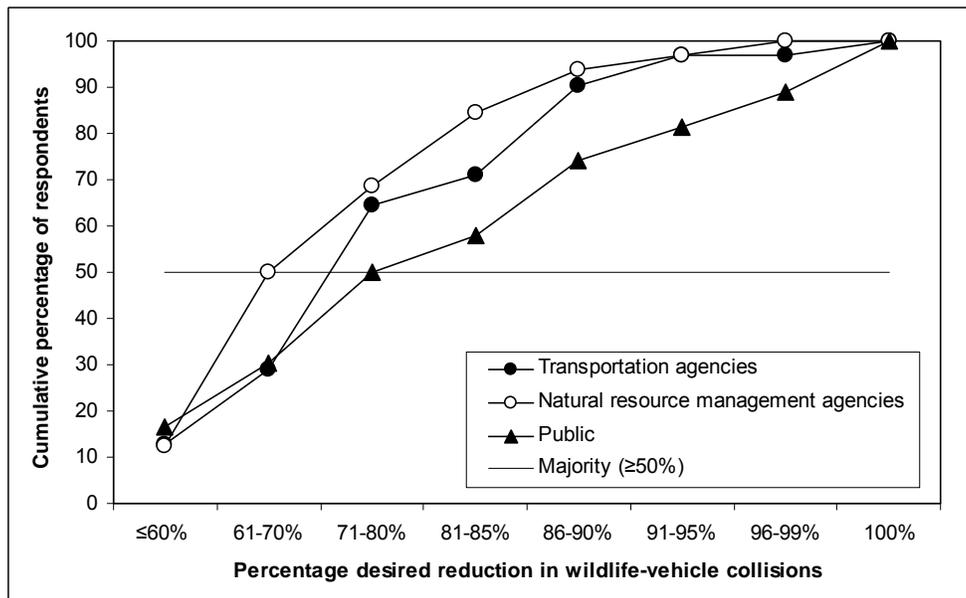


Figure 8.4: The percentage reduction in wildlife–vehicle collisions that is considered desirable. The number of respondents included in the analysis was 31 for transportation agencies, 32 for natural resource management agencies, and 128 for the public.

8.4. Discussion and Conclusion

The stakeholders had considerable agreement in their responses with regard to the reliability and effectiveness of animal detection systems. Based on the survey results, researchers recommend the following performance requirements for the reliability and effectiveness of animal detection systems:

- Animal detection systems should detect 91–95% or more of all large animals that approach the road.
- Animal detection systems that had a false detection rate (false positives) of 6–10% or less would be acceptable.
- Use of animal detection systems should result in a reduction of 71–80% or more in wildlife–vehicle collisions.

The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests (chapter 4) (Table 8.2). Five of the nine systems meet the recommended performance requirements for reliability. Note that the reliability performance for the Camrix system was split into before and after system modification as system modification had a significant effect on its reliability performance (see Table 5.4, Chapter 5).

While the researchers recommend performance requirements that would satisfy the majority ($\geq 50\%$) of all three stakeholder groups, stakeholders may decide to adopt higher (e.g., 80% of all respondents agree) or lower (e.g., 40% of stakeholders agree) norms for these performance requirements. This can cause additional systems to meet or no longer meet such performance requirements for reliability. If and once the stakeholder groups agree on performance requirements for the reliability and effectiveness of animal detection systems, agencies or other organizations can clearly communicate internally and externally, including to the public and other stakeholders, what animal detection systems that may be installed can and cannot be expected to do. Furthermore, performance requirements for the reliability of animal detection systems provide important guidance for vendors and manufacturers of animal detection systems.

Table 8.2: The reliability of each system in relation to the recommended minimum norms. The percentage of intrusions detected is similar, though not exactly the same as the inverse of the percentage of false negatives (see chapter 4) (*¹alternative calculation: 81.2%; *²alternative calculation: 81.8%; *³alternative calculation: 75.5%).

System number (Figure 3.2)	Manufacturer and system name	ID number	False positives (%)	False negatives (all types combined) (%)	Intrusions detected (%)	Meets recommended norms (yes/no)
1	Xtralis (ADPRO)	7	0.00	10.29	91.75	Yes
2	Xtralis (ADPRO)	5-6	0.00	20.88	85.43	No
3	STS (RADS I)	1	0.00	30.91	72.47	No
4	STS (RADS II)	2	0.00	15.94	88.35	No
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	0.60	0.48	99.54	Yes
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	0.00	1.16	98.85	Yes
7	Camrix (A.L.E.R.T.)	Overall	0.07	30.21	89.41 ^{*1}	No
		Before mod.	0.07	30.41	89.33 ^{*2}	No
		After mod.	0.00	27.00	90.20 ^{*3}	No
8	Xtralis (ADPRO)	1-2	0.97	6.53	95.19	Yes
9	Goodson		0.82	0.00	100.00	Yes

9. SITE REVIEWS

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9.1. Sites

Seven different road sections in western Montana, USA, were reviewed for the potential installation of an animal detection system (Table 9.1). These road sections were suggested by Pat Basting and Deb Wambach of the Montana Department of Transportation. It is not the purpose of this chapter to select the "best" road section for the potential installation of an animal detection system. The purpose is to provide site descriptions so that the Montana Department of Transportation has information to make an educated decision for each site individually.

Table 9.1: Site locations.

Site	Road name	Mi reference posts	Length road section (km (mi))	Location description
1	I-90	14.4-16.0	2.6 km (1.6 mi)	DeBorgia West
2	I-90	19.5-20.7	1.9 km (1.2 mi)	DeBorgia East
3	I-90	82.5-83.6	1.8 km (1.1 mi)	Ninemile
4	Hwy 206	1.7-4.0	3.7 km (2.3 mi)	Kalispell
5	MT Hwy 200	31.1-34.2	5.0 km (3.1 mi)	Clearwater Jct / Blackfoot Clearwater Game Range
6	MT Hwy 83	0.5-4.0	5.6 km (3.5 mi)	Clearwater Jct / Blackfoot Clearwater Game Range
7	I-15	162.0-165.0	4.8 km (3.0 mi)	Boulder

The road sections are shown in figures 9.1 through 9.7. The images show the location of the mile reference posts (ending in ".0") and the approximate tenth of a mile points in between with satellite imagery background. Note that these locations are the exact locations where images were taken of the road and right-of-way, and sometimes of the surrounding landscape as well (See Appendix B). Also note that the tenth of a mile locations are not always a tenth of a mile apart as the distance between mile reference posts is not always exactly one mile.



Figure 9.1: I-90 DeBorgia West. EB = East Bound; WB = West Bound.



Figure 9.2: I-90 DeBorgia East. EB = East Bound; WB = West Bound.



Figure 9.3: I-90 Ninemile. EB = East Bound; WB = West Bound.



Figure 9.4: Hwy 206 Kalispell.



Figure 9.5: MT Hwy 200 Clearwater Jct / Blackfoot Clearwater Game Range.



Figure 9.6: MT Hwy 83 Clearwater Jct / Blackfoot Clearwater Game Range.



Figure 9.7: I-15 Boulder. NB = North Bound; SB = South Bound.

9.2. Review Parameters

Each road section was reviewed with regard to the following parameters, as long as the data were available to the researchers. These parameters are partially based on Huijser et al. (2006a):

- **Animal-vehicle collisions.** The site should have a history of a relatively high number of animal-vehicle collisions with large animals, especially ungulates (e.g., deer, elk or moose). This is for two reasons: 1. the costs associated with the purchase, installation, and operation and maintenance of an animal detection system may be compensated by the savings associated with reduced animal vehicle collisions, and 2. if an animal detection system is evaluated for its effectiveness in reducing animal-vehicle collisions, historic data on animal-vehicle collisions should preferably be available (comparison in time). In addition, historic animal-vehicle collisions from control sites are helpful (comparison in space).

- Animal movements. The site should preferably be located in an area where many large animals (e.g., deer, elk or moose) are known to cross the road (daily movements or seasonal migration). Note: not all animal movements across a road result in animal-vehicle collisions. This may protect travelers against potential future animal-vehicle collisions and, in addition, the animals that cross the road should, at least theoretically, be better protected against potential future collisions with vehicles.
- Traffic volume and trucks. As traffic volume increases it becomes less and less desirable to have large animals cross at grade. In addition, above a certain traffic volume, the barrier effect of the road may be close to absolute with few animals that even try to still cross the road. In that type of situation, the problem of collisions has been large replaced by that of a barrier to animals. Furthermore, large vehicles such as freight trucks may be less likely to respond to the activated warning signs because the expense and perhaps also risk involved in braking when carrying a heavy load and because large ungulates may not cause substantial damage to the vehicle to begin with.
- Terrain. The terrain must allow for the installation of an animal detection system. For example, an abundance of ridges, gullies and rocky outcrops may make a location less suitable for an animal detection system, especially break-the-beam systems. Difficult terrain may also require more sensors and other equipment than relatively flat areas would require.
- Curves and access roads. The number of curves and access roads should be kept to a minimum to minimize the number of sensors and to avoid gaps (blind spots) or excessive false positives caused by traffic turning on or off the road, depending on what sets off the sensors.
- Vegetation. The vegetation should allow for the installation of an animal detection system. For example, bushes and trees that grow up to the edge of the pavement increase the chance of triggering the system, i.e., they would cause excessive false positives for most area cover, or break-the-beam systems.
- Length road section. If an animal detection system is deployed as a stand alone mitigation measure, the road section must be at least 805-1609 m (0.5–1.0 mi) long to be able to accommodate for potential spatial errors in the location of historic road kill data that was used to select the site. If an animal detection system is installed in a gap in a wildlife fence, the gap width can be variable, but a gap is typically between 30 and 200 m wide, depending on the range of the sensors and the local conditions.
- Changes in road or landscape. The road and surrounding landscape should not be scheduled to undergo major changes within the life span of the mitigation measure; for animal detection systems about 10 years. However, should changes in the landscape occur and change where animals cross the road and where animals are hit by vehicles, then one may consider relocating an animal detection system. Nonetheless, there are relocation costs involved for such an effort. In addition, major changes, other than the installation of the animal detection system, would confound the results of a potential study into the effectiveness of the animal detection system in reducing animal-vehicle collisions.

- Project partners. All the organizations and individuals that have jurisdiction or that are stakeholders in activities at the study site should support the project. This includes support for installation, operation and maintenance.
- Travel costs. The site should preferably be close to where operation and maintenance personnel have their offices. This reduces costs for travel and stay.
- Power. The site should allow for either solar power or a connection to 110 V power source.
- Pull-out. The site should preferably have a safe pull-out location for vendors and maintenance and research personnel.
- Controlled access. The site should preferably have a low risk of theft and vandalism, e.g., a controlled access road.

9.3. Site Conditions

The site conditions are described in detail in the sections below. Table 9.2 provides a summary of the site conditions.

9.3.1. Animal-vehicle collisions

Wildlife carcass removal data were obtained from the Montana Department of Transportation to estimate the costs associated with wildlife-vehicle collisions on the road sections concerned. These data do not include all wildlife-vehicle collisions, as some animals are never found or not removed. Thus the data provide a minimum estimate on the number of wildlife-vehicle collisions. Only large ungulates (deer, elk, and moose) were included in our analyses, but other large mammals (mountain lions, wolves, and black bear were estimated to result in damage similar to deer). The costs for the average collision with a deer, an elk, and a moose has been estimated at \$6,617, \$17,483, and \$30,760 respectively (Huijser et al., Submitted). These cost estimates were combined with the wildlife carcass removal data to calculate the costs associated with deer-, elk-, and moose-vehicle collisions combined per kilometer per year. These costs were presented in graphs for the road sections concerned. The graphs also showed the thresholds the costs must meet in order to have different mitigation measures generate benefits in excess of costs. The thresholds shown are for the following combinations of mitigation measures (see Huijser et al., Submitted for details):

- Animal detection system
- Fence, gap (once every 2 km), animal detection system in gap, jump-outs
- Fence, under- and overpass (underpass once every 2 km, overpass once every 24 km), jump-outs
- Fence, under pass (once every 2 km), jump-outs

At locations where the costs reach or exceed the threshold values, the mitigation measure concerned would generate benefits in excess of costs. Note that the road sections were expanded on either side by a few miles to accommodate for edge effects (zero values) for the average costs per kilometer.

I-90 DeBorgia West and I-90 DeBorgia East combined

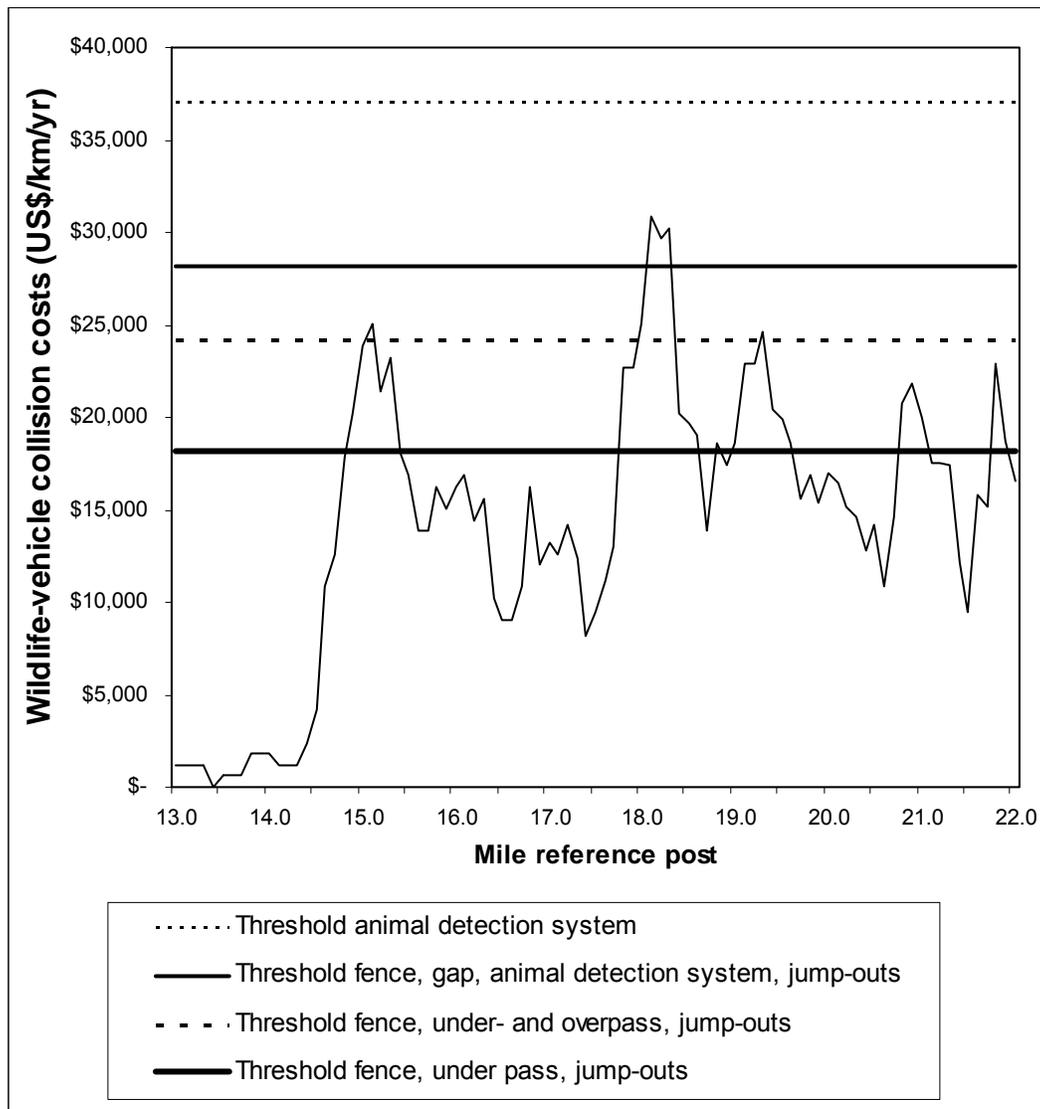


Figure 9.8: I-90 DeBorgia East and West. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, elk, moose, and 7 black bears and 1 mountain lion (black bears and mountain lions were estimated to have equal cost as deer) along the 4-lane I-90 (mi reference posts 13.0-22.0) per year (average 1998-2008), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

I-90 Ninemile

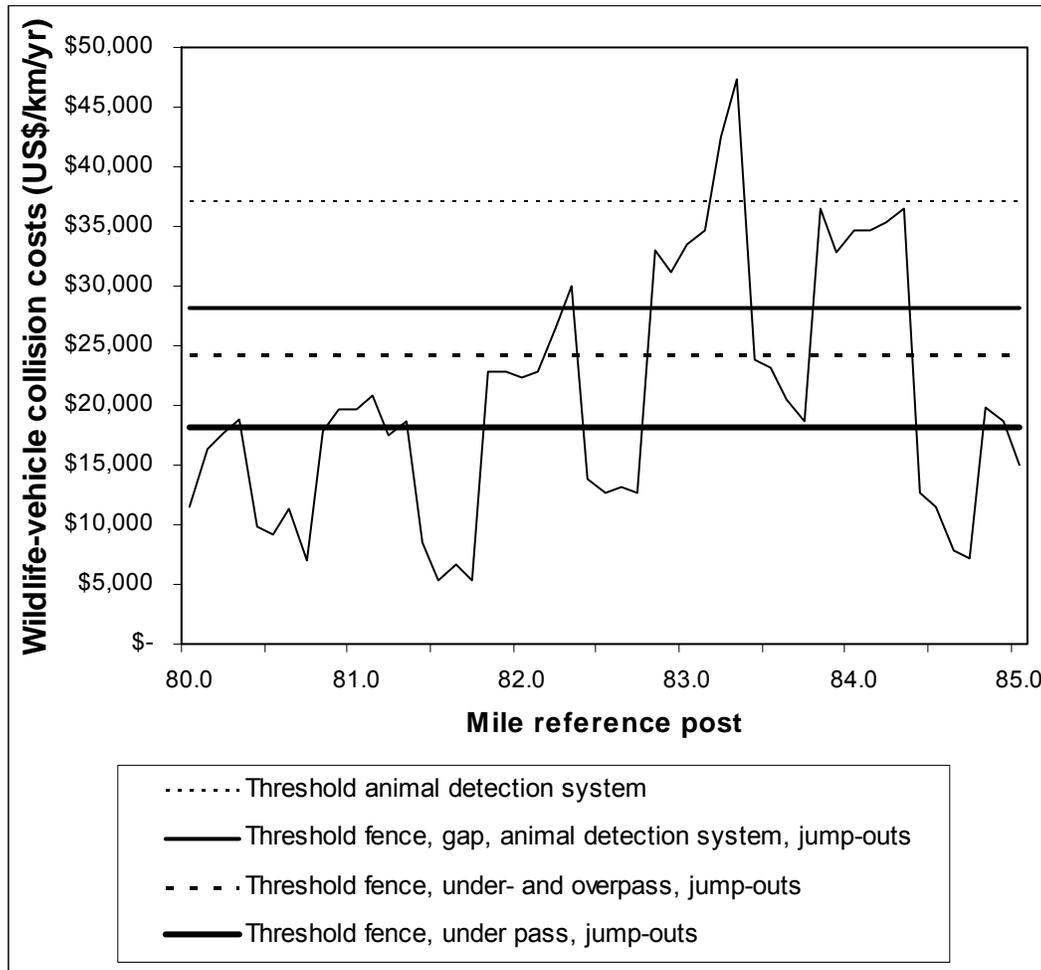


Figure 9.9: I-90 Ninemile. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, and 2 black bears and 1 wolf (black bears and wolves were estimated to have equal cost as deer) along the 4-lane I-90 (mi reference posts 80.0-85.0) per year (average 1998-2008), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

Hwy 206 Kalispell

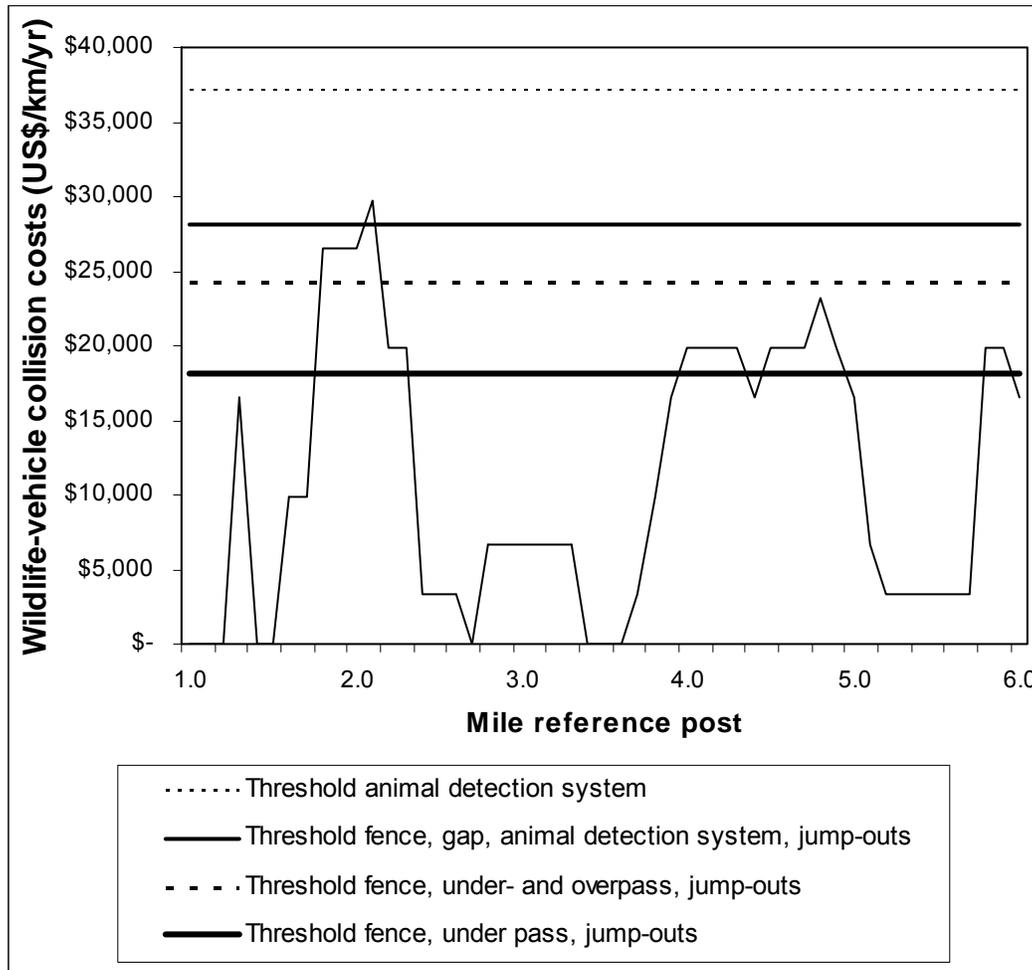


Figure 9.10: Hwy 206 Kalispell. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, and 3 mountain lions (mountain lions were estimated to have equal cost as deer) along the 2-lane Hwy 206 (mi reference posts 1.0-6.0) per year (average 2005-2006), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

MT Hwy 200 Clearwater Jct

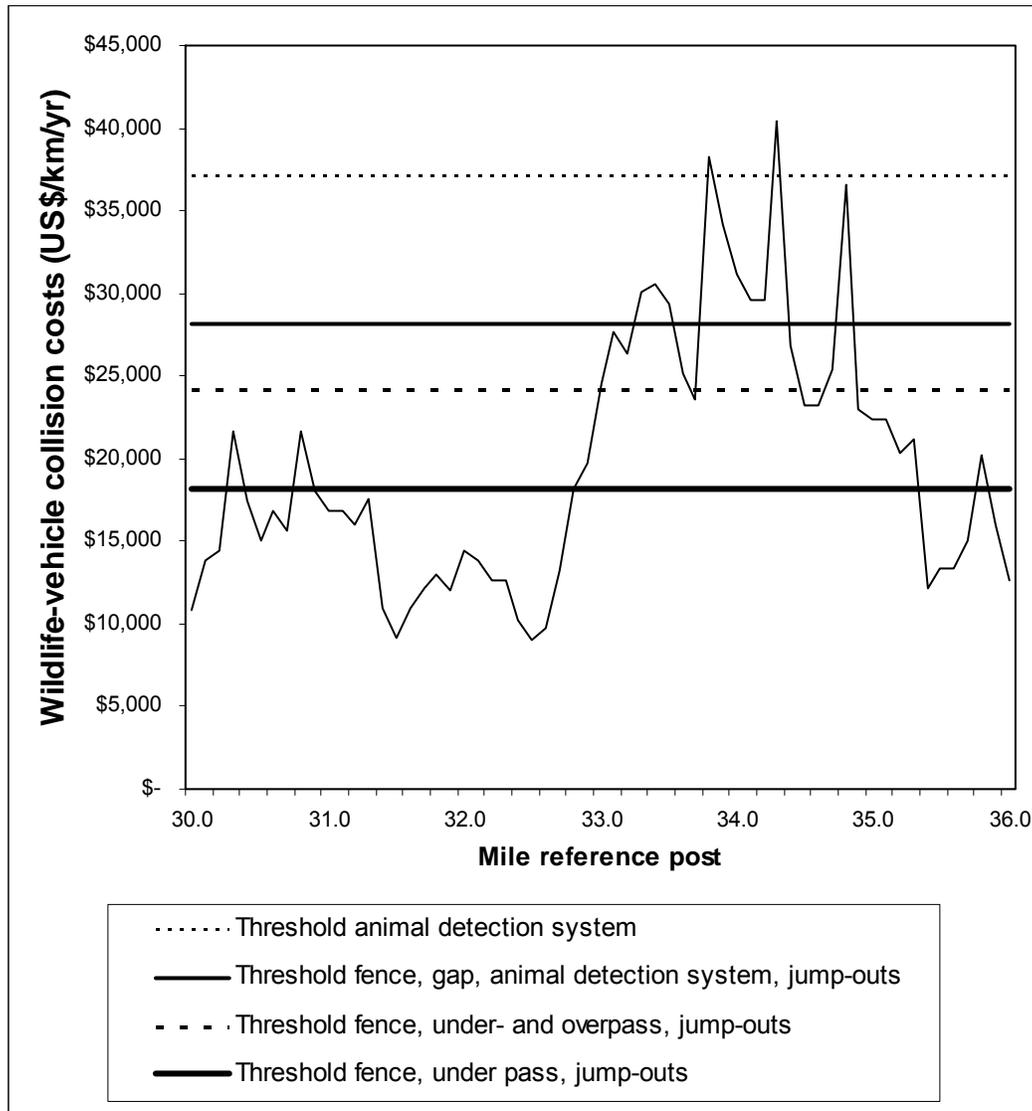


Figure 9.11: MT Hwy 200 Clearwater Jct. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, elk, and 2 black bears and 1 mountain lion (black bears and mountain lion were estimated to have equal cost as deer) along the 2-lane MT Hwy 200 (mi reference posts 30.0-36.0) per year (average 1998-2008), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

MT Hwy 83 Clearwater Jct

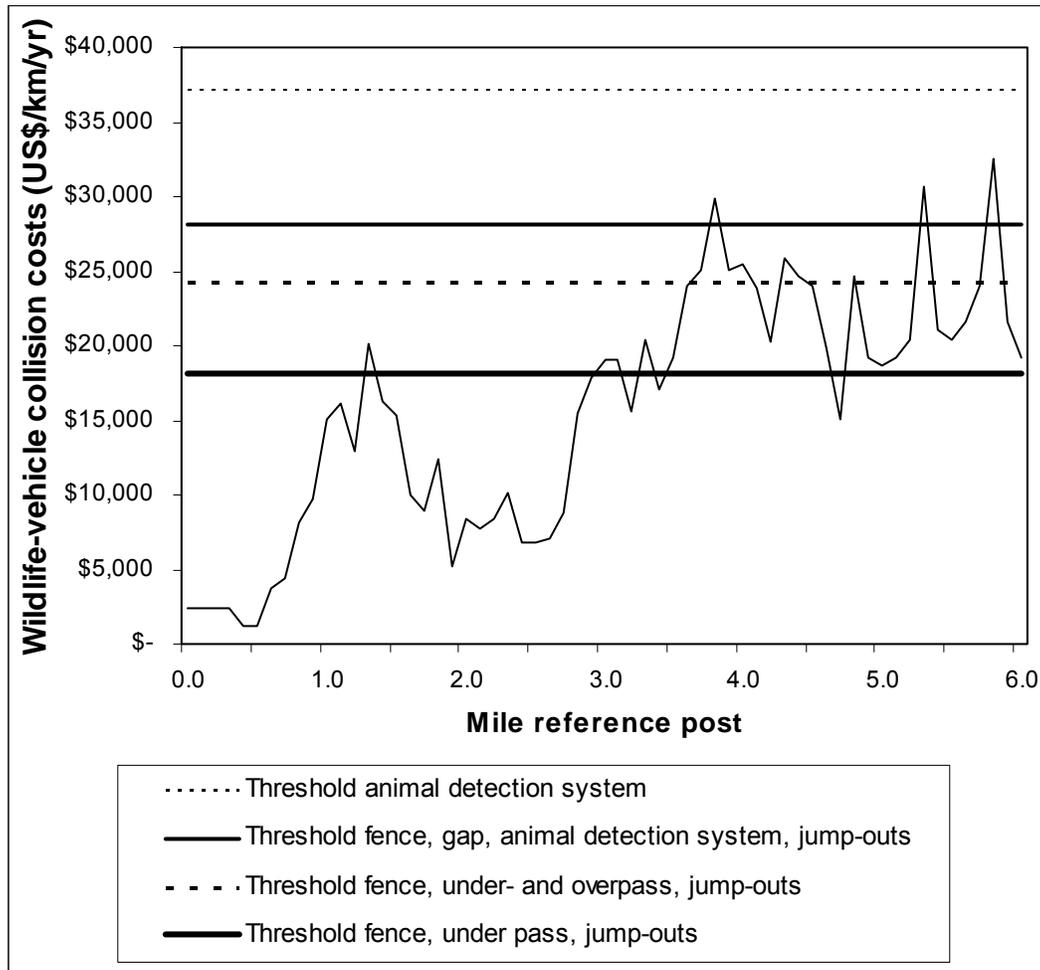


Figure 9.12: MT Hwy 83 Clearwater Jct. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, elk, 1 mountain lion (mountain lion were estimated to have equal cost as deer) along the 2-lane MT Hwy 83 (mi reference posts 0.0-6.0) per year (average 1998–2008), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

I-15 Boulder

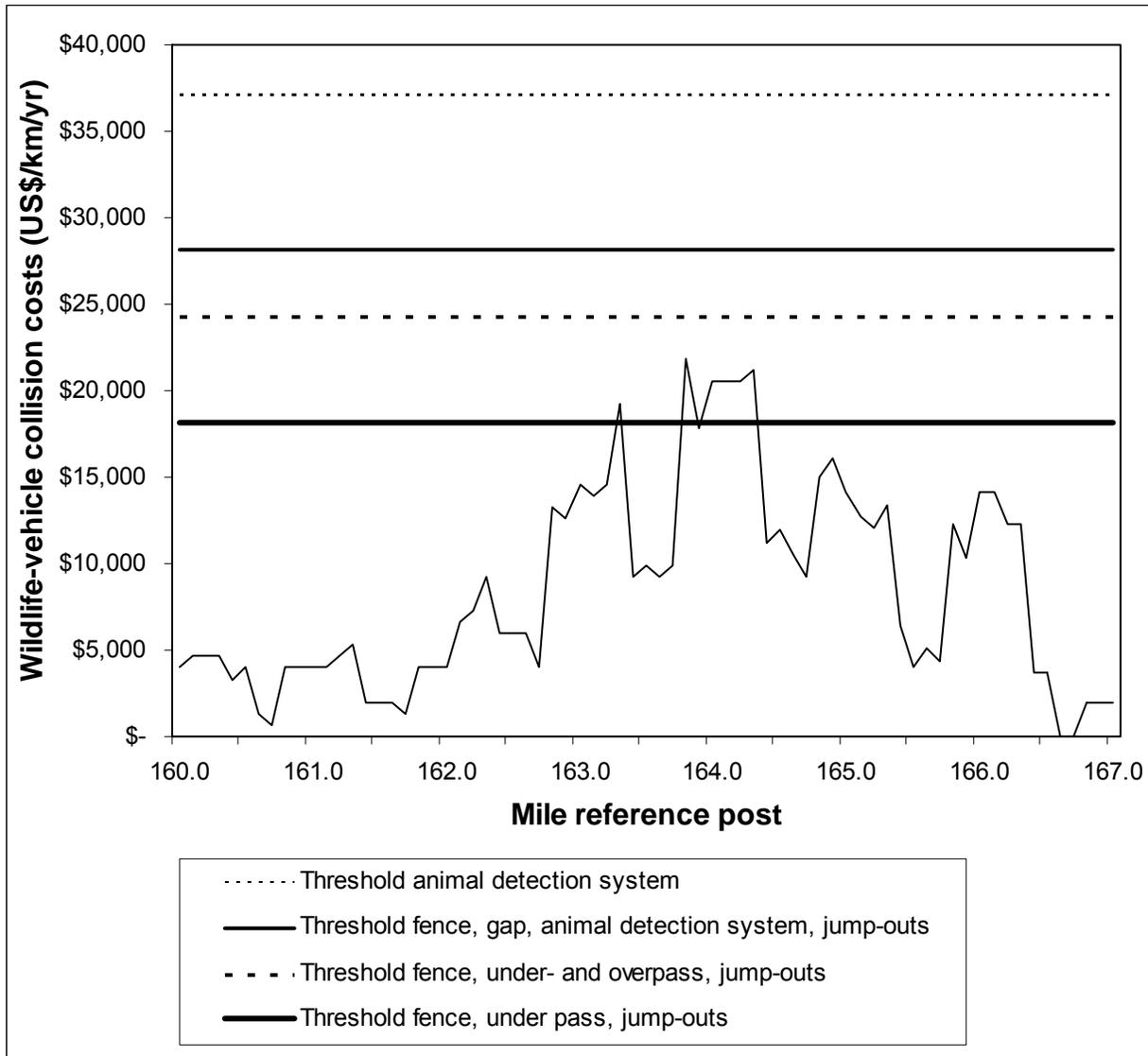


Figure 9.13: I-15 Boulder. The costs (in 2007 US\$) associated with wildlife-vehicle collisions (deer and elk) along the 4-lane I-15 (mi reference posts 160.0-167.0) per year (average 1998–2007), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

9.3.2. Animal movements

No information is available to the authors of this report. Interviews with people who have local experience and knowledge with regard to animal movements is recommended.

9.3.3. Traffic Volume

I-90 DeBorgia West

This is a four lane (two lanes in each direction) interstate. Average Annual Daily Traffic (AADT) in 2007: 6,720 at reference post 47.8 (MDT, 2008). Percentage of large trucks in 2007: 25.5% (MDT, 2008). Average Annual Daily Traffic (AADT) in 2007: 7,570 at reference post 15.5 (MDT, 2009).

I-90 DeBorgia East

This is a four lane (two lanes in each direction) interstate. Average Annual Daily Traffic (AADT) in 2007: 6,720 at reference post 47.8 (MDT, 2008). Percentage of large trucks in 2007: 25.5% (MDT, 2008). Average Annual Daily Traffic (AADT) in 2007: 7,570 at reference post 15.5 (MDT, 2008).

I-90 Ninemile

This is a four lane (two lanes in each direction) interstate. Average Annual Daily Traffic (AADT) in 2007: 6,720 at reference post 47.8 (MDT, 2008). Percentage of large trucks in 2007: 25.5% (MDT, 2008). Average Annual Daily Traffic (AADT) in 2007: 7,370 at reference post 76.8 (MDT, 2009).

Hwy 206 Kalispell

This is a two lane (one lane in each direction) highway. Average Annual Daily Traffic (AADT) in 2007: 4,380 at reference post 0.5 (MDT, 2009).

MT Hwy 200 Clearwater Jct

This is a two lane (one lane in each direction) highway. Average Annual Daily Traffic (AADT) in 2007: 2,854 at reference post 30.8 (MDT, 2008). Percentage of large trucks in 2007: 6.1% (MDT, 2008).

MT Hwy 83 Clearwater Jct

This is a two lane (one lane in each direction) highway. Average Annual Daily Traffic (AADT) in 2007: 2,235 at reference post 0.8 (MDT, 2008). Percentage of large trucks in 2007: 5.1% (MDT, 2008).

I-15 Boulder

This is a four lane (two lanes in each direction) interstate. Average Annual Daily Traffic (AADT) in 2007: 3,120 at reference post 164.5 (MDT, 2009).

9.3.4. Terrain

I-90 DeBorgia West

There is a large culvert at about reference point 15.7, which coincides with a depression in the terrain. However, depending on the species, animals may use the culvert as opposed to crossing at grade. There is guard rail associated with the underpass for both travel directions. For the eastbound lanes there is guard rail present between reference points 14.4-14.5, 14.9-15.0, and 15.6-15.8 because of steep slopes and the nearby river. Concrete barriers are present in the median between reference point 14.4-14.5.

I-90 DeBorgia East

The section is mostly flat. There is one short section of guardrail along the eastbound lanes (reference points 20.6-20.7) that is associated with a slope.

I-90 Ninemile

This section climbs up towards the west, but the right-of-way does not have major rises or depressions. A guard rail and, mostly concrete barriers, are present in the median for most of the road section (reference posts 8 2.5-83.4). The westbound lanes have guardrail and a steep slope at 83.6. The eastbound lanes have guardrail and slopes between reference points 82.7 and 83.2, and at 83.6. These are all associated with steep slopes.

Hwy 206 Kalispell

The road section between reference points 1.7 and 2.4 was recently re-contoured. However, the road section between reference points 2.4 and 4.0 is relatively uneven because of access roads or farm land entries. There are two substantial hills in this road section (around reference points 1.8 and 2.8).

MT Hwy 200 Clearwater Jct

This road section is mostly flat. Exceptions are the bridge across the Clearwater river (reference point 31.3), and a rise in a curve towards the east end (around reference point 33.5). Furthermore, there is a short section of guardrail on both sides of the road at the bridge across the Clearwater river (reference point 31.3), and there is a guardrail at the east end (reference point 14.2) because of a slope.

MT Hwy 83 Clearwater Jct

This road section is mostly flat. Exceptions are slopes adjacent to the southbound lane at reference point 2.3 and 4.0.

I-15 Boulder

This road section is mostly flat. Exceptions are a hill at reference points 163.6-163.7, and two bridges for the Boulder river for the northbound lanes at reference points 162.0 and 163.0 and at a bridge at reference point 164.1 (both travel directions). For the northbound lanes guard rails and associated slopes are present at reference points 162.0, 162.0-162.2 (median), 162.4-162.5 (median), 162.9-163.1 (median), 163.0-163.1, 163.2-163.5, 164.1 (both sides). For the southbound lanes guard rails and associated slopes are present at reference points 164.2 (both sides), 163.3-163.5, and 162.0-162.4 (median).

9.3.5. Curves and Access Roads

I-90 DeBorgia West

The westbound lane has two curves whereas the eastbound lane is straighter and has only one curve. Furthermore, this road section is characterized by a wide median with on and off ramps (four in total) for a truck weigh station in the median. There are no on or off ramps on the "outside" of the road section, but there is an access road to a gravel pit that connects to the westbound lane at about reference point 14.95. There are two turn around points for cars in the median (restricted access) at about reference point 14.6 and 15.8.

I-90 DeBorgia East

Both the westbound and eastbound lanes are straight. Furthermore, this road section is characterized by a relatively wide median, mostly with trees and shrubs. There are no on or off ramps. There is turn around point for cars in the median (restricted access) at about reference point 19.6.

I-90 Ninemile

Both the westbound and eastbound lanes are curvy at the beginning and end. Furthermore, this road section is characterized by the absence of a median. There is an on and off ramp on the far west side (reference points 82.5-82.6).

Hwy 206 Kalispell

This road section is straight. However, there are six cross roads or drive ways on the east side, and 16 on the west side.

MT Hwy 200 Clearwater Jct

This road section is mostly straight except for a couple of curves close to either end. However, there are 15 cross roads or drive ways on the east side, and eight on the west side.

MT Hwy 83 Clearwater Jct

This road section is mostly straight, but it has a few slight curves and a more substantial curve at reference point 3.5. However, there are nine cross roads, drive ways, or pull-outs on the east side, and four on the west side.

I-15 Boulder

This is a relatively curvy road section with a wide median, especially between reference points 162.0-163.0 where the Boulder river is located in the median. There are on and off ramps at 164.7 and just north of 165.0. There are turn around points for cars in the median (restricted access) at about reference point 163.1 and 164.3.

9.3.6. Vegetation

I-90 DeBorgia West

The first few meters (yards) from the edge of the pavement are dominated by grasses and herbs. Trees and shrubs are far enough from the edge of the pavement to allow for the installation of break-the-beam systems.

I-90 DeBorgia East

The first few meters (yards) from the edge of the pavement are dominated by grasses and herbs. Trees and shrubs are far enough from the edge of the pavement to allow for the installation of break-the-beam systems.

I-90 Ninemile

The vegetation in the right-of-way is dominated by grasses and herbs.

The first few meters (yards) from the edge of the pavement are dominated by grasses and herbs. Trees and shrubs are far enough from the edge of the pavement to allow for the installation of break-the-beam systems.

Hwy 206 Kalispell

The first few meters (yards) from the edge of the pavement are dominated by grasses and herbs. Trees and shrubs come close to the road in some sections (e.g. around reference points 3.7-3.9).

MT Hwy 200 Clearwater Jct

The vegetation in the right-of-way is dominated by grasses and herbs. Trees and shrubs are scarce and only come close to the road at the bridge across the Clearwater (reference point 31.3).

MT Hwy 83 Clearwater Jct

The vegetation in the right-of-way is dominated by grasses and herbs. Trees and shrubs are scarce, except for the north end.

I-15 Boulder

The vegetation in the right-of-way is dominated by grasses and herbs. The northern road section is mostly open, but trees and shrubs are closer to the road where the Boulder river runs in the median.

9.3.7. Length Road Section

See Table 9.1.

9.3.8. Changes in Road or Landscape

If implementation of an animal detection system is considered at a road section, other changes in the road and landscape should be evaluated, especially if the system is to be evaluated for its effectiveness in reducing animal-vehicle collisions.

9.3.9. Project Partners

No information is currently available on potential partners for the potential implementation of the animal detection systems.

9.3.10. Travel Costs

No information is currently available on who would be responsible for operation and maintenance of the animal detection systems, should any be installed.

9.3.11. Power

I-90 DeBorgia West

There are power lines at varying distance (a few hundred feet to perhaps a few hundred yards) north of the road section.

I-90 DeBorgia East

There are power lines at a few dozen feet on the north side of the westbound lane, just north of the frontage road. In addition, there are larger power lines that parallel the eastbound lanes on the south side a few hundred feet from the edge of the pavement.

I-90 Ninemile

There are power lines that cross the road at reference point 83.3.

Hwy 206 Kalispell

There are power lines that parallel the road between reference points 1.7-2.9. There are street lights present between reference points 3.6-4.0.

MT Hwy 200 Clearwater Jct

Power lines come close north of the road at reference point 32.1, cross the road at reference point 31.8, and run parallel to the road on the south side until reference point 33.2.

MT Hwy 83 Clearwater Jct

Power lines run parallel to the west side of the road. Additionally, power lines cross the road at reference point 4.0.

I-15 Boulder

Power lines cross the road at reference point 162.0, run parallel to the east side of the road between reference points 162.0-163.0, cross the road at 163.0, 164.2-164.3, and run parallel to the west side at a distance of a few hundred meters (yards).

9.3.12. Pull-out

I-90 DeBorgia West

There is safe stopping and parking everywhere because of the wide shoulder and clear zone, except in road sections that have guard rail.

I-90 DeBorgia East

There is safe stopping and parking everywhere because of the wide shoulder and clear zone, except in the one short road section that has a guard rail.

I-90 Ninemile

There is safe stopping and parking along most of the westbound lanes because of the wide shoulder and clear zone, except in the one short road section that has a guard rail. There is a guard rail along most of the eastbound lanes, making it unsuitable for frequent or long stops.

Hwy 206 Kalispell

There is safe stopping and parking between reference points 1.7 and 2.4 as this section was recently re-contoured. However, it is generally not safe to stop frequently and long between reference points 2.4 and 4.0 because of the narrow shoulders and slopes. Furthermore, there are two substantial hills in this road section (around reference points 1.8 and 2.8) that limit the sight distance to drivers.

MT Hwy 200 Clearwater Jct

There is safe stopping and parking along most of the road section (wide shoulders, clear zone, short grass-herb vegetation).

MT Hwy 83 Clearwater Jct

There is safe stopping and parking along most of the road section (wide shoulders, clear zone, short grass-herb vegetation).

I-15 Boulder

There is safe stopping and parking everywhere because of the wide shoulder and clear zone, except in road sections that have guard rail.

9.3.13. Controlled Access

I-90 DeBorgia West

Drivers are unlikely to stop in this road section, except for truck drivers that must stop at the weigh station in the median. Unless a detection system is also installed at the median, people are unlikely to access a potential animal detection system. The access road to the gravel pit (westbound lanes, mile reference post 14.95) as well as the frontage road that parallels the westbound lanes between mile reference posts 15.5 and 16.0, may cause a few users to investigate a potential animal detection system though.

I-90 DeBorgia East

Drivers are unlikely to stop in this road section. The frontage road that parallels the westbound lanes may cause a few users to investigate a potential animal detection system though.

I-90 Ninemile

Drivers are unlikely to stop in this road section, except for the on and off ramps at reference point 82.5.

Hwy 206 Kalispell

Drivers are unlikely to stop, especially between reference points 2.4 and 4.0 because of the narrow shoulders and slopes. However, because of nearby houses, people are likely to investigate potential equipment, especially between reference points 1.7-3.0 and 3.6-4.0.

MT Hwy 200 Clearwater Jct

Drivers are unlikely to stop, except at the junction with MT Hwy 83 (gas station, rest stop). Other road sections where people may investigate the equipment are at driveways and access roads, particularly at reference points 33.8-33.9.

MT Hwy 83 Clearwater Jct

Drivers are unlikely to stop, except at the junction with MT Hwy 83 (gas station). Other road sections where people may investigate the equipment are at driveways, access roads, and pull-outs.

I-15 Boulder

Drivers are unlikely to stop at this road section.

Table 9.2: The suitability of the road sections with regard to the installation of an animal detection system. + + + = strongly suitable; - - - strongly not suitable or a severe concern.

Site	I-90 DeBorgia West	I-90 DeBorgia East	I-90 Ninemile	Hwy 206 Kalispell	MT Hwy 200 Clearwater Jct	MT Hwy 83 Clearwater Jct	I-15 Boulder
A-V collisions	++	++	+++	+++	+++	+++	+
Animal movements	?	?	?	?	?	?	?
Traffic volume/trucks	--	--	--	+	++	++	+
Terrain	+	++	-	-	++	+	-
Curves/access roads	+	+++	-	-	++	+	-
Vegetation height	+	++	+	-	++	++	+
Length road section	+	+	+	+	+	+	+
Changes road/landscape	?	?	?	?	?	?	?
Project partners	?	?	?	?	?	?	?
Travel costs	?	?	?	?	?	?	?
Power source	+	+	+	+	+	+	+
Pull-out	++	++	-	--	++	+	++
Controlled access	++	+++	+++	--	--	--	+++

10. DISCUSSION AND CONCLUSIONS

Author: Marcel P. Huijser, Western Transportation Institute, College of Engineering, Montana State University

10.1. Discussion

The results of the reliability tests showed that different detection technologies detect large animals more or less frequently as an animal passes through the detection area or line of detection. The percentage of false positives and the average number of false positives per hour was relatively low for all systems ($\leq 1\%$; $\leq 0.10/\text{hr}$). The percentage of false negatives (all types of false negatives combined) and the average number of false negatives per hour was highly variable (0–31%; 0–1.61/hr). The percentage of intrusions (i.e., animal movements across the detection line) that were detected varied between 73% and 100%. The results suggest that some animal detection systems are quite reliable in detecting large mammals with few false positives and false negatives, whereas other systems suffer from relatively many false negatives.

The reliability of animal detection systems is influenced by a range of environmental conditions. High winds were associated with an increase in different types of false negatives for most passive infrared area-cover systems. High winds were associated with both an increase in false positives and a decrease in false positives for different types of systems, suggesting that passive infrared area-cover systems become less sensitive with high winds whereas break-the-beam systems that rely on a very narrow beam may start generating false positives, presumably because the sensors sway slightly in and out of alignment. The latter suggests the importance of a stable foundation and pole for break-the-beam systems. Stable foundations and poles may also be beneficial to passive infrared area-cover systems, but it is unclear if the increase in false negatives for such systems is caused by movement of the sensors, which tend to be higher up on a pole than sensors for break-the-beam systems, or by vegetation or pockets of hot and cold air that move in the wind. The effects of wind direction are hard to interpret, but it may be that winds oriented perpendicular to the systems caused vegetation or pockets of hot and cold air to trigger systems more often than winds oriented more parallel to the systems. Higher temperatures are generally associated with higher error rates. This could be due to temperature causing reduced performance of the equipment. In addition, passive infrared systems may not be able to distinguish clearly between pockets of hot air and moving animals. However, higher temperatures are concentrated in time (summer) and it is possible that factors other than temperature caused more errors in summer. Animal behavior and possible effects on the likelihood of correct detections and errors may have also been influenced by temperature. Three systems had fewer false negatives during the night compared to during the day. This may be related to lower temperatures or higher contrasts in temperatures between the animals and their surroundings during the night. However one system had more false negatives during the night compared to during the day. Excellent visibility was associated with fewer false positives for a break-the-beam system, which suggests that relatively low visibility may block or reduce the narrow signal path of optical break-the-beam systems. It is unclear why excellent visibility may have caused another system to increase a particular type of false negatives. Precipitation was rarely observed during the test periods and its effect on system reliability is unclear. However, higher relative humidity was mostly associated with an increase in errors, and to a lesser extent with a decrease in errors. Finally, llamas were substantially harder to detect for most systems,

especially passive infrared area-cover systems, than horses, probably because of their smaller body size.

Three stakeholder groups—, employees of transportation agencies, employees of natural resource management agencies, and the traveling public—were surveyed with regard to their expectations on the reliability and effectiveness of animal detection systems. There was considerable agreement in the responses of the three stakeholders. The researchers recommend the following performance requirements for the reliability and effectiveness of animal detection systems:

- Animal detection systems should detect 91–95% or more of all large animals that approach the road.
- Animal detection systems that had a false detection rate of 6–10% or less would be acceptable.
- Use of animal detection systems should result in a reduction of 71–80% or more in wildlife–vehicle collisions.

The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests. Five of the nine systems met the recommended performance requirements for reliability. However, experiences with installation, operation and maintenance show that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

This report also presented a concept of operation and a review of ITS architecture and infrastructure for animal detection systems. Currently, roadside animal detection systems present drivers with warnings displayed on road signs. In the future, roadside animal detection systems may also transmit warning signals to traffic approaching a location where a large animal has been detected on or near the road. This procedure would require a two-way GPS-based communication system. With animal detection system deployments becoming more numerous, standards for communication and ITS integration will have to be further developed and accepted.

10.2. Conclusions

- Different detection technologies detect large animals more or less frequently as an animal passes through the detection area or line of detection. This implies that care must be taken in evaluating the reliability of different technologies, and in comparing systems or minimum performance requirements.
- The percentage of false positives and the average number of false positives per hour was relatively low for all systems ($\leq 1\%$; $\leq 0.10/\text{hr}$). False positives do not appear to be a major concern with regard to the reliability of animal detection systems.
- The percentage of false negatives (all types of false negatives combined) and the average number of false negatives per hour was highly variable (0–31%; 0–1.61/hr). The percentage of intrusions (i.e., animal movements across the detection line) that were detected varied between 73% and 100%. The results suggest that false negatives are a major concern for some animal detection systems, but not for others.
- Environmental conditions and the target species influence the reliability performance of animal detection systems. Therefore the environmental conditions at a site and the target

species should be carefully evaluated before selecting a suitable system. Besides system reliability, system robustness, and the road length that the sensors are able to cover needs to be considered.

- The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests. Five of the nine systems met the recommended performance requirements for reliability. However, experiences with installation, operation, and maintenance show that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.
- Currently, roadside animal detection systems present drivers with warnings displayed on road signs. In the future, roadside animal detection systems may also transmit warning signals to traffic approaching a location where a large animal has been detected on or near the road. With animal detection system deployments becoming more numerous, standards for communication and ITS integration will have to be further developed and accepted.

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12. APPENDIX A: CONTACT DETAILS FOR MANUFACTURERS AND LIVESTOCK SUPPLIER

Systems 1, 2 and 8

Xtralis

700 Longwater Drive #100

Norwell, MA 02061

Main contact: Steve Stettner

Phone: 781-740-2223, Fax: 781-740-4433,

E-mail: [sstettner@xtralis.com](mailto:ssettner@xtralis.com)

Web site: <http://www.xtralis.com>

Systems 3 and 4

ICx Radar Systems

(formerly Sensor Technologies and Systems, Inc.)

“RADS (Roadside Animal Detection System)”

8900 East Chaparral Road

Scottsdale, AZ 85250, USA

Main contact: Walker Butler

E-mail: walker.butler@icxt.com

Phone: 480-483-1997, Fax: 480-483-2011

Web site: <http://radarsystems.icxt.com>

Systems 5 and 6

Calonder Energy

“CAL 92”

Willy Berchtold

1436 Van Asche Drive

Fayetteville, AR 72704, USA

Phone: 479-521-0056, Fax: 479-521-9116

E-mail: info@calonderenergy.com

Web site: www.calonderenergy.com

System 7

Camrix

“A.L.E.R.T. (Animal Location and Evasive Response Technology)”

Main contact: Mike Doyle

1139 Holly Dr.

Bozeman, MT 59715, USA

Phone: 406-209-1928 (cell)

System 9

Goodson and Associates, Inc

10614 Widmer

Lenexa, KS 66215, USA

Main contact: Bill Goodson

Phone: 1-800-544-5415 / 913-345-8555, Fax: 913-345-8555

E-mail: bgoodson@trailmaster.com

<http://www.trailmaster.com/company.php>

IR cameras

Fuhrman Diversified, Inc.

2912 Bayport Blvd.

Seabrook, TX 77586-1501, USA

Main contact: Richard Fuhrman

Phone: 281-474-1388, Fax: 281-474-1390

E-mail: fdi@flash.net

Web site: <http://www.fieldcam.com/>

Livestock supplier

Lethia Olson

5520 Grinde Rd.

Lewistown, MT 59457-8044, USA

Phone: 406-538-5818, Fax: 406-538-2893

13.APPENDIX B: PHOTOS FROM THE SITES REVIEWED IN CHAPTER 9

Because:

1. The number of photos, and thus the file size (1.6 GB) and number of pages involved, and;
 2. The fact that the photos from the site review are only of interest to a few people,
- the photos were submitted to the Montana Department of Transportation (MDT) and the Federal Highway Administration (FHWA) on DVD only.

The DVD with photos from the sites was delivered to the following MDT and FHWA employees:

Name: BALSLEY, Phillard
Location: TRAFFIC - ELECTRICAL
City: Helena
Phone Number: (406) 444-6218
Email: pbalsley@mt.gov

Name: BASTING, Pat
Location: MISSOULA - ENVIRONMENTAL
City: Missoula
Phone Number: (406) 523-5872
Email: pbasting@mt.gov

Name: SELISKAR, Bob
Location: FHWA
City: Helena
Phone Number: (406) 441-3903
Email: a0420@mt.gov

Name: SILLICK, Susan
Location: HELENA - RESEARCH
City: Helena
Phone Number: (406) 444-7693
Email: ssillick@mt.gov

Name: WAMBACH, Deborah
Location: HELENA - ENVIRONMENTAL
City: Helena
Phone Number: (406) 444-0461
Email: dwambach@mt.gov