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Evaluation of an Animal Warning System Effectiveness

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CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

EVALUATION OF AN ANIMAL WARNING SYSTEM EFFECTIVENESS

FINAL REPORT

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ABSTRACT

The problem of vehicle/animal crashes is being addressed in this research. There have been a few new technologies that claim to accurately detect the large animals that cross our roadways. Each one has its own strengths and shortcomings. A close attention must be given to the selected site and the technology deployed based on its weather, vegetation, topography, and local animal types and sizes. In this project, we have reviewed a number of animal detection systems and selected one system with the most potential to serve the characteristics of the selected site and the local Deer. We did a preliminary test of the reliability of this system in a testbed in Lewistown, Montana. The results were encouraging. We also carefully selected a site that we felt could benefit the most from this safety improvement based on its physical and climatic characteristics as well as its high number of vehicle/animal crashes. We also designed and developed a data monitoring and recording system that records and archives the response of the driver to our designed animal warning signs. This system incorporates radars, video cameras, communication links, and computer hardware and software. In the next phase of this project, we will analyze the effectiveness of our entire system by analyzing the driver's response to the animal warning signs. We will also continue our evaluation of reliability of the selected animal detection system both in study site and in Lewistown's testbed.

Key Words: Vehicle/animal crashes, animal detection systems, driver's warning of animals on the road, driver's response to warning, animal warning signs

ACKNOWLEDGEMENTS

1. Executive summary

The Phase one of "evaluation of an Animal Warning System Effectiveness" project was done under an agreement between Caltrans and California Path Program with Task Order of 6604. This contract does not call this phase as "phase one" but since a follow up project have already being agreed between the above mentioned parties, this report refers to this contract as "phase one".

The number of animal-vehicle collisions is rising. This is one of the few areas of the surface transportation that safety is not improving. As more roads are being built, the areas that animal inhabit is shrinking and thus causing more crashes between vehicles and animals. The human fatalities and injuries, animal fatalities and injuries, and material costs of these crashes emphasize the need for a solution to this problem. A wide array of crash reduction solutions have been sought, including fencing, overpasses, dynamic flashing systems, animal repellant, and whistles. Two main factors affect the effectiveness of a system: the quality of the detection rate of wild animals and the communication of the threat to the drivers. The quality of the detection is the ratio of good detection vs. bad detection. The communication of the threat to the driver involves the amount of information that can be delivered about a threat in a short amount of time.

The eventual goal of this project after the completion of the next phase is to achieve two objectives: i) study the effectiveness of animal warning systems to detect wildlife on the roadside, ii) measure driver's response to the warnings resulting from the animal detection system selected. During this first phase, we have selected a site for our study. Based on the characteristics of the chosen site, an animal detection system using microwave beams was selected to provide input for our driver's warning system. Next, we developed a data collection and recording system that combines the triggers received from animal detectors to the animal warning signs with data collected from the vehicular radars and videos to measure the driver's response to these warning signs. A complete design of the system along with infrastructural requirements was shared with Caltrans District 2 personnel and their inputs were incorporated into the final design. District 2 constructed the study site that covers roughly 5/8 of a mile of a section of SR3, on both sides of the road, near Fort Jones in Northern California. During the second phase, we will evaluate the effectiveness of this system in terms of deer detection and study driver response to our animal warning system.

In addition, a testbed was built in Lewistown, Montana, in order to comprehensively evaluate the reliability of the chosen animal detection system under closed facility conditions. The results of a limited 10-day evaluation of RADS system are given in WTI's report to PATH. (See Appendix E) The results of this test showed the number of false negatives and false positives were relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high. Based on the values of the false negatives and false positives, the RADS system detected 97% of all intrusions into the detection area. This rate of detection easily meets the recommended minimum norms for the reliability of animal detection systems. However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused

the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation.

2. Background

Based on carcass counts and insurance industry estimates, it is possible that one to two million animals collide with vehicles each year. A wide array of crash reduction solutions have been sought, including fencing, overpasses, dynamic flashing systems, animal repellant, and whistles. These solutions can be categorized as infrastructure adaptation, animal detection warning (warn drivers that there is an animal near the road) or vehicle detection warning (warn the animal that a vehicle is coming). Efforts have been made to evaluate these solutions from a crash reduction perspective (see Huijser et al. 2003 and Knapp et al, 2004). From these assessments, it appears that the very promising systems are dynamic flashing signs when an animal is present, with a detection system based on beam break technologies. Little data is available to evaluate the long term benefit of these systems as most of these prototype systems have been installed in the past few years in the United States (Huijser et al. 2003). The majority of these systems required a few months for initial problems to be fixed, such as resistance to weather conditions, reduction of false positives[1] and false negatives[2].

Two main factors affect the effectiveness of a system: the quality of the detection rate of wild animals and the communication of the threat to the drivers. The quality of the detection is the ratio of good detection vs. bad detection. The communication of the threat to the driver involves the amount of information that can be delivered about a threat in a short amount of time. Most of the current prototypes tested do not emphasize much this aspect and can lose the benefit of an adapted warning by a poor communication about the threat.

Several factors influence the occurrence of wildlife vehicle collisions. For example, these collisions occur more often at specific times or periods, such as dusk and night time, and during mating season, when animals are more likely to cross in less predictable ways. For this reason, in order to measure an appreciable difference on wildlife vehicle crashes, it is necessary to collect data for an extensive period of time. The evaluation of animal warning systems should analyze outcome factors, such as speed reduction and other driver behavior rather than solely analyzing the frequency of vehicle-animal collisions. The reason to evaluate driver behavior is that even though there are some wildlife vehicle collisions on this section of highway, this is a small number of events from a statistical point of view.

The eventual goal of this project after the completion of the next phase is to achieve two objectives: i) study the effectiveness of animal warning systems to detect wildlife on the roadside, ii) measure driver's response to the warnings resulting from the animal detection system selected. In order to do so, during the first phase, we have installed a commercial product in order to detect deer in the section of SR3 near Fort Jones. Also, we have developed a data collection and recording system that will be used to evaluate the effectiveness of the system and

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[1] A false positive happens when a system triggers a message for a reason other than the one that it has been designed to: here, the system triggers the activation of flashing lights when there is no wildlife around. This occurs when other elements present the same characteristic than the one triggering the system

[2] A false negative happens when a system did not trigger a message and should have. This is usually linked to detection and interpretation issues by the algorithm.

driver behavior and we installed it at the study site. During the second phase, we will evaluate the effectiveness of this system in terms of deer detection and study driver response to our animal warning system.

Solutions for Avoiding Wildlife Vehicle Crashes
The accurate and reliable data on vehicle-animal crashes are hard to find in the U.S. A recent data shows that in the United States there are more than 1.5 million reports of motor vehicle collisions with animals every year, accounting for over 1.5 billion dollars in insurance claims.[3] Annually, there are about 150 human fatalities due to animal-motor vehicle collisions with elk, moose, deer, cows, and other animals. This number of human fatalities could be as high as 250.

There are three types of solutions for avoiding wildlife-vehicle collisions. The first approach focuses on actions aimed at the animal population, most often, the reduction of herd size through hunting. Hunting and other means of population maintenance is rarely aimed to eliminate entire animal populations, so wildlife-vehicle collisions might occur less frequently, but nevertheless still occur. Although controversial, expanded hunting seasons are also used to reduce the number of animal-vehicle collisions. Herd size reduction is also not practical in areas such as wildlife protection areas or for endangered herd animals. The other approaches to wildlife-vehicle collision are interventions at the driver/vehicle level, and changes to the roadway and its surrounding landscape.

Wildlife-vehicle collision prevention tools can be chosen by drivers. Of course, these interventions are not general solutions; they only aid the driver who chooses to buy them. In some luxury vehicles, owners can choose an in-vehicle warning system that detects objects (deer) on the road. However, these warning systems typically cannot "see" around a bend in the road. These systems are also expensive. Other products aimed at consumers can be sold commercially and installed into any vehicle. For example, The Hornet V120, retailing for $60, is an electronically powered whistle that produces a constant sonic wave to alert deer and other animals (sound pressure 120dB, operating base frequency of 4.8 kHz, WV ultrasonic wave of 18 to 21 kHz). Another product, the Maxsa Deer Alert, retails for $40 and also wards off animals by producing ultrasonic waves. The Maxsa can be reactivated & deactivated from inside a vehicle.[4] However, many groups are skeptical about these noise repellants, claiming that deer often do not respond, and the noise is often obstructed from the animal by roadway curvature, trees, and other obstacles.[5]

States and municipalities also have a wide range of choices in attempts to prevent animal-vehicle collisions by making changes to roadways and to the landscape surrounding the roadway. Road signs, some equipped with flashing beacons, are the most common means of alerting drivers to the possibility of animals in the roadway. Fenced roadways are another option, although fences tend to be very expensive, deer might dig under wire fences, deer might change their travel patterns by crossing the highway at the end of a fence or by moving its habitat "neighborhood" onto other nearby streets, and animals that somehow end up on the fenced roadway are trapped. In some states such as Colorado and Alaska, highway construction crews have build tunnels or

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[3] Perrin, 2003 (see lit review folder)
[4] http://www.autoanything.com/products/product_sp.aspx?p_id=1578&se=car_safety_deer_alert
[5] http://www.usroads.com/journals/rmj/9705/rm970503.htm

"underpasses" for animals to cross under highways, and engineer the surrounding landscape to encourage the animals to use the underpass. The Insurance Institute for Highway Safety endorses roadside light reflectors, such as the Swareflex Wildlife Reflector, that use reflected light from oncoming vehicles to create a low-intensity red beam that bounces across the roadway and into ditches and the woods.[6] While drivers do not see this light, the animal does see this moving light which appears unnatural to the animal, stopping it from crossing the road. When no vehicles are on the road, this light "fence" immediately vanishes. Then animal can cross the road.

Yet another method is camera-based detection of deer, used to trigger dynamic warning signs to the driver. For example, InTransTech in cooperation with the Insurance Corporation of British Columbia developed a system based on infrared cameras and software from QWIP Technologies to detect wildlife on or near roadways.[7] When animals are detected, flashing beacons on roadway signs are triggered and warn drivers to anticipate animals in the roadway.[8] This system does not affect the animals and, like roadside light reflectors, is portable.

Previous studies have found that herd reduction, highway fences, and underpasses are the most effective and whistles and other sound devices are the least effective.[9] Roadway signage and roadside light reflectors seem to help in the short-term, but in the long-term their effects seem to diminish.[10] Less is known about camera-based dynamic warning signs.

Animal Warning Signs

The Manual on Uniform Traffic Control Device (MUTCD) provides the following definition of warning signs: "[they] call attention to unexpected conditions on or adjacent to a highway or street and to situations that might not be readily apparent to road users. Warning signs alert road users to conditions that might call for a reduction of speed or an action in the interest of safety and efficient traffic operations."[11] The MUTCD also recommends that "the use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs. In situations where the condition or activity is seasonal or temporary, the warning sign should be removed or covered when the condition or activity does not exist."[12]

Knapp et al. (2004)[13] conducted a review of deer crossing signs and technologies. They raise the point that the current typical deer sign does not seem to influence driver speed and highlight the need for improving their effectiveness. One of the weaknesses of the current setting is that

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[6] http://www.usroads.com/journals/rmj/9705/rm970503.htm

[7] Kinley T, Page H, Newhouse N. Use of Infrared Camera Video Footage from a *Wildlife Protection System* to Assess Collision-Risk Behavior by Deer in Kootenay National Park, British Columbia. March, 2003. Prepared for the Insurance Corporation of British Columbia.

[8] Ibid

[9] Hedlund, 2004 (see lit review folder)

[10] Hedlund (see lit review)

[11] in MUTCD 2003 edition, p. 2C-1 http://mutcd.fhwa.dot.gov/pdfs/2003r1/Ch2C.pdf

[12] Ibid

[13] Knapp K.K., Yi X., Oakasa T., Thimm W., Hudson E., and Rathmann C. (2004) Deer-Vehicle Crash Countermeasure Toolbox: A Decision and Choice Resource – DVCIC - 02

warning sign used to alert drivers of sporadic and/or general possibilities do not have a consistent effect on drivers. The authors list several studies conducted in order to increase the effectiveness (measured by a speed reduction) of typical deer crossing signs. The solutions range from displaying the sign only during higher risk season to dynamic deer crossing sign. They refer to five studies relying on different sensing technologies for detecting wildlife. Four of these studies are conducted within the United States. They all use the current deer crossing sign with an addition of flashing amber light triggered when an animal is detected, as well as additional "When Flashing" or "Dear on the road when flashing" signs.

3. PAWS Data Monitoring and Recording System Description

The PAWS data monitoring and recording system is constructed of a network of components meant to detect deer crossing, warn drivers with flashing signs (animal warning signs), and measure driver's reaction to the warnings. The system is composed of four primary types of electronic hardware:

1) 6 pairs of STS animal warning detector networked receivers and transmitters
2) 4 ElectroTech flashing animal warning signs (also networked)
3) 7 Smart Micro (SMS) radar detectors (also networked)
4) 6 Omcon video cameras (also networked)
5) PAWS computer (on site)

These components are all connected by an Ethernet network to a monitoring computer ("PAWS computer") that tracks the status of each component of the data monitoring and recording system. The PAWS computer records video and radar data of the roadway when the STS animal warning system indicates one of its animal detection beams has been triggered and the animal warning signs are turned on.

The site consists of 9 poles covering about 1030 meters of California State Highway 3 near the city of Fort Jones with four on the southeast side of the road and 5 on the northwest. The components on the poles are connected to the PAWS computer that is placed in a roadside cabinet. Three independent STS animal warning "beams" are set up between pairs of poles on each side of the road (typical pole spacing is about 300 meters). These beams form an uninterrupted detection system on each side of the road. When a local black-tailed deer or other similar size animal crosses one of the beams, the STS system detects that the beam is broken and sends a message over the Ethernet network. This message is received by the animal warning signs, which flash for about 3 minutes to warn drivers that an animal has been detected near the road. The signs will continue to flash if more beam breaks are detected, and will flash until no new beam break is seen for 3 minutes.

While that describes the fundamental working of the animal warning system, the site is also under radar and video monitoring as part of PATH's research to see how drivers react to the flashing animal warning signs. Radar monitoring is in place to measure vehicle's speed and trajectory, and is comprised of the SMS radar units and associated networking and computational hardware. The radar heads are connected together and fused in a single logical coordinate

system with primary focus on the roadway to determine vehicle trajectories. New data is output by the radar system at a 20 Hz rate and recorded permanently by the PAWS computer.

The video cameras are also connected to the site Ethernet network, and broadcast a continuous video stream to the PAWS computer. Because it would be cost-prohibitive to save all the video data for each of the six cameras, only data related to periods when an animal detector beam is broken is saved. Otherwise the cameras save data to temporary files that are over-written every three minutes.

When the PAWS computer receives a message from the STS system that a beam has been broken (the same message that starts the flashing animal warning signs), the video data is permanently saved in a new directory for the "event". Video and other data is saved to this directory until no beam has been broken for 3 minutes. The video, radar, and other data are then saved for later analysis by PATH researchers to determine how drivers are reacting to the animal warning signs.

The directories of saved data are stored on an external solid state drive attached to the PAWS computer in the roadside cabinet. Periodically this drive is swapped for an empty one and the drive with the saved data is sent to PATH.

The PAWS computer is also connected to the internet via a DSL line that allows PATH to remotely monitor the status of the equipment on site, including whether each component is still sending messages on the site network, whether the network links to each device are working, how busy the CPU is, how much space is available for saved data, etc. It is also possible for PATH staff with proper access to log in to the recording computer remotely and start and stop software, check log files, etc. It should be noted that the DSL connection is not fast enough to download the amount of data we expect to collect at the site.

In addition to the DSL access, the PAWS computer has network monitoring and administration software running to allow people with proper access to check on the condition of the equipment from a web browser, including checking on the condition of the cameras by examining a screen shot retained from the last temporary video file.

Network Hardware Configuration

Each pole on the site is provided with its own network link and an industrial network switch and media converter. Because the poles are so far apart, the network links between poles are made with fiber optic cable, while the connections to networked components on the pole are made with category 5 or better twisted pair copper cabling. The power to each pole can be controlled independently. The switch and many other components run on 12 volt power. Below is a diagram of fiber optic roadside local area network of LAN.

Fiber Optic Roadside LAN
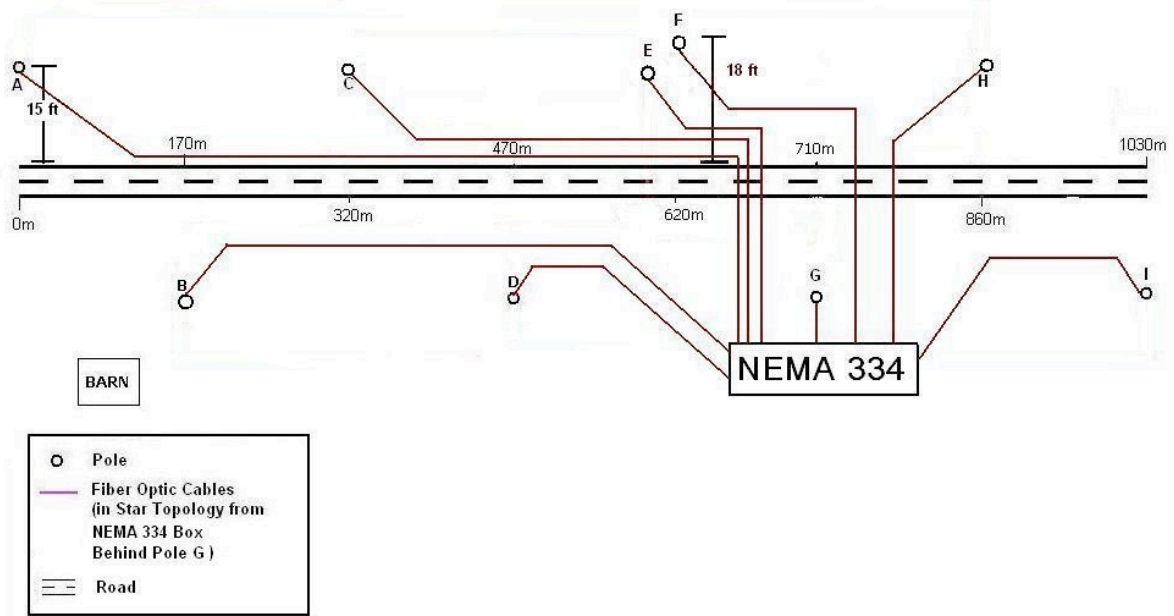
Diagram 1: A diagram of fiber optic roadside LAN layout

The network connections between poles are made in a star configuration so each pole has an independent connection to the network, with a concentrating switch located with the PAWS computer in the roadside cabinet.

The SMS radars are connected by a specialized "CAN" bus network, with special hardware that concentrates the messages and repeats them ("bumper boxes") in particular locations at the site. The messages are eventually all received in a single bumper box that converts the data into a single stream in the site coordinate system. This data stream is sent over an Ethernet interface to the PAWS computer via the same fiber/twisted pair network described above. Below is a diagram of Specialized "CAN" bus cables for SMS radars.

CAN BUS (SMS VEHICLE RADAR)
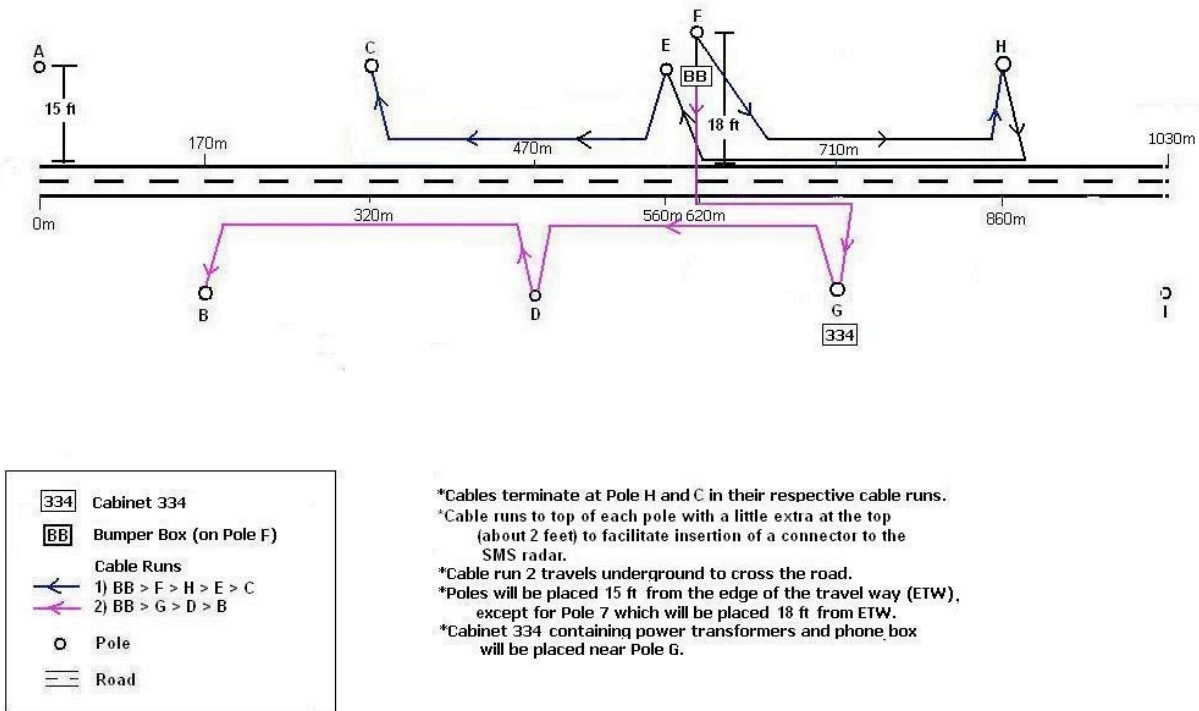
Diagram 2: A diagram of specialized "CAN" bus cables layout for SMS radars

Software Configuration

The PAWS monitoring computer runs CentOS Linux version 5.3. It has two network interfaces, one for the site network, the second for the DSL connection. The DSL connection has a static IP address assigned to allow for simpler management and monitoring. Messages from each of the site's electronic systems are managed by a different software process running in Linux. The STS animal warning system and ElectroTech animal warning signs are monitored by a process called 'awsrcv'. The SMS radar system messages are handled by 'smsparse'. Each camera has a separate copy of the 'pawsrecord' software managing its 500K bps stream. Each of these separate processes is coordinated by a PATH inter-process communication system called 'db_slv', and non-video data is logged to files by a process names 'wrfiles'. The monitoring software for remote web access is Nagios version 3.2.0. Remote login to the PAWS computer is enabled only through encrypted connections using 'ssh'.

See Appendixes A1 and A2 for a detailed description PAWS Monitoring and Recording System and B for Network Addressing and Communication Port Plan.

4. Deliverables

Task 1: Literature review on animal warning systems

An extensive literature review was conducted on animal warning system evaluation and dynamic signs used to warn drivers that deer is present. We collected information about evaluation methods, their shortcoming, and signs that were used to warn drivers and seemed to work best. This work was done by PATH's subcontractor Montana State's Western Transportation Institute (WTI).

Note: Please, see Attachment E for a copy of WTI's report to PATH

Task 2: Installation of animal detection system near Fort Jones

Site survey and site selection

The original site selected for this project was in Humboldt County in highway 101 between Mile Post 114 to 116 north of Eureka. The highway belongs to District one of Caltrans. Due to a variety of reasons, Caltrans and research team agreed to abandon this site after almost one year and half. The biggest challenge for this site was the jurisdiction of Coastal Commission over any roadside installations. Obtaining the necessary approvals from Coastal Commission for this project was not guaranteed and would have taken a very long time. This was unacceptable for reasons of disappearing funds and other contractual issues between PATH and Caltrans. Thus, a decision was made in December of 2007 that a new site should be selected. Also, a site selection checklist was developed and was used in finding the most desirable site for this study. See Appendix D for a copy of this checklist.

A team composed of PATH and DRI members in two separate trips visited potential sites at Caltrans Districts 2, 3, and 5 during months of February and March of 2008. A checklist of characteristics that make a site suitable for our study was developed and was used in selection of the final site. The selected site was in District 2 along State Highway 3 (SR-3) between the towns of Yreka and Fort Jones. A number of staff from District 2 met with the visiting team and was briefed on the project. They took us to the site the next day. There seemed to be a great deal of cooperation available to this project from the district and research team welcomed this fact. District 2 also pledged to provide for the cost of construction of the poles and conduits as well as the cost of bringing power and phone line to this site.

This study site is in an area where a local herd of deer cross SR-3 all year long and the local Caltrans maintenance crew has been picking up carcasses every month for a long time now. It stretches about 1,030 meters and it is between post miles 36.6 and 37.3 of SR-3. District 2's maintenance crew have installed a post mile marker paddles every 1/10 of mile for the whole 5 mile corridor of SR-3 that lay north of Fort Jones. The site's topology and road geometry made this site a perfect location to install the animal and vehicular detection systems. Below is an aerial picture of the study site.
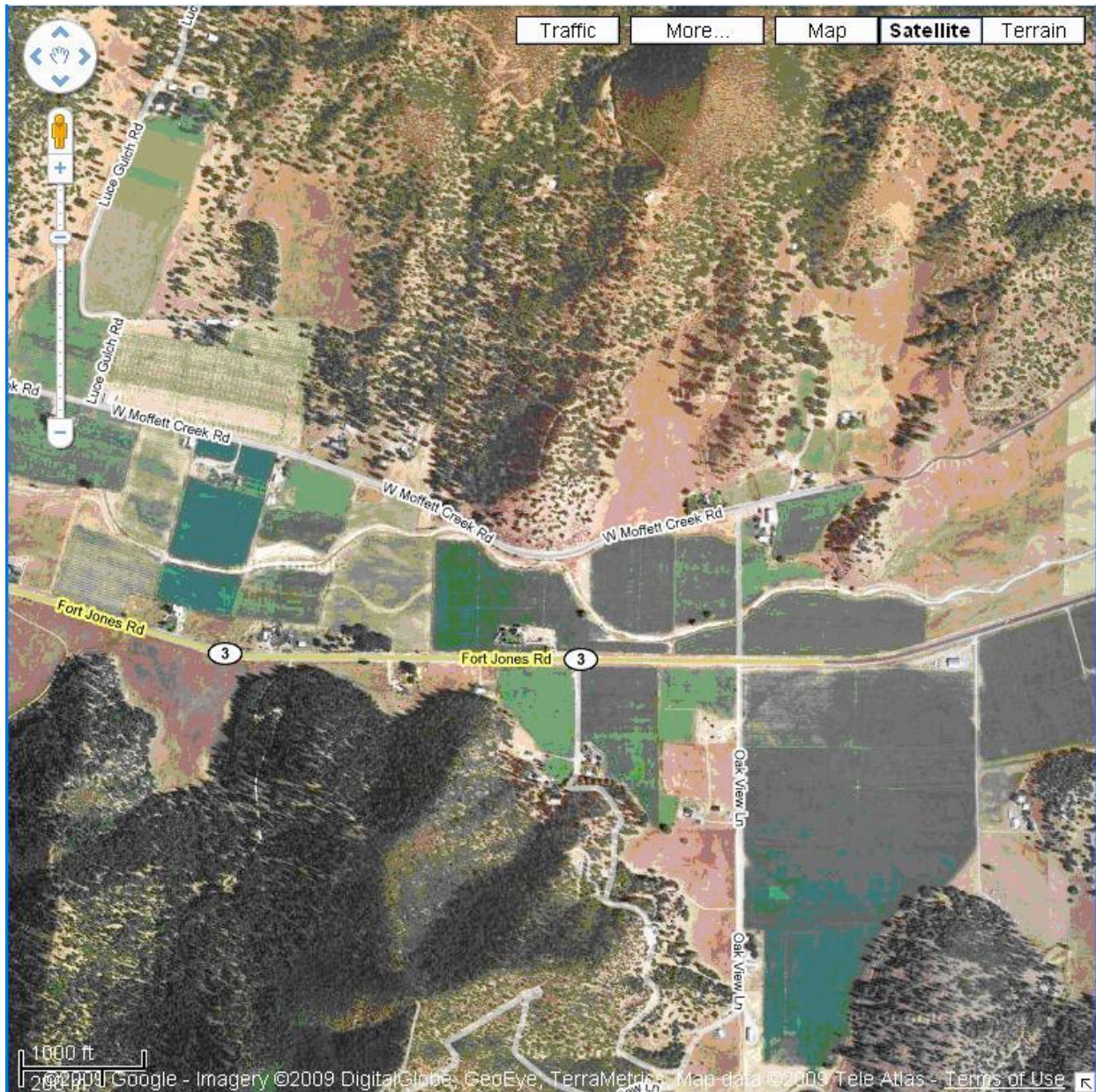
Figure 1: An aerial picture of the study site on SR-3 near of Fort Jones

Selection of Animal Detection System

The selection of the animal detection system was done by WTI in consultation with PATH. After careful review of many different alternatives and based on the topology, climate, and other characteristics of the selected site, the decision was made to install Roadway Animal Detection System (RADS) by ICx Technologies. It is a break the beam system operating with Radio Frequencies. The detection range is approximately 400 meters. The system performs under any weather and light condition (see http://www.sensor-tech.com/ under Transportation system for complete description). Also, see Appendix E for more discussion on selection of animal detection system.

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Installation of PAWS data monitoring and recording system

RADS Animal Detection System

The RADS system was installed and calibrated in September of 2009 with the help of an ICx support engineer. The acceptance tests were done by PATH staff on location. There are six breakaway beams that are established with three beams on each side of the roadway. Below is a diagram of the RADS.
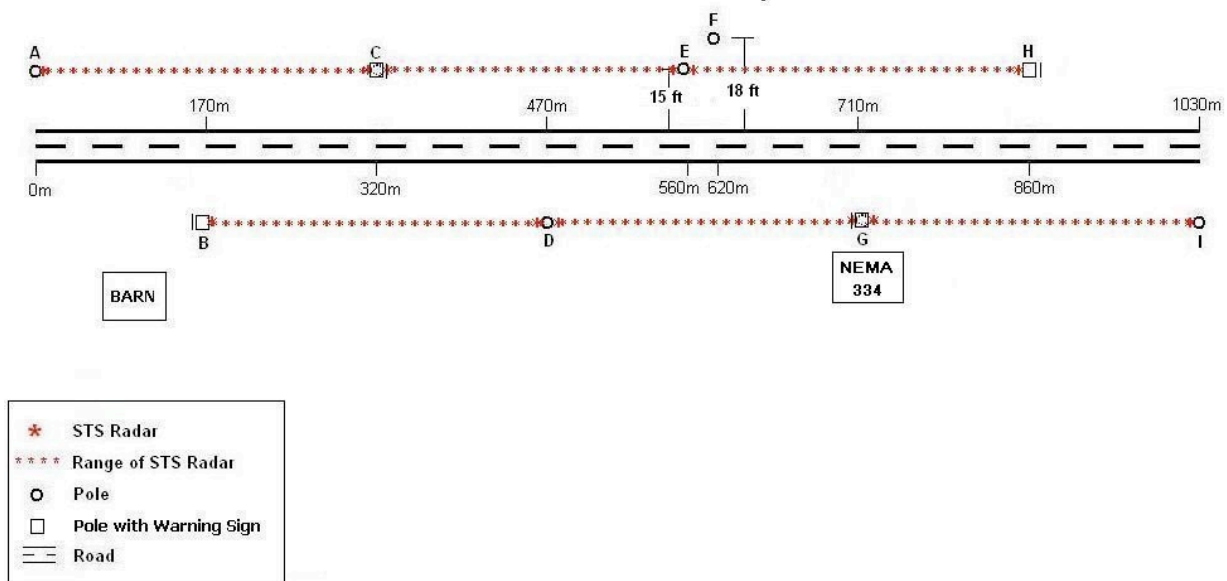
Diagram 3: A diagram of RADS system layout

SMS Radars

The SMS radar system was installed and calibrated in September of 2009 with the help of a SMS support engineer. The acceptance tests were done by PATH staff on location. There are seven SMS radars with three one side of the road and four on the other. This configuration was used to maximum the coverage of theses radars given the number of available poles as well topography and geometry of the study site. Below is a diagram of the SMS radars.

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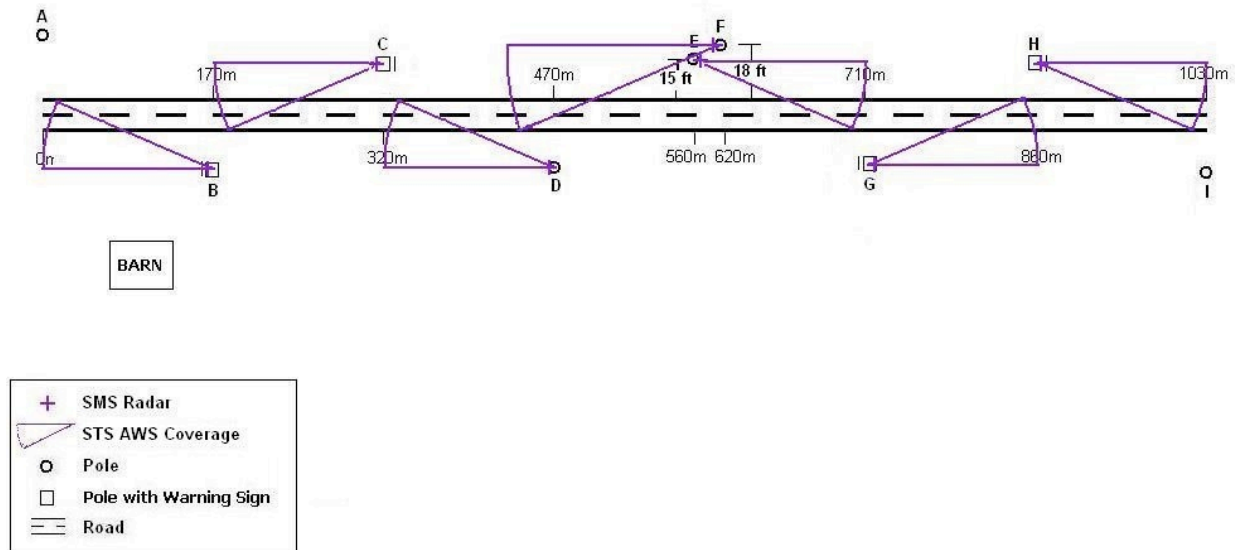
SMS Radar

Diagram 4: A diagram of SMS radars layout

Omcon Video Cameras

The Omcon video cameras were installed and calibrated in September of 2009. The acceptance tests were done by PATH staff on location. There are six Omcon videos with three on each side of the road. This configuration was used to maximum the coverage of these videos given the number of available poles as well topography and geometry of the study site. Below is a diagram of the Omcon video cameras.

Omcon Camera
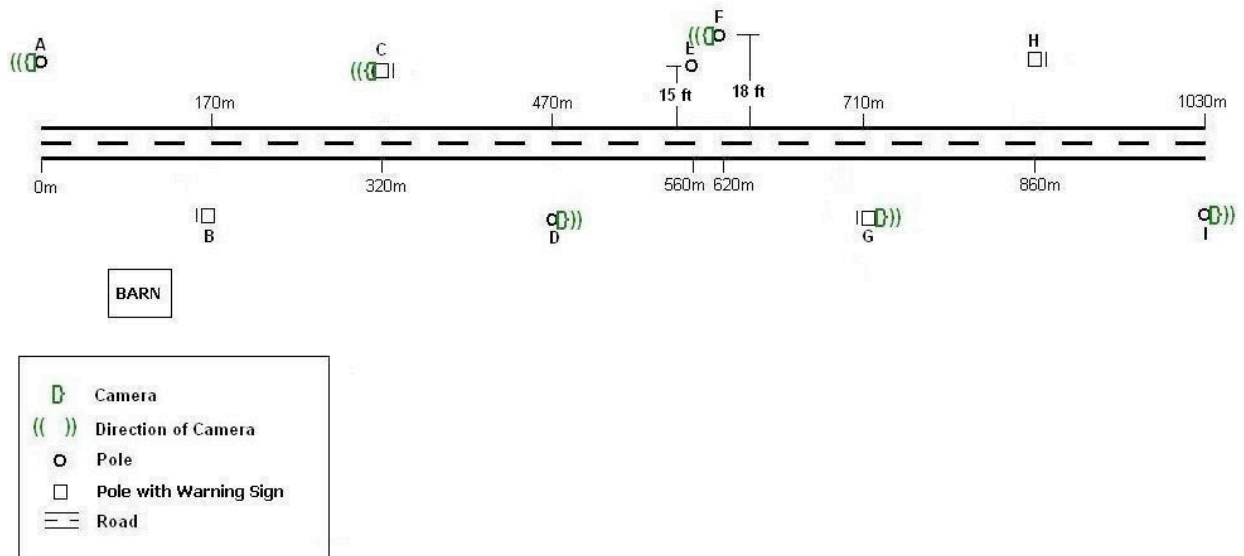
Diagram 5: A diagram of Omcon video cameras layout

Animal Warning Signs
The four animal warning signs were designed and manufactured by Electro-Tech. Two animal warning signs were installed for each road direction: on Poles B and G on one direction and poles H and C on the other direction of diagram 5 above. The acceptance tests were done by PATH staff on location.

PAWS Computer
PAWS computer was built to PATH's specifications by Advanced Digital Logic Inc. and was installed in the road side NEMA cabinet.   The acceptance tests were done by PATH staff on location.

Typical pole installation side-view
Figure 2 below shows a typical side view of the pole installations.

Typical Pole Side-View
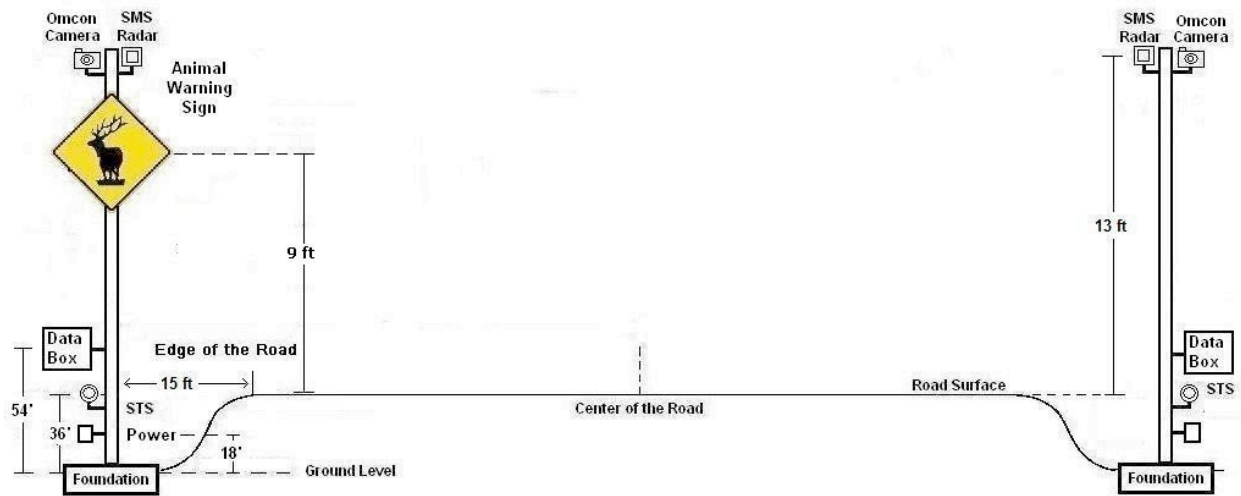
Item	Weight	Size	Power Consumption	Output
Mobotix Camera	0.85 kg	14.2 x 15.5 x 17 cm	2.5W	RS 232, USB, Ethernet 10/100
SMS Radar	0.310 kg (Al Body)	10.8 x 9.7 x 3.7 cm (W x H x D)	8...32V Comsumption: 3.6W	CAN BUS Interface V2.0B (1Mbit/s), RS 232
STS Radar	2.72 kg	30.5 x 50.8 cm (diameter x length)	12 VDC	RS 232, Ethernet (using bridge set), Radio Link
Animal Warning Sign	31.7 kg	98 x 98 x 11 cm (W x H x D)		

Figure 2: Typical pole installation side-view

Figure 3 shows a picture of system installation.

Figure 3: A picture of system installation

Task 3: The installation and evaluation of RADS in Lewistown testbed
This task was completely done by PATH's subcontractor, WTI. Please, see Appendix E for full description of testbed layout, method of data collection and analysis, and results of a limited 10-day evaluation of the RADS in Lewistown testbed in Montana.

5. Conclusions

The number of animal-vehicle collisions is rising. This is one of the few areas of the surface transportation that safety is not improving. As more roads are being built, the areas that animal inhabit is shrinking and thus causing more crashes between vehicles and animals. The human fatalities and injuries, animal fatalities and injuries, and material costs of these crashes emphasize the need for a solution to this problem. A wide array of crash reduction solutions have been sought, including fencing, overpasses, dynamic flashing systems, animal repellant, and whistles. Two main factors affect the effectiveness of a system: the quality of the detection rate of wild animals and the communication of the threat to the drivers. The quality of the detection is the ratio of good detection vs. bad detection. The communication of the threat to the driver involves the amount of information that can be delivered about a threat in a short amount of time.

In the Phase one of "evaluation of an Animal Warning System Effectiveness" project many tasks and objectives were achieved. They include the selection of an animal detection system, the selection of a very promising test site in Caltrans D-2 near Fort Jones, the continuous collection of carcass data in the area, the design and successful installation of PAWS data monitoring and recording system at the test site, and finally the evaluation of RADS system that was done in a Lewistown testbed. All of these have set the stage for the second phase that has two objectives: i) study the effectiveness of animal warning systems to detect wildlife on the roadside, ii) measure driver's response to the warnings resulting from the animal detection system selected.

In addition, a testbed was built in Lewistown, Montana, in order to comprehensively evaluate the reliability of the chosen animal detection system under closed facility conditions. The results of a limited 10-day evaluation of RADS system are given in WTI's report to PATH. (See Appendix E) The results of this test showed the number of false negatives and false positives were relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high. Based on the values of the false negatives and false positives, the RADS system detected 97% of all intrusions into the detection area. This rate of detection easily meets the recommended minimum norms for the reliability of animal detection systems. However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation. As part of phase two, more evaluation of RADS system are planned to take place in Lewistown testbed.

APPENDIX A1: PAWS Data Monitoring and Recording System – Software Architecture

The PAWS data acquisition system is based on a publish/subscribe data pool system developed at PATH for other transportation purposes. A data server is created; it serves as a buffer for data coming in from the animal warning system and SMS radar, and as a trigger source for controls and data going out to wrfiles and pawsrecord (Figure A1).
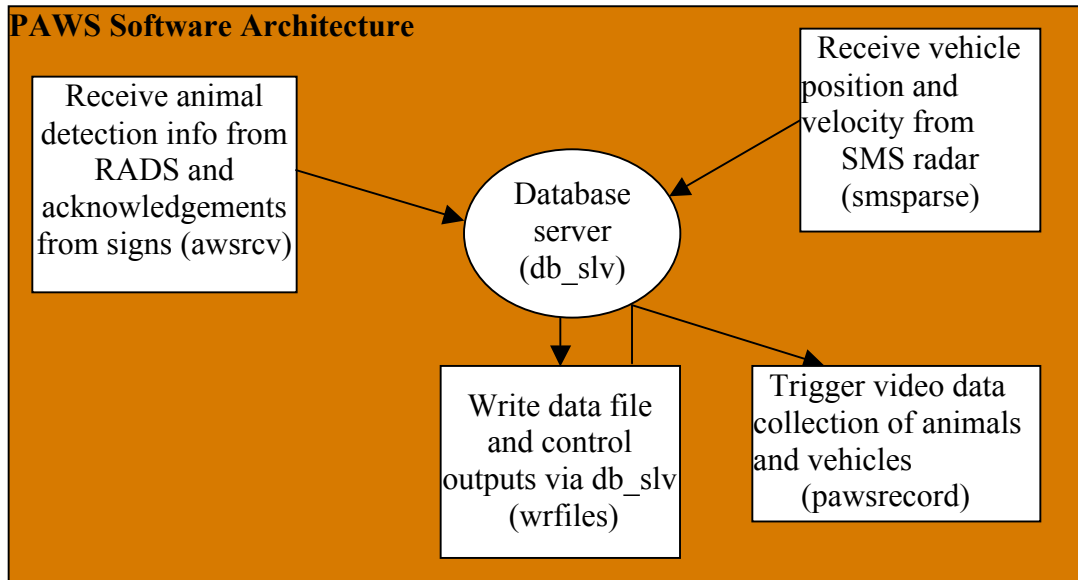
Figure A1: Schematic of PAWS data acquisition software and control

Database clients subscribe to the data server by requesting a connection using a database variable defined by an arbitrary unique number selected by the programmer. Only one instantiation of a given database variable is allowed. The client may read, write, or both to this variable, as may other database clients. The variable is usually associated with a C structure containing fields important to a task, such as range, velocity, length, and ID of an SMS radar target. The client may also set a trigger with the database: when any field in the database variable's structure changes, the data server sends a trigger to the client, which then can read the new value in realtime and handle the trigger.

In the case of PAWS, input data from the animal warning and SMS radar systems is constantly being written to an engineering file with wrfiles. Video data from the distributed Ethernet cameras are written to temporary video files. When an animal is detected, wrfiles sets appropriate database variables that trigger the permanent video data collection; the previous three minutes of video data that were in temporary files are now moved to a permanent file, and three more minutes (after the end of a triggering event) of video data are written to permanent files. Also, an event file containing a summary of the event is written.

All remote sensors and actuators use an Ethernet-based LAN for communication with the PAWS host. Messages from the RADS system are composed of UDP packets containing a comma separated text string containing beam status (among other things). These messages are received

by the signs and parsed; if one of the beams is broken, all the signs are triggered, and they transmit their own acknowledgements. Messages from the signs are also a simple UDP packet containing the string "ON" or "OFF". wrfiles monitors this Ethernet traffic and saves all messages to the logfile.

APPENDIX A2: PAWS Data Monitoring and Recording System - Website Description

Purpose:
The PAWS monitoring system provides a quick and easy way to see at a glance how all the project components are functioning. It also allows researchers to quickly see if the PAWS system has detected any recent events. Furthermore, the system is responsible for notifying researchers if some component has failed or if the system has logged an event. In the event of component failure, the monitoring system provides helpful information that allows researchers to diagnose and fix the problem more easily.

Design:
The PAWS monitoring system is made up of three different classes of components. There are hardware components, software components, and the monitoring website.

Hardware Components:
Managed network switches were chosen when the project's network infrastructure was designed. Managed network switches provide a lot of diagnostic information that is not typically available in non-managed network switches, as can be seen in Figure A2.

Figure A2: Switch Management Menu

Other components used by PAWS such as the SMS vehicular radars, the flashing animal warning signs, and the STS animal detectors were designed to send out status information which the monitoring and recording system collect. The cameras used by PAWS are network enabled. In addition to checking their uptime, the monitoring and recording system creates still images from each camera periodically so that researchers can easily see what each camera sees.

Software Components:

The software components of the data monitoring and recording system are responsible for collecting the diagnostic data that is constantly being sent by the various hardware components. The monitoring of the networked components is done with a free open source package called Nagios. (http://www.nagios.org/). Nagios provides a framework that developers can use to create components for almost any sort of system monitoring. These components can be anything from simple ones that determine whether or not a device is online to more complicated ones that could monitor an entire data center.

For PAWS we want to know whether or not all the networked components are online and we want to know the general health of the PAWS data collection computer. Figure A3 is a screen shot of a Nagios webpage that provides an overview of the health of each individual component in its component group. Figure A4 is a screen shot of a Nagios webpage that provides detailed host information of PAWS computer.

Figure A3: Nagios overview by component group

Current Network Status
Last Updated: Tue Sep 29 11:11:16 PDT 2009
Updated every 90 seconds
Nagios® Core™ 3.2.0 - www.nagios.org
Logged in as nagiosadmin

View History For This Host
View Notifications For This Host
View Service Status Detail For All Hosts

Host Status Totals

Up	Down	Unreachable	Pending
1	0	0	0

All Problems	All Types
0	1

Service Status Totals

Ok	Warning	Unknown	Critical	Pending
7	0	0	0	0

All Problems	All Types
0	7

Service Status Details For Host 'localhost'

Host	Service	Status	Last Check	Duration	Attempt	Status Information
localhost	Current Load	OK	09-29-2009 11:09:39	0d 0h 36m 37s	1/4	OK - load average: 0.55, 0.34, 0.23
	Current Users	OK	09-29-2009 11:07:14	0d 0h 34m 2s	1/4	USERS OK - 7 users currently logged in
	PING	OK	09-29-2009 11:09:48	0d 0h 36m 28s	1/4	PING OK - Packet loss = 0%, RTA = 0.05 ms
	Root Partition	OK	09-29-2009 11:07:23	0d 0h 33m 53s	1/4	DISK OK - free space: / 56915 MB (85% inode=98%):
	SSH	OK	09-29-2009 11:09:58	0d 0h 36m 18s	1/4	SSH OK - OpenSSH_4.3 (protocol 2.0)
	Swap Usage	OK	09-29-2009 11:07:32	0d 0h 33m 44s	1/4	SWAP OK - 100% free (4094 MB out of 4094 MB)
	Total Processes	OK	09-29-2009 11:10:07	0d 0h 36m 9s	1/4	PROCS OK: 55 processes with STATE = RSZDT

Figure A4: Nagios detailed host information

Figure A5 is a screen shot of a Nagios webpage of a detailed service view. In this case, what is shown is detailed information about this particular server's CPU load. Information displayed includes when the last check was made, what the result was, and how long the status has been "OK".

Service Information
Last Updated: Tue Sep 29 11:14:06 PDT 2009
Updated every 90 seconds
Nagios® Core™ 3.2.0 - www.nagios.org
Logged in as nagiosadmin

View Information For This Host
View Status Detail For This Host
View Alert History For This Service
View Trends For This Service
View Alert Histogram For This Service
View Availability Report For This Service
View Notifications For This Service

Service
Current Load
On Host
localhost
(localhost)

Member of
No servicegroups.

127.0.0.1

Service State Information

Current Status:	OK (for 0d 0h 39m 27s)
Status Information:	OK - load average: 0.55, 0.34, 0.23
Performance Data:	load1=0.550;5.000;10.000;0; load5=0.340;4.000;6.000;0; load15=0.230;3.000;4.000;0;
Current Attempt:	1/4 (HARD state)
Last Check Time:	09-29-2009 11:09:39
Check Type:	ACTIVE
Check Latency / Duration:	0.126 / 0.010 seconds
Next Scheduled Check:	09-29-2009 11:14:39
Last State Change:	09-29-2009 10:34:39
Last Notification:	N/A (notification 0)
Is This Service Flapping?	NO (0.00% state change)
In Scheduled Downtime?	NO
Last Update:	09-29-2009 11:13:58 (0d 0h 0m 8s ago)

Active Checks:	ENABLED
Passive Checks:	ENABLED
Obsessing:	ENABLED
Notifications:	ENABLED
Event Handler:	ENABLED
Flap Detection:	ENABLED

Service Commands

Disable active checks of this service
Re-schedule the next check of this service
Submit passive check result for this service
Stop accepting passive checks for this service
Stop obsessing over this service
Disable notifications for this service
Send custom service notification
Schedule downtime for this service
Disable event handler for this service
Disable flap detection for this service

Figure A5: Nagios detailed service view

Nagios is also responsible for sending out flexible, customizable notifications in the event that a problem is detected. The notifications can be emails, SMS messages, automated website updates, or a wide variety of other possibilities.

PAWS Monitoring Website:

The final component of the PAWS monitoring and recording system is the monitoring website. The website brings together all of the monitoring information and displays it in a very easy to navigate fashion.

The website provides links to Nagios and displays the most recent still images recorded from each camera. Figure A6 below provides a sample of still images.
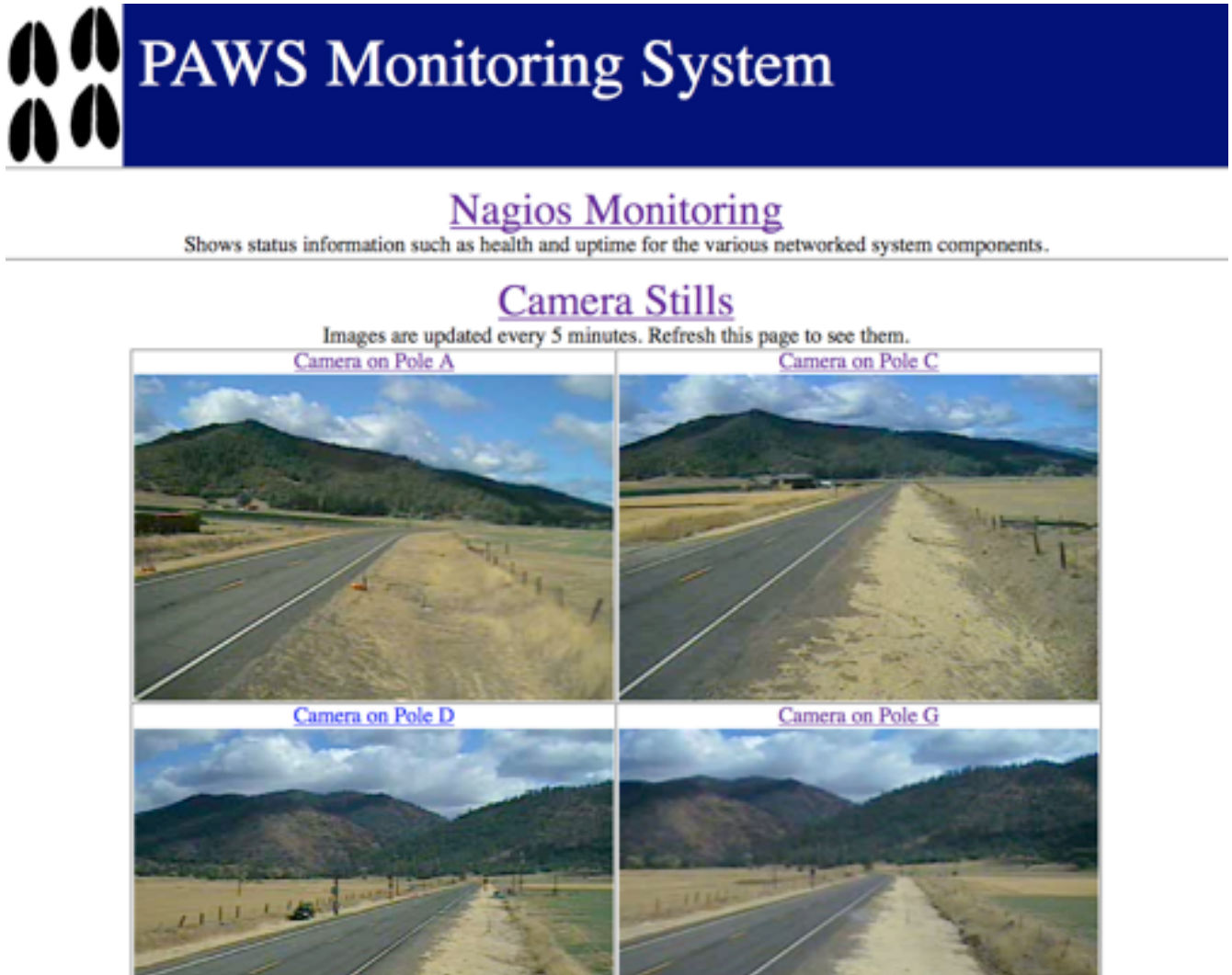
Figure A6: PAWS Monitoring Website

APPENDIX B: Network Addressing and Communication Port Plan

We're using the 10.x.y.z class A network range, following a general
scheme of 10.p.d.y, with some exceptions.
  p for pole
  d for device type
  y is for device number (on a given pole, defaults to 10)

In the cabinet:
RSE CPU IP address: 10.0.0.10   internal address
                    63.170.86.3 external (DSL)

West side poles   East side poles
A: 10.1.d.y   B: 10.2.d.y
C: 10.3.d.y   D: 10.4.d.y
E: 10.5.d.y   G: 10.6.d.y
F: 10.7.d.y   I: 10.8.d.y
H: 10.9.d.y

Device types --- NOTE Cameras are a special case!
Computer: 10.p.0.y
Switch: 10.p.1.y
Animal Warning Rcvr:10.p.4.y
Sign: 10.p.5.y
SMS bumper box: 10.p.6.y
**Camera: 10.0.0.3p

There is a MOXA Switch/fiber converter on each pole at the given
address(10.p.1.10). The other equipment is placed on particular poles
as indicated below:

Cameras:
10.0.0.31 -- pole A
10.0.0.33 -- pole C
10.0.0.34 -- pole D
10.0.0.36 -- pole G
10.0.0.37 -- pole F
10.0.0.38 -- pole I
The cameras are configured with netmask 255.255.255.0, which was
required for them to function on a network together with the computer
at 10.0.0.10.

STS animal warning receivers:
10.3.4.10 Beam ID 1 (pole C, trans on pole A)
10.3.4.11 Beam ID 2 (pole C, trans on pole E)
10.4.4.10 Beam ID 3 (pole D, trans on pole B)
10.4.4.11 Beam ID 4 (pole D, trans on pole G)
10.5.4.10 Beam ID 5 (pole E, trans on pole H)
10.6.4.10 Beam ID 6 (pole G, trans on pole I)
Messages sent by the STS receivers will be broadcast from/to UDP port
7777, with netmask (?) 0.0.0.0 and broadcast address 255.255.255.255.

```
Signs -- NOTE Two of these are switched!
10.3.5.10  -- on pole H
10.9.5.10  -- on pole C
10.2.5.10  -- on pole B
10.6.5.10  -- on pole G
Signs listen on UDP port 7777 for messages sent from the 6 STS
receivers above.  They also broadcast on port 7777 with broadcast
address 10.255.255.255 and netmask 255.0.0.0.

SMS bumper box 3 has address 10.7.6.10 (pole F).


Pole  STS           SMS           Sign          Camera       Switch(model)
A(1)  TX            --            ---------     10.0.0.31    10.1.1.10(505)
B(2)  TX            RX            10.2.5.10     ---------    10.2.1.10(505)
C(3)  10.3.4.10     RX            10.9.5.10     10.0.0.33    10.3.1.10(516)
      10.3.4.11     --            ---------     ---------    -------------
D(4)  10.4.4.10     RX            ---------     10.0.0.34    10.4.1.10(508)
      10.4.4.11     --            ---------     ---------    -------------
E(5)  TX            RX            ---------     ---------    10.5.1.10(505)
      10.5.4.10     --            ---------     ---------    -------------
F(7)  --            10.7.6.10     ---------     10.0.0.37    10.7.1.10(505)
      --            RX            ---------     ---------    -------------
G(6)  TX            RX            10.6.5.10     10.0.0.36    10.6.1.10(508)
      10.6.4.10     --            ---------     ---------    -------------
H(9)  TX            RX            10.3.5.10     ---------    10.9.1.10(505)
I(8)  TX            --            ---------     10.0.0.38    10.8.1.10(505)
```

APPENDIX C: STS Message Format

Function:
RADS system issues an autonomous UDP message for changes in receiver status. These changes can be the result of a "beam break" event, a beam restoration (after a break), an "out-of-service" condition, a "return-to-service" condition, or a system fault.

Specification:
When the beam is attenuated (assumed blockage by an animal), a "beam-break" event message is issued. The system must be "ready" for a "beam-break" event to be valid.

When the beam attenuation is decreased (the animal exits the beam), a "beam-restore" event message is issued. The system must be "ready" for a "beam-restore" event to be valid.

When the receiver is "out-of-service", the beam status is indeterminate. When the receiver is restored to service, the beam status is valid as indicated.

Every ten minutes, a "heartbeat" message is issued. This message indicates the system status of each receiver.

Format:

Name	Example	Unit	Description
Message ID	$STRAD		RADS protocol header
Message Type	0	decimal [0,1,2]	Message type: 0 = event, 1 = heartbeat, 2 = fault
Beam ID	2	decimal [0..99]	Receiver ID [0..99]
Receiver Condition	1	decimal [0,1]	Receiver Condition, 0 = Out-of-Service, 1 = Ready
Beam Break Status	1	decimal [0,1]	Beam Condition, 0 = Broken, 1 = Closed
Sequence Number	88	decimal [1..9999]	Monotonic Message Sequence number [1..9999]
Message Time	123	seconds	Time from last message sent
Checksum	*3A	hexadecimal	Checksum
<CR><LF>			End of Message termination

Example:
An example "heartbeat" message is:

$STRAD,1,1,1,1,45,60*xx

This message indicates that the station #1 is sending a "heartbeat" message, that the system is "ready" – monitoring the beam, the beam is established (not broken), the message sequence number is 45, and the last message was issued 60 seconds ago.

An example of a "beam break" event is:

$STRAD,0,3,1,0,97,22*xx

This message indicates that the station #3 is sending a "beam break" event message. The system is "ready" so the event is valid. The message sequence number is 97. The last message was issued 22 seconds ago.

APPENDIX D: Engineering File Format

Following is the file format of the engineering file. Column numbers in the file are in normal type, as are their descriptions. System names and indices of each system are in bold type. So, for instance, the beam status of Animal Warning System receiver 0 is in column 5.

```
Timestamp   1
```

Animal Warning System

AWS receiver index N	0	1	2	3	4	5
Message type	2	8	14	20	26	32
Beam id	3	9	15	21	27	33
Receiver state	4	10	16	22	28	34
Beam status	5	11	17	23	29	35
Sequence number	6	12	18	24	30	36
Time since last measure	7	13	19	25	31	37

Animal Warning Signs

Animal Warning Sign Index	0	1	2	3
Sign N state	38	39	40	41

Smart Micro Systems Vehicle Radar
```
SMS_sensor_control_CAN_status 42
SMS_sensor_control_sensors_present  43
SMS_sensor_control_ethernet_status  44
SMS_sensor_control_timestamp  45
```

SMS_object_fields

Index N	0	1	2	3	4	5	6	7	8	9
ID	46	52	58	64	70	76	82	88	94	100
X range (m)	47	53	59	65	71	77	83	89	95	101
Y range (m)	48	54	60	66	72	78	84	90	96	102
X vel (m/s)	49	55	61	67	73	79	85	91	97	103
Y vel (m/s)	50	56	62	68	74	80	86	92	98	104
Length (m)	51	57	63	69	75	81	87	93	99	105

PAWS Site Selection Checklist

Completed By/Date:

Site Name/Location:

Done?	Site Information	Observed/Follow-up	Notes
	Milepost Markers/GPS points		
	Animal activity, trails, common crossing		
	Common Weather-Fog, Snow, Wind		
	Streams, Lakes, Wetlands		
	Road configuration, Terrain		
	Side Roads, Pull-Outs, Parking Areas		
	Vegetation Near Road -Native/Non-Nat.		
	Soil Composition -Native/Non-Nat.		
	Current Signage for Animal Warnings		
	Human Neighbors, Buildings Near-By		
	Endangered Species Present/Nearby		
	Road Kill, Animal Collision Statistics		
	Average Vehicle Traffic		

Done?	Prep/Installation of Equipment	Due By	Notes
	Electricity-How far away is power?		
	Solar Panels/Battery Option		
	Phone line-How far away?		
	Satellite or Cell Coverage		
	Terms of Right Away		
	Maintenance of Vegetation near system		
	Ability to Trench		

Done?	Site Clearances Needed?	Due By	Notes
	Coastal Commission/Army Core of Eng.		
	Minor A/B for pole installation		
	Landscape Aesthetics Issues		
	Accidents, vandalism, theft probability		
	Archeology, Anthropology Assessment		

Please remember to take photo's and video of the proposed area for further review.

Evaluation of the Reliability of an Animal Detection System in a Test-Bed

Final Report

by

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and
Larry Hayden, MSc, Design Engineer

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ABSTRACT

This document reports on the work related to an animal detection system project in northern California. It describes the site that was selected for the installation of an animal detection system, the rationale for the selection of a particular animal detection system technology, and a reliability test of the system at a controlled access facility.

The system that was selected is a microwave break-the-beam system manufactured by ICx Radar Systems (Scottsdale, AZ). The reliability test took place at a test-bed specifically constructed to investigate the reliability of animal detection systems. The test-bed consists of an animal enclosure, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities. The animal enclosure includes shelter, water, and an area alongside the fence that was designated for feeding. These three resources are located in different parts of the enclosure to maximize animal movement through the detection areas.

The detection system recorded the date and time of each detection. In addition, there were infrared cameras and a video recording system that recorded all animal movements within the enclosure. The detection log was compared to the images from the infrared cameras, which also had a date and time stamp, to investigate the reliability of the system. Horses, llamas, and sheep were used as a model for wild ungulates (e.g. deer, elk, and moose).

The reliability tests showed that there was 1 false positive in the 18 hours that detection data were available for. The percentage of false positives was 0.007% (1 false positive / 140 valid detections). In addition, there were 4 false negatives in the 18 hours that detection data were available for. The percentage of false negatives was 0.03% (4 false negatives / 140 valid detections). All 4 false negatives related to sheep. Furthermore, there were 148 intrusions in the detection area, of which 144 were detected, resulting in detecting 97% of all intrusions in the detection area. The detection system went out of operation on the 7th day of the 10 day test period. This coincided with a snowstorm. The beam appeared to have come back in operation by itself after the test was completed. Since the beam was out of operation for 4 of the 10 days of the test the "downtime" of the system was 40%.

The number of false negatives and false positives of the system was relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high (see Huijser et al., 2009c). The false negatives that did occur all related to sheep, the shortest of the three species that were present in the enclosure. This suggests that the false negatives may have been the result of the beam shooting over the heads and shoulders of the sheep in some places due to depressions in the terrain, rather than an unreliable detection technology. Lowering the beam several inches, in combination with mowing the grass-herb vegetation in the enclosure may reduce or eliminate the false negatives.

Based on the values of the false negatives and false positives, the RADS III systems easily meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation.

INTRODUCTION

Animal–vehicle collisions affect human safety, property, and wildlife. In the United States, more than 90% of animal–vehicle collisions involve deer (Hughes et al., 1996), with the total number of deer–vehicle collisions estimated at one to two million per year (Conover et al., 1995; Huijser et al., 2008). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries, and over $1 billion in associated costs per year (Conover et al., 1995). These numbers have increased even further over the last decade (Hughes et al., 1996; Romin & Bissonette, 1996; Anonymous, 2003; Huijser et al., 2008). 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; Huijser et al., 2009a).

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) and wildlife warning mirrors or reflectors may simply not be effective (Reeve & Anderson, 1993; Ujvári et al., 1998). Wildlife fences can isolate populations, but have been combined with wildlife crossing structures to address these limitations (e.g., Foster & Humphrey, 1995; Clevenger et al., 2002). Primarily due to their high upfront cost, such crossing structures are limited in number and size.
For this project, the Western Transportation Institute at Montana State University (WTI/MSU), as a subcontractor to California PATH, investigated a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape: animal detection systems. Animal detection systems detect large animals (e.g., deer, elk, moose, or pronghorn) as they approach the road. When an animal 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; Huijser et al., 2009b). Warning signs may also 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., 2006). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82% (Kistler, 1998) or 81% (Romer et al., 2003). Similar results come from Arizona (91%; Dodd & Gagnon, 2008) and Montana (58–67%; Huijser et al., 2009b). Since the effectiveness of animal detection systems depends on driver response, reliable warning systems are very important.

Objectives
For this project WTI/MSU assisted with:

- Site description: The general description of the selected site for the installation of an animal detection system along a road in California.

- System selection: The selection of an animal detection system type and manufacturer given the location and potential other requirements.

- System reliability: Investigation of the reliability of the system at a controlled access facility in central Montana.

These objectives are discussed in the following chapters.

SITE DESCRIPTION

Originally, an animal detection system was scheduled to be installed along Hwy 1, near Orick, CA (Cody & Huijser, 2005). However, that site was abandoned and, after review by PATH and discussion with WTI-MSU, a new site was selected: an about 1.3 km (0.8 mi) long section of Hwy 3 (Ft. Jones Rd.), near Ft Jones, CA (Figure 1).

Below is a brief description of the site near Ft Jones, CA, where the animal detection system was installed in the summer of 2009. The road section near Ft. Jones was primarily selected because of its history of collisions with black-tailed deer (*Odocoileus hemionus columbianus*) and the interest of California Department of Transportation (CALTRANS) District 2 personnel in the project.

Figure 1. The road section (in red, about 0.8 mi (1.3 km) long) of the location of an animal detection system along Hwy 3 (Ft. Jones Rd.) near Ft Jones, CA.

Caltrans maintenance personnel recorded deer carcasses removed between 18 June 2008 and 12 December 2008 between mile reference posts 33.50 and 38.50. To increase the consistency and spatial accuracy, Caltrans personnel installed reference signs at every tenth of a mile on the road section. During this time period of about six months, 23 black-tailed deer carcasses were recorded on the five mile long road section (4.6 per mile), with one carcass recorded between mile reference posts 36.60 and 37.30, the approximate future location of the animal detection system. Caltrans personnel will continue to record carcass removal data until a few years after system installation.

SYSTEM SELECTION

System selection took place based on the following criteria:

- Reliability and effectiveness data from previous publications (Huijser et al., 2006).

- Preliminary results from reliability tests for multiple systems in a test bed near Lewistown in central MT (Huijser et al., 2007).

- Site specific conditions and requirements, including:

    o The system must be able to continue to operate with (ice) fog that occurs occasionally at the site.

    o The desire from Caltrans and California PATH to implement an animal detection system over a longer road section (about 1 mile in length) rather than at a gap in a wildlife fence. The road length over which the system is implemented is especially important for the driver behavior part of the study which is focused on tracking vehicles and measuring driver behavior as the vehicles approach, travel through, and leave the road section with the system.

    o The need to keep the number of sensors at a minimum to reduce the costs associated with the animal detection system and the associated equipment (including poles and foundations).

The site specific conditions ((ice) fog) ruled out optic based systems (active infra red or laser signals). The combination of the road length that needed to be covered in combination with minimizing the number of sensors ruled out passive infra red systems that typically have a short range (e.g. up to about 98 ft (30 m)). These considerations, in combination with the results of previous studies (Huijser et al. 2006; 2007) favored the selection of a microwave break-the-beam system that is not influenced by fog and that allows for relatively great distances between the sensors (about 1,312 ft (400 m) or more, depending on site conditions). Thus a system manufactured by ICx Radar Systems (formerly Sensor Technologies and Systems (STS), Scottsdale, AZ, USA) was selected for implementation at the site near Ft Jones.
ICx Radar Systems had developed a 3rd generation of their animal detection technology equipment. This equipment was installed at the site near Ft Jones in September 2009.

SYSTEM RELIABILITY

Introduction

The reliability testing of the animal detection system took place in the test-bed for animal detection systems near Lewistown, central Montana. This site consists of an enclosure for domesticated animals, posts and underground conduit for animal detection systems, infrared cameras that record the location of the animals in the enclosure 24 hours a day, and a mobile office space in which the data are stored (Figures 2 through 4). This site has been used for the testing of the reliability of animal detection systems since 2006 (Huijser et al., 2007; Huijser et al., 2009c). This site, and the associated equipment, was not available at the time (2005) the original proposal was written for the animal detection system test bed in California. The advantages of using this site for the current project are:

- Evaluate false positives and false negatives: Because the IR cameras aimed at the enclosure cover the entire detection area of the animal detection system, it is always certain whether an animal was present or absent from the detection area and whether false positives or false negatives occur. This is in contrast to animal detection system in California, where the video cameras will not cover 100% of the length of the road section with the animal detection system and where the researchers cannot be certain that there really was or was not an animal present if a detection occurred, and where a false negative does not trigger the animal detection system and is therefore not recorded by the video recording system. In addition, the researchers will not be able to see deer that trigger the animal detection system in CA during the night. While system acceptance tests and detailed analyses of the detection data at the CA site may provide an indication of false positives and false negatives, the evidence is circumstantial as it is based on patterns in the detection data only without having a verification that an animal was or was not there. Furthermore, while triggering the system at regular interval using humans as a model for wildlife does allow for investigation of false negatives, these efforts are limited in number compared to animal movements in an enclosure.

- Sample size: By using domesticated animals in an enclosure as opposed to wildlife in unfenced areas the researchers can assure that sufficient animal movements are recorded to allow for a precise assessment of the reliability of animal detection systems under a range of environmental conditions. This is in contrast to animal detection systems along real roadsides, such as the one in California, where the number of animal movements is unknown and sample size cannot be controlled.

- Effect of environmental conditions: The researchers propose that this research continues beyond the test that is reported on in this manuscript, and that additional tests are conducted in different seasons. The nearby location of a weather station allows the researchers to investigate the effect of environmental conditions on the reliability performance of the animal detection system. This is in contrast to animal detection systems along real roadsides, such as the one in California, where the number of animal movements are likely to be too small for an accurate assessment of system reliability, where reliability assessments cannot be done at a similar scale, and where data on environmental conditions may not readily be available. In summary, this effort not only allows the researchers to measure the reliability of the system, but also allows the

researchers to understand which environmental conditions may influence the performance of the system. The current project only includes one ten day test (Huijser, 2009).

- Different sized species: By using horses, llamas, and sheep, as a model for deer, elk and moose, the reliability of the system is evaluated for a range of differently sized species. This is in contrast to animal detection systems along real roadsides, where one species may dominate. At the study site in California, only black-tailed deer are present; there are no elk or moose in the area.

For this project the microwave radio signal break-the-beam system manufactured by ICx Radar Systems was evaluated for its reliability for one 10 day test period. The reliability of the system was not related to environmental conditions as the 10 day test period did not cover a wide range of environmental conditions. The potential effect of environmental conditions on system reliability can only be investigated in combination with additional tests in different seasons.

Methods

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, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities (Figures 2 through 5). The distance covered by the system tested for this project was 91 m (300 ft) (from the left to the right side of the enclosure). The animal enclosure includes shelter, water, and an area alongside the fence that was designated for feeding. These three resources are located in different parts of the enclosure to maximize animal movement through the detection areas.

Figure 2. 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.
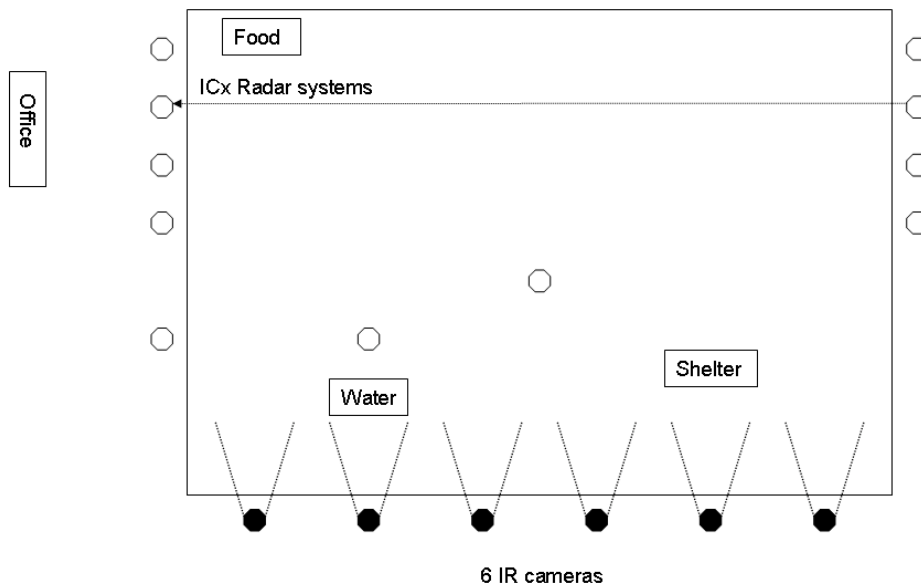
Figure 3. Test-bed design including an animal enclosure, the animal detection system tested for this project (open circles represent poles on which sensors can be attached), the six infrared (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. The arrow shows the direction towards which the transmitter is pointed.

Figure 4. The test bed with the remote office, poles on which sensors can be attached, the shelter, and a llama (Photo: Marcel Huijser, WTI/MSU).

Figure 5. The infrared cameras that monitor animal movements in the enclosure (Photo: Marcel Huijser, WTI/MSU).

Animal Detection System and Recording Equipment

The system tested for this project is a microwave radio signal break-the-beam system manufactured by ICx Radar Systems (Scottsdale, Arizona (formerly Sensor Technologies and Systems, Inc.). The system is the third generation of this detection technology (RADS III) (Figure 6). Previous generations (RADS I and RADS II) were evaluated for their reliability in an earlier project (Huijser et al., 2009c). The RADS III is the exactly the same detection technology as was installed near Ft Jones, CA, in September 2009. The delivery of the system for the test site in Lewistown, MT was delayed and the equipment was not received until 24 September 2009. Certain parts were not functional and were shipped back to the manufacturer for repair and replacement. Functional equipment was received on 14 December 2009, and the system was successfully installed in Lewistown, MT on 16 December 2009. The center of the beam was set at about 73.7 cm (29 inches) above the ground. However, because of rises and depressions in the terrain, the center of the beam was estimated to have varied between 71.1 and 76.2 cm (28-30 inches) above the ground. Setting the center of the beam lower may have resulted in false positives as a result of the grass-herb vegetation in the enclosure.

Figure 6. The receiver of the third generation break-the-beam system manufactured by ICx Radar Systems. Note: the transmitter looks similar to the receiver.

The RADS III system transmits microwave radio signals (around 35.5 GHz). 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. The detection line is the line between the transmitter and receiver sensors where the break-the-beam systems should detect large animals. The detection line was marked with cones just adjacent to the actual detection line to prevent interference with the microwave radio signal (Figure 7). The cones were visible on the images from the individual cameras. For the RADS III system the detection line is 40.6 cm (16 in) wide consistently (Pers. com. Lloyd Salsman, ICx Radar Systems). In addition, RADS III has a wider detection area 4.5 m (15 ft) close to the sensors (Pers. com., Lloyd Salsman, ICx Radar Systems).

The six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection system. These cameras and a video recording system record all animal movements within the enclosure continuously, day and night. The RADS III animal detection system saved its 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 the system.

Figure 7. The detection line was marked with cones to be able to record the position of the animals (Photo: Marcel Huijser, WTI/MSU).

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*). In Montana, it is not legal to have deer, elk or moose in captivity. Therefore the researchers use domesticated species as a model for wildlife. For this study, which took place within an enclosure, two horses, two llamas, and two sheep were used as models for these wildlife target species. Horses are similar in body shape and size to moose, llamas represent deer and elk, and sheep represent small deer (Tables 1 and 2). The body size and weight of the individual horses, llamas, and sheep used in this experiment are shown in Table 3. Some of the test animals are shown in figures 8 through 10.

Table 1: Height and length of wildlife target species and horses and llamas. *1 Black-tailed deer are a subspecies of mule deer.

Species	Height at shoulder	Length (nose to tip tail)	Source
Target species			
Moose	6'5"-7'5" (195-225 cm)	6'9"-9'2" (206-279 cm)	Whitaker (1997)
Elk	4'6"-5' (137-150 cm)	6'8"-9'9" (203-297 cm)	Whitaker (1997)
White-tailed deer	27-45" (68-114 cm)	6'2"-7' (188-213 cm)	Whitaker (1997)
Mule deer[*1]	3'-3'5" (90-105 cm)	3'10"-7'6" (116-199 cm)	Whitaker (1997)
Black-tailed deer	3'0" (91 cm)		Western Hunter (2008)
Black-tailed deer	2'3"–3'9" (68–114 cm)		National geographic (2008)
Pronghorn	2'11"-3'5" (89-104 cm)	4'1"-4'-9" (125-145 cm)	Whitaker (1997)
Models			
Feral horse	4'8"-5' (142-152 cm)		Whitaker (1997)
Quarter horse	4'11"-5'4" (150-163 cm)		UHS (2007), Wikepedia (2007)
Llama	3'-3'11" (91-119 cm)		Llamapaedia (2007)
Goat	23"-30" (59-75 cm)		
Sheep	26"-50" (65-127) cm		

Table 2: Body weight of wildlife target species and horses and llamas.

Species	Weight male	Weight female	Source
Target species			
Moose	900-1400 lbs (400-635 kg)	700-1100 lbs (315-500 kg)	Whitaker (1997)
Elk	600-1089 lbs (272-494 kg)	450-650 lbs (204-295 kg)	Whitaker (1997)
White-tailed deer	150-310 lbs (68-141 kg)	90-211 lbs (41-96 kg)	Whitaker (1997)
Mule deer	110-475 lbs (50-215 kg)	70-160 lbs (32-73 kg)	Whitaker (1997)
Black-tailed deer	Some are >140 lbs (63 kg)		Western Hunter (2008)
Black-tailed deer	150–310 lb (68–141 kg)	90–211 lb (41–96 kg)	National geographic (2008)
Pronghorn	90-140 lbs (41-64 kg)	75-105 lbs (34-48 kg)	Whitaker (1997)
Models			
Feral horse	795-860 lbs (360-390 kg)	595-750 lbs (270-340 kg)	Whitaker (1997)
Quarter horse	850-1200 lbs (386-540 kg)		UHS (2007), Wikepedia (2007)
Llama	250-450 lbs (113-204 kg)		Llamapaedia (2007)
Goat	111 lbs (50 kg)	144-156 lbs (65-70 kg)	
Sheep	100-350 lbs (45–160 kg)	100-225 lbs (45-100 kg)	Wikepedia (2008)

Table 3: Body size and weight of the horses, llamas, and sheep used in the experiment (Pers. com. Lethia Olson, live stock supplier). The measurements were taken in November 2009.

Individual	Height at shoulder	Weight
Horse 1 (Bubba)	5' (152 cm)	1130 lbs (513 kg)
Horse 2 (Buster)	5'2'' (157 cm)	1450 lbs (659 kg)
Llama 1 (Sparkle)	3'9'' (114 cm)	350 lbs (159 kg)
Llama 2 (Cocoa)	3'9'' (114 cm)	470 lbs (213 kg)
Sheep 1	71 cm (2'4")	To be measured
Sheep 2	74 cm (2'5")	To be measured

Figure 8. The horses that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Figure 9. One of the two llamas that were used in the test (Photo: Marcel Huijser, WTI/MSU).
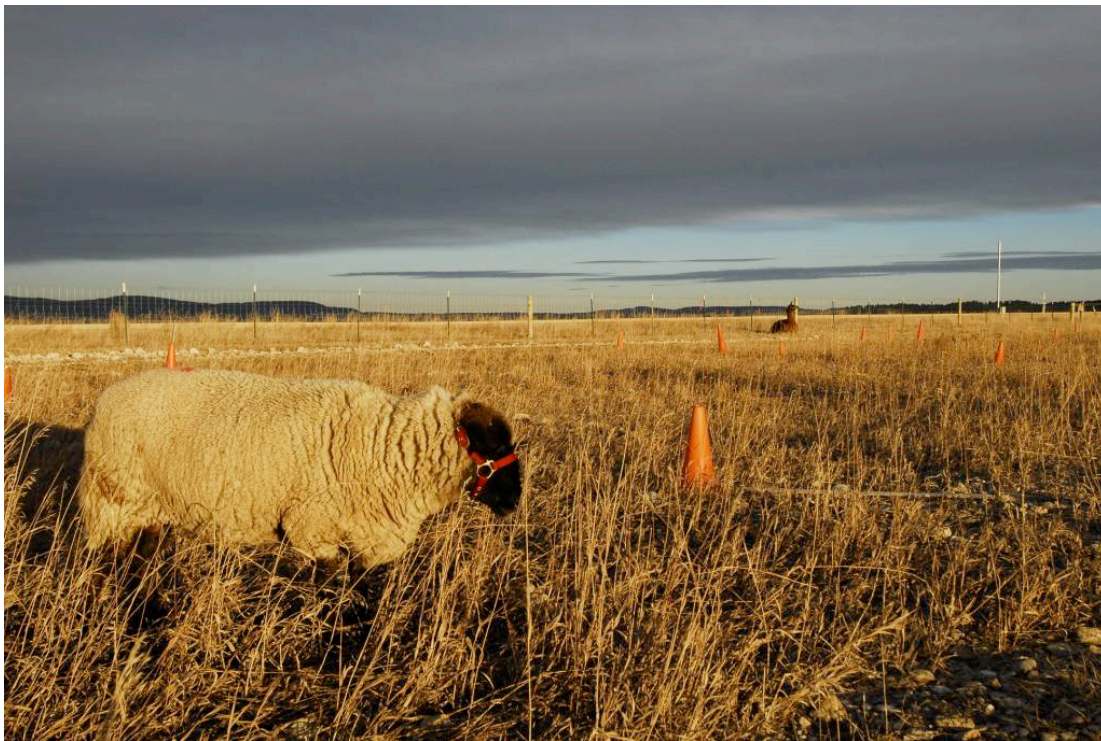
Figure 10. One of the two sheep that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Test Period

The ten day test period started on 17 December 2009 (at midnight) and it ended on 26 December 2009 (end at midnight). Three, one-hour-long sections of video were randomly selected for each test day for review (stratified random). This resulted in a total of 30 hours during which the reliability of the system was investigated. The images from the time periods that were analyzed were all saved on DVD. Time periods that were not analyzed were not saved.

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 in or immediately adjacent to the detection line 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. The RADS III system reports the beam status, including potential detections, once every minute, and whenever a change in the beam status occurs. If an animal blocks the signal for some time, the beam becomes desensitized, and after the animal moves out of the beam again, the system may need three minutes before it can report the next detection. For the time periods reviewed, the date, time, and species were recorded for all valid detections. Note: there was no non-target species (e.g. deer, birds etc.) observed crossing the detection line for the time periods that were analyzed.

- *False positives* – A false positive was defined as "when the system reported the presence of an animal, but there was no animal in the detection line or immediately adjacent to it". Thus, each incident in which the system's data logger recorded a detection, but there was no animal present in the detection zone of that system, was recorded as a false positive. The date and time were recorded for all false positives. Note: should non-target species have been present and caused a detection, they would have been considered a valid explanation for a detection and would not have resulted in 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 the system (i.e., the RADS III system can become 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. 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:

o The sensors are desensitized after a detection and need some time before they can detect another animal. The manufacturer of the RADS III system recommends three minutes reset time for the sensors to become fully sensitive again after a detection.

o The warning signs of an animal detection system need to stay activated for a certain amount of time after a detection has occurred 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 (Huijser et al., 2009b). 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 would have entered the enclosure would not have been considered in evaluating false negatives. However, when deer would have entered the enclosure, the incident would have been 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 two event types described below. The event types were hierarchical—while an intrusion was in progress, the classification could change from E2 to E1, but not from E1 to E2.

  The first type of event, classified as "event 1" or "E1," occurred when an animal was in the line of detection or immediately adjacent to it 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 the system for an event 2.

- *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.

Data Analyses

Time periods that were classified as downtime or time periods for which no detection data were may have been available due to external circumstances (e.g., power outage) were excluded from the analyses.

The following parameters were calculated for the RADS III system:

- The average number of valid detections per hour:

$$\overline{N}_{t(valid\,det\,ections)} = \frac{N_{t\,(valid\,detections)}}{N_{h(with\,data\,available)}}$$

Where:

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

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

- The percentage of false positives:

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

Where:

F_{N}^{+} = total number of false positives

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

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

- The average number of false positives per hour:

$$\overline{F}^{+} = \frac{F_{N}^{+}}{N_{h(with\,data\,available)}}$$

Where:

F_{N}^{+} = total number of false positives

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

- The percentage of false negatives:

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

Where:

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

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

$\text{N}_{d\,(\text{center line})}$ = total number of times an animal crossed the line of detection 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:

$$\overline{F}^- = \frac{F_N^-}{\text{N}_{h(\text{with data available})}}$$

Where:

F_N^- = total number of false negatives

$\text{N}_{h\,(\text{with data available})}$ = 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 (i.e., animal presence in or immediately adjacent to the line of detection):

$$I_{\%\,\det ected} = \frac{I_d}{I_t} * 100 = \frac{E_1}{E_1 + E_2} * 100$$

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

Results

There were 140 valid detections in 18 hours that detection data were available for, resulting in an average of 7.78 valid detections per hour.

There was 1 false positive in 18 hours that detection data were available for. The percentage of false positives was 0.007% (1 false positive / 140 valid detections). There were 0.06 false positives per hour (1 false positive in 18 hours).

There were 4 false negatives (all false negatives; there were no false negatives 1 or false negatives 2) in 18 hours that detection data were available for. The percentage of false negatives was 0.03% (4 false negatives / 140 valid detections). All 4 false negatives related to sheep. There were 0.22 false negatives per hour (4 false negatives in 18 hours).

There were 148 intrusions in the detection area, of which 144 were detected, resulting in detecting 97% of all intrusions in the detection area.

The beam went out of operation in the early hours of 23 December 2009. This coincided with a snowstorm. The beam appeared to have come back in operation by itself after the test. Since the beam was out of operation for all time periods analyzed for 23, 24, 25, and 26 December 2009, the total number of hours that the system was "down" was 12 out of the 30 hours analyzed (40%).

Discussion and Conclusion

The number of false negatives and false positives was relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high (see Huijser et al., 2009c). The false negatives that did occur all related to sheep, the shortest of the three species that were present in the enclosure. This suggests that the false negatives may have been the result of the beam shooting over the heads and shoulders of the sheep in some places due to depressions in the terrain, rather than an unreliable detection technology. Lowering the beam several inches, in combination with mowing the grass-herb vegetation in the enclosure may reduce or eliminate the false negatives.

Based on the values of the false negatives and false positives, the RADS III systems easily meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation.

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Appendix F

SENSOR LAYOUT
=============
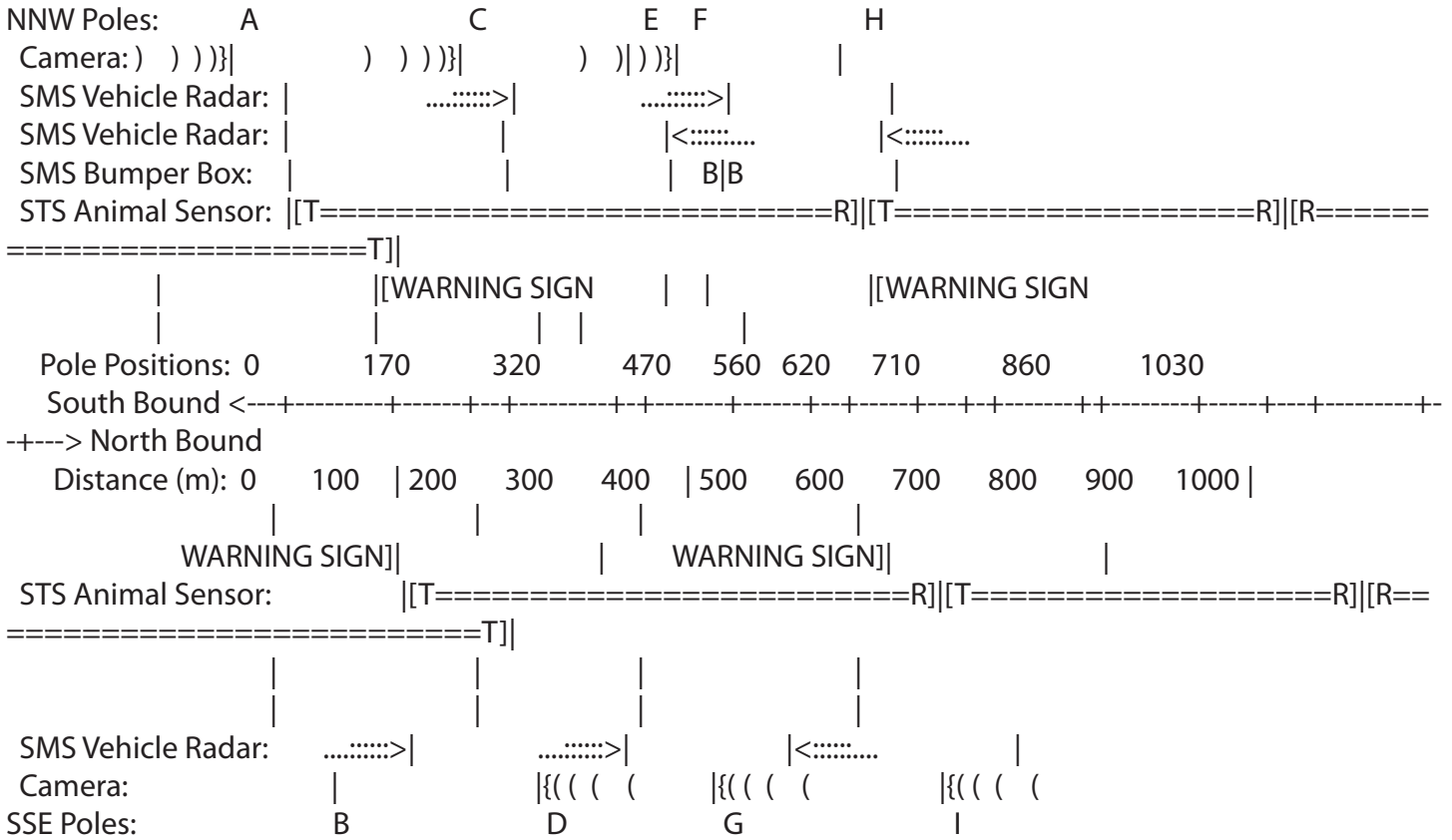
```
NNW Poles:           A                    C                E  F              H
 Camera: )   )  ) )}|            )   )  ) )}|          )   )|) )}|            |
  SMS Vehicle Radar:  |              ....::::::>|            ....:::::>|              |
  SMS Vehicle Radar:  |                    |              |<:::::....            |<:::::....
  SMS Bumper Box:     |                    |              | B|B               |
  STS Animal Sensor: |[T============================R]|[T==================R]|[R======
==================T]|
                     |                    |[WARNING SIGN     |  |              |[WARNING SIGN
                     |                    |            |  |              |
    Pole Positions:  0          170         320       470    560 620  710         860         1030
      South Bound <---+---------+------+--+---------+-+-------+------+-+-+-----+---+-+-------++--------+-----+---+---------+-
--+---> North Bound
      Distance (m): 0     100   |200     300     400  |500     600     700      800      900     1000 |
                     |           |              |              |
               WARNING SIGN]|           |       WARNING SIGN]|           |
  STS Animal Sensor:         |[T========================R]|[T==================R]|[R==
========================T]|
                     |            |            |            |
                     |            |            |            |
   SMS Vehicle Radar:      ....:::::>|           ....:::::>|            |<:::::....           |
   Camera:                 |           |{( ( (   (        |{( ( (   (         |{( ( (   (
  SSE Poles:             B              D              G               I


CAN BUS 1 (BumperBox(F) > SMS(F) > SMS(H) > SMS(E) > SMS(C))
CAN BUS 2 (BumperBox(F) > Tunnel > SMS(G) > SMS(D) > SMS(B))

===============================================================

NNW Poles:        A                 C           E   F              H
 SMS Vehicle Radar:  |              ....:::::>+          ....:::::>+              |
 SMS Vehicle Radar:  |                  |\             +<:::/:\....            +<:::::....
 SMS Bumper Box:     |                  |\          /|\  +BB+\              /|\
                     |         | \        / | \  || \        / | \
                     |         |  \  CAN BUS 1  / | \ ||  +---------------+ | \
                     |         |   +-------------+  |  +--|-----------------------+
    Pole Positions:  0         170        320       470    560 620|   710         860         1030
      South Bound <---+---------+------+--+---------+-+-------+------+-+-+-----+---+-+-------++--------+-----+---+---------+-
--+---> North Bound
      Distance (m): 0     100   |200     300     400  |500     600 |   700      800      900     1000 |
                     |           |            +-----------+              |
                     |  +-------------------+  |  +-------------+  | /            |
                     | /    CAN BUS 2     \ | /        \ | /        |
                     |/            \|/          \|/           |
                     |/            \|/          \|/           |
```

```
  SMS Vehicle Radar:      ....:::::::>+            ....:::::>+               +<:::::.....            |
 SSE Poles:               B              D              G              I
 ROADSIDE LAN (star topology centered at NEMA 334 box behind pole G)
 =================================================================

 NNW Poles:        A                C             E   F              H
  Camera: )   )  ) )}|          )   )  ) )}|          )   )|) )}|           |
   SMS Bumper Box:  |              |               |  B|B            |
   STS Animal Sensor: |[T===========================R]|[T==================R]|[R======
 ==================T]|
            |                 |[WARNING SIGN     |   |            |[WARNING SIGN
  Ethernet Hub:     #                #             #   #              #
            |\               |\            \   +-------------+    /|
            |\               |\              +---------+    |+----+ |
            | \              | +--------------------------+|     ||    |
            |  +-------------------------------------------------------+ ||     ||    |
     Pole Positions:  0         170        320       470    560  620|||710  ||  860        1030
        South Bound <---+---------+------+--+--------+-+-------+------+-+-----+---+-+-------++--------+-----+---+---------+-
 -+---> North Bound
     Distance (m):  0      100  | 200    300     400   | 500     600 |||700   ||800    900     1000 |
             | +----------------------------+     |||| |    ||               |
             |/                |+-+\       ||| |+  ||       +----------+ |
             |/                |/  \\      ||| |/\ ||      /          \|
   Ethernet Hub:          #              #   \\     ||| #  +||     /          #
            WARNING SIGN]|               |    \\WARNING SIGN]|  |||    /         |
   STS Animal Sensor:          |[T========================R]|[T=====\=\======|=|=|R]|[R=|=|=|=
 =====/==============T]|
   Camera:               |            |{( ( ( \ \    ||| |{(| |(|  (/           |{( ( (  (
 SSE Poles:               B              D        \\  ||| G  |||   /            I
                                         \\ |||     ||| /
                                          \\ |||    ||| /
                                          +-+-+-+-+-+------+-+-+-+-+
                                          |           |
                                          |    [NEMA 334]    |
                                          |           |
                                          +----------------------+
```